CALIBRATION AND VALIDATION OF THE ADVANCED SCATTEROMETER ON METOP-B

Craig Anderson, Julia Figa-Saldaña, Julian Wilson, Helmut Bauch, Colin Duff & James Miller.

EUMETSAT, Eumetsat Allee 1, 64295 Darmstadt, Germany.

Abstract

The Advanced Scatterometer (ASCAT) is a six beam radar instrument operating at C band with vertical polarisation. It is designed to accurately measure the surface backscatter allowing the retrieval of wind fields over the ocean. The data it provides is also used by a number of other applications including sea ice monitoring and soil moisture retrieval.

An ASCAT is carried on each of the ESA/EUMETSAT METOP satellites. The ASCAT on board the METOP-B satellite (ASCAT-B) became operational in 2013. We describe the calibration process using three ground-based transponders and present an analysis which estimates the calibration accuracy to be ±0.04 dB.

The ASCAT carried by the METOP-A satellite (ASCAT-A) has been operational since 2007 and flies in the same orbit as ASCAT-B but with a lead of around 50 minutes. A comparison of the data from the two instruments over ocean and rainforest natural targets is presented and shows that they agree to a very high level. These results indicate that the data from the two ASCAT instruments is calibrated to a high quality and can be used interchangeably for most applications.

INTRODUCTION

The Advanced Scatterometer (ASCAT) on the ESA/EUMETSAT METOP series of satellites is a six beam, real aperture, vertical polarised, C-band radar whose primary objective is to allow the wind field at the ocean surface to be determined from the Normalized Radar Cross Section (NRCS) output [Klaes et al 2007, Figa-Saldaña et al 2002]. Other important applications have emerged in recent years over land and sea ice areas, where information on parameters such as soil moisture, snow and ice properties can be obtained.

Data is provided on swath-based grids of 12.5 and 25 km in two swaths each 550 km wide on either side of the nadir track. The nominal resolution of the data is around 30 km and 50 km respectively. Figure 1 shows the viewing geometry of the six ASCAT antennas.

METOP-A was launched in 2006 and METOP-B in 2012. Dual operation of METOP-A and B is the current baseline and this situation is reviewed yearly with regard to the health of platform and instruments. The next satellite in the series, METOP-C, will be launched 2018 and is expected to operate until 2022.

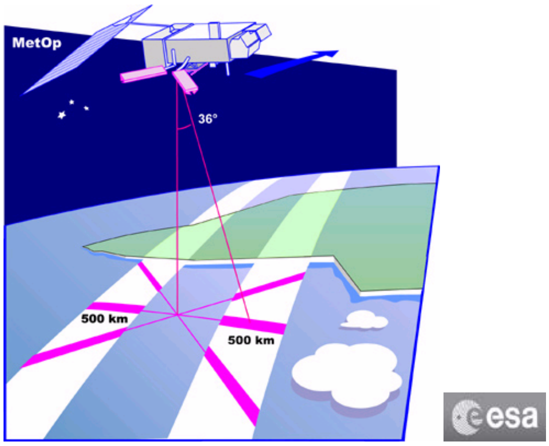


Figure 1: Schematic showing the viewing geometry of the ASCAT.

Three transponders are used to accurately estimate the ASCAT gain patterns, which allows an absolute calibration to be determined [Wilson et al 2010]. A number of natural distributed targets (rainforest, sea ice and ocean) are routinely used by to validate and monitor the calibration of the instrument.

INITIAL CALIBRATION

As It takes several months to collect sufficient transponder data to estimate the antenna gain patterns, an initial calibration was performed by tuning the default ASCAT-B gain pattern so that the resulting NRCS over the Amazon rainforest was as similar as possible to that of ASCAT-A.

Figure 2a shows the mean rainforest γ_0 (which is given by $\sigma_0/\cos\theta$ where σ_0 is the NRCS and θ is incidence angle) as a function of incidence angle from the two instruments for the FORE LEFT beam, before the cross calibration. There are significant differences across the swath.

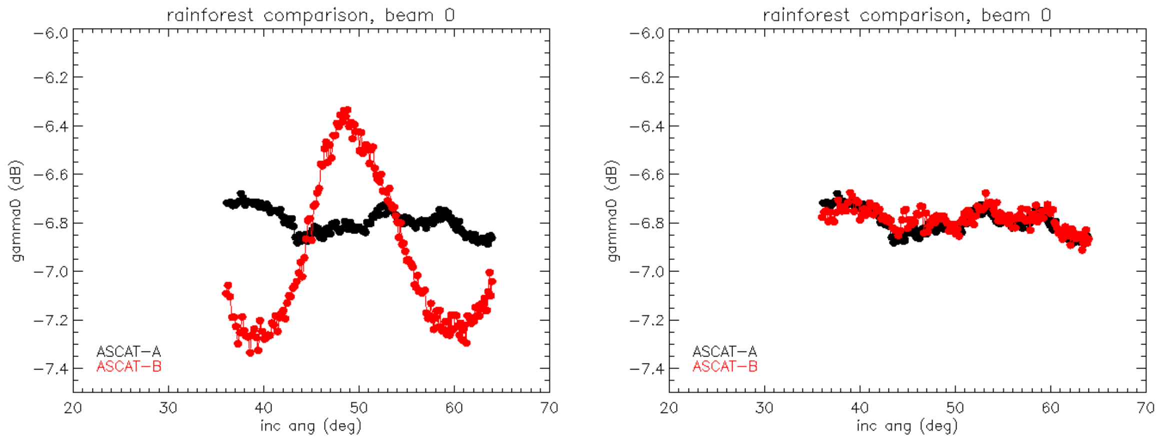


Figure 2: Comparison of ASCAT-A and B data over the Amazon rainforest before and after cross calibration.

Figure 2b shows the results after the cross calibration and the NRCS from the two ASCAT's is now within 0.1 dB (which corresponds to about 0.1 ms^{-1} in retrieved wind speed). This allowed the data from ASCAT-B to be distributed and used immediately, before the completion of the transponder calibration.

TRANSPONDER CALIBRATION

EUMETSAT uses three transponders located in Turkey to calibrate the ASCAT instruments. The location of these transponders is carefully selected to minimise interference and to give an optimum sampling of the gain patterns. Figure 3a shows one of the transponders on site.

As the ASCAT passes over the transponders, it switches into calibration mode. When the transponders detect an signal from ASCAT they transmit a signal of known strength back towards the antenna with a pre-determined delay, in order to allow for the ASCAT pulse echoes to reach the instrument before this tranponder pulse. The magnitude of the signal recieved by ASCAT varies depending on the position of the transponder in the gain pattern . Figure 3b shows an example of the calibration mode data from ASCAT-B showing the signal from two transponders in each of the three beams.

Figure 3: (a) Transponder on site in Turkey and (b) transponder signals in ASCAT calibration data.

The ASCAT-B calibration campaign ran from October 2012 to January 2013 and data was obtained from around 250 passes over the transponders.

In the first step of the calibration procedure we convert the signal from the transponder into an antenna gain in the antenna coordinate system. Figure 4 shows the results for the LEFT MID and LEFT FORE beams, as a function of the normalised antenna elevation angle. We note that the LEFT MID beam shows the same minor distortion in gain pattern that was observed in ASCAT-A and the LEFT FORE beam shows same type of differences between ascending/descending passes at edge of the beam as ASCAT-A.

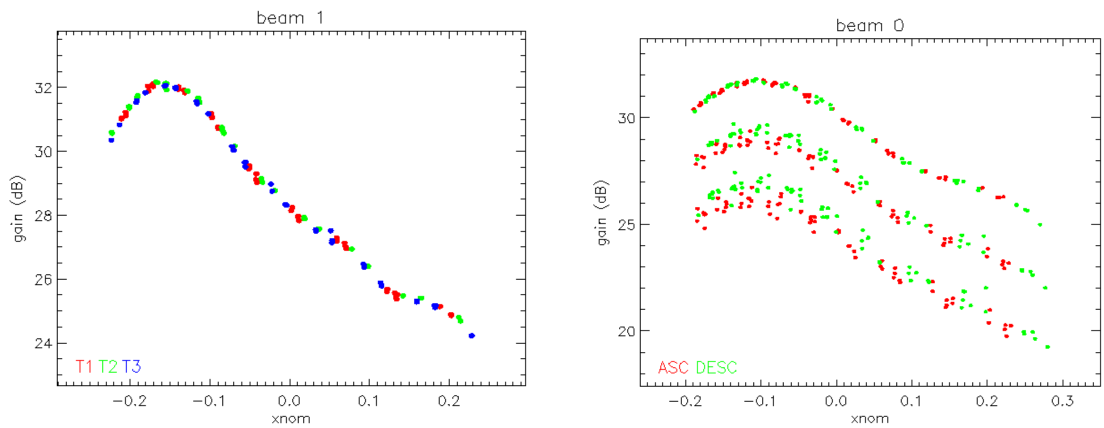


Figure 4: (a) transponder data LEFT MID beam, showing minor distortion and (b) transponder data in LEFT FORE beam at three different azimuth angles, showing differences between ascending and descending passes.

In the second step of the calibration procedure we fit a model of the antenna pointing and gain to the data set. The model gain pattern is obtained using kernel smoothing: for each value at which we require the model gain we find the data points within a distance Δ, weight them according to how close they are to the required value, fit a low order polynomial to the weighted data and use it to produce a gain value. Figure 5a shows a schematic of the model gain as a function of the antenna elevation and azimuth angles. Figure 5b shows a cut through the data and gain model for the LEFT MID beam, along the elevation angle axis.

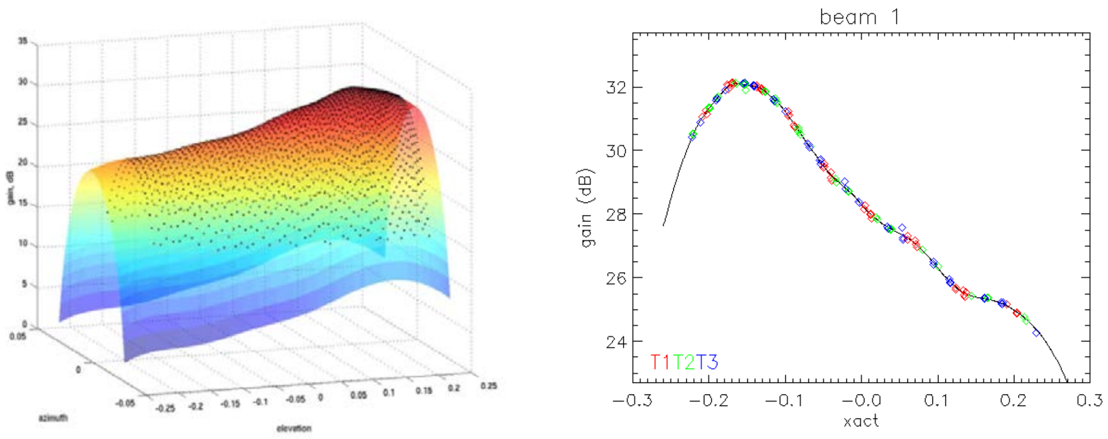


Figure 5: (a) Example gain pattern as a function of antenna elevation and azimuth angles and (b) a section through LEFT MID beam gain pattern as a function of elevation angle.

The resulting gain pattern is used in the operational processing to calculate the normalisation factors which convert ASCAT measurements into calibrated backscatter.

ERROR ANALYSIS

The residual between transponder data and the fitted gain model is of interest as it gives a direct indication of calibration accuracy.

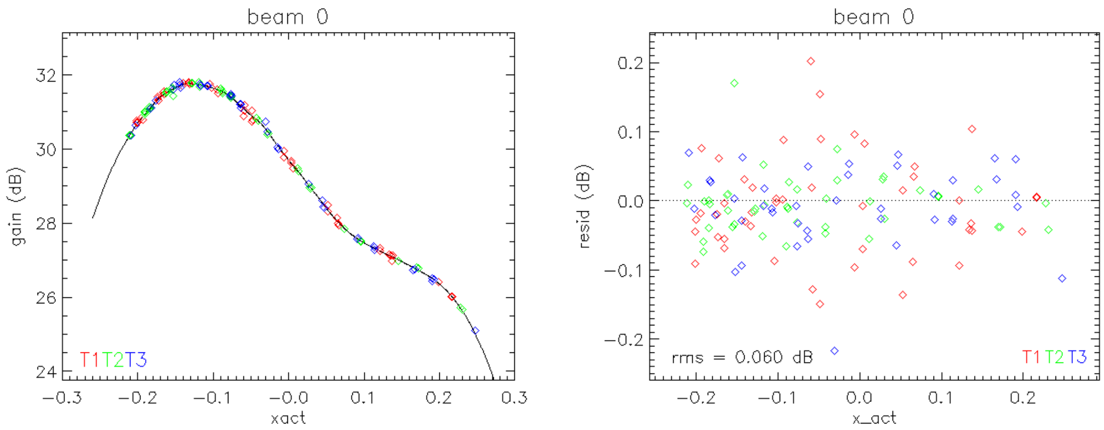


Figure 6: (a) Transponder data with the fitted gain model and (b) the residual between data and model, for the LEFT FORE beam

Figure 6a shows an example of the transponder data and fitted gain pattern and Figure 6b shows the residuals with respect to this fitted model. The RMSE of the residuals is around 0.06-0.07 dB, depending on the beam.

The optimum value of Δ in the kernel smoothing is determined by cross validation and is typically around 0.045. The number of data points within this distance used to fit the low order polynomial is around 24 and the sum of the weights, shown in figure 7 for the left fore beam, is typically around 13.

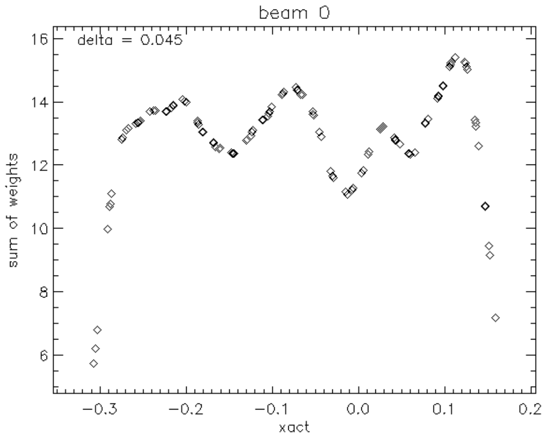


Figure 7: Sum of the weights used to fit the low order polynomial in the kernel smoothing for the LEFT FORE beam.

We take RMSE/√(sum of weights) as an estimate the error in the fitted gain pattern. This gives a value of 0.07/√13 = 0.02 dB. As the normalisation factors used to convert the ASCAT measurements into calibrated backscatter are derived from the two way gain pattern we double this figure to convert an error in the gain pattern to an error in the backscatter. This leads to an estimated calibration accuracy of ± 0.04 dB.

VALIDATION USING RAINFOREST DATA

Rainforest has been extensively studied by a number of scatterometers and the parameter $\gamma_0 = \sigma_0/\cos\theta$, is found to be approximately constant with respect to viewing geometry, spatial location and time, with a value of approximately -6.5 dB in C band vertical polarisation [see e.g. Lecomte and Wagner 1998]. This makes rainforest data useful for validating and comparing scatterometers.

We examine ASCAT-A and B data over the Amazon rainforest in the region enclosed by longitudes [-70° to -60.5°] E and latitudes [-5° to 2.5°] N, during February 2013. The ASCAT-A data is calibrated according to the results from the 2010 transponder calibration campaign. The ASCAT-B data is calibrated according to the results of the October 2012 to January 2013 campaign. Figure 8 shows the difference in the mean γ_0 values from the two instruments as a function of incidence angle in the six beams.

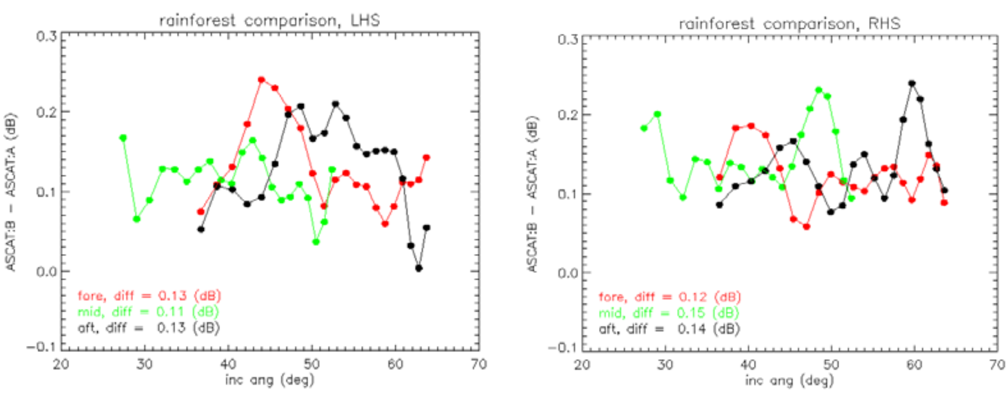


Figure 8: Difference in mean γ_0 between the rainforest data from ASCAT-A and B during February 2013.

These show a difference between the two insturments of approximately 0.15 dB. However, the more recent calibration of ASCAT-A based on the transponder calibration campaign during 2012 gives a lower estimation of the antenna gain w.r.t. 2010 by almost 0.1 dB. Consequently, the actual calibration difference between ASCAT-A and B instruments is better than 0.1 dB.

VALIDATION USING OCEAN DATA

Any point in the ASCAT swath is observed by the fore, mid and aft beams giving three backscatter measurements with different azimuth angles. When the backscatter triplets from the open ocean are plotted as points in a three dimensional space they form a cone shape [see e.g. Stoffelen 1998].

The position of the cone can be determined by taking slices through the data and locating the position of maximum data density. Figure 9 shows different sections through a month of ASCAT-B data over the open ocean with the position of the maximum data density in several slices marked in red.

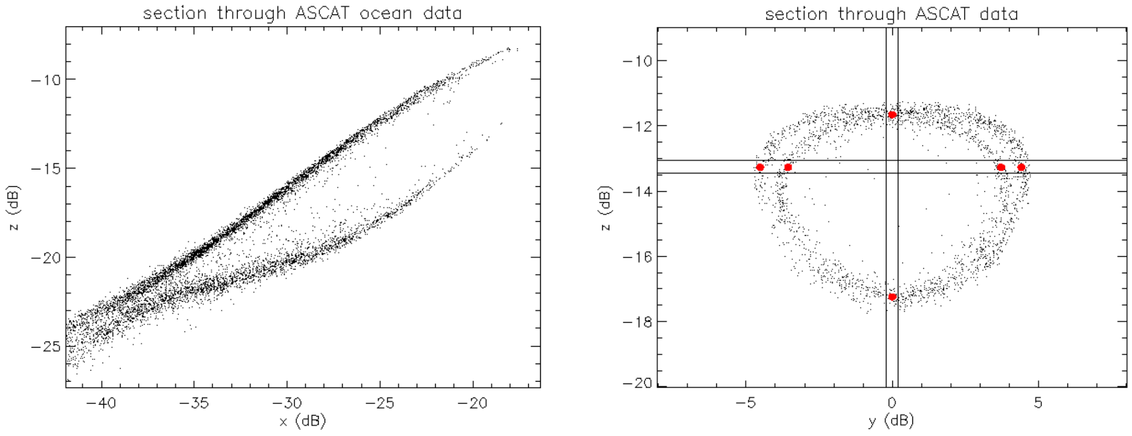


Figure 9: Example of sections through a month of ASCAT-B data from the open ocean with the position of maximum data density in two slices marked in red. These sections vary with incident angle.

If the position of the cone in ASCAT-A and B data can be determined, then the difference between them can be used to examine the difference in calibration between the two instruments. Figure 10 shows the results for data from the left swath beams, collected during February 2013. It shows similar across swath behaviour to the rainforest results in the previous section, but is slightly larger at around 0.15–0.2 dB.

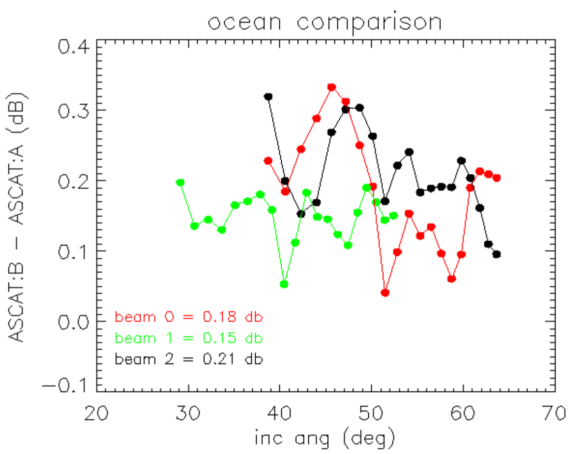
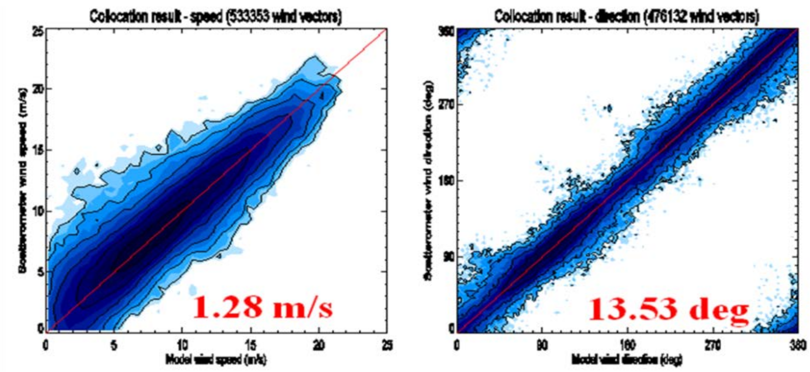


Figure 10: Difference in the cone position for open ocean NRCS from ASCAT-A and B during February 2013.

FEEDBACK FROM USERS

Data from ASCAT-B has been examined by a number of users. KNMI (part of the Ocean and Sea Ice Satellite Application Facility, OSI-SAF) has compared the wind vectors derived from ocean NRCS triplets to the output of the ECMWF NWP model. The results are shown below and the RMS differences are almost identical to those given by data from ASCAT-A.



OSI SAF

Koninklijk Nederlands Meteorologisch Instituut
Ministerie van Infrastructuur en Milieu

Figure 11: Difference in wind speed and direction between wind vectors derived from ASCAT-B data and ECMWF NWP output. Plots courtesy of KNMI (OSI-SAF).

Feedback from TU-Wien (part of the Hydrology SAF) also indicates that the quality of soil moisture derived from ASCAT-B is very similar to that from ASCAT-A (not shown).

This indicates that the calibration of ASCAT-B has been successful and the data from the two ASCAT instruments can be used interchangable for many applications.

SUMMARY

This paper has described the calibration procedure for the ASCAT on METOP-B. The results presented show that both the initial cross calibration with the ASCAT on METOP-A and the subsequent transponder calibration were successful.

An analysis of the of the calibration results was given, which estimates the calibration accuracy of ASCAT-B to be around ±0.04 dB. Data from the two ASCAT instruments over both rainforest and ocean natural targets was examined and we find a typical difference of around 0.1-0.15 dB (which corresponds approximately to a difference in retrieved wind speed of around 0.1 ms^{-1}).

Feedback from the Level 2 producers and users is encouraging, revealing that the two NRCS data sets from ASCAT-A and ASCAT–B provide almost identical winds and soil moisture values.

Another transponder calibration campaign is currently being carried out for ASCAT-A. It is expected that this calibration will bring the data from ASCAT-A and B into even closer agreement.

REFERENCES

Figa-Saldaña J, Wilson JJW, Attema E, Gelsthorpe R, Drinkwater MA & Stoffelen A (2002) The advanced scatterometer (ASCAT) on the meteorological operational (MetOp) platform: A follow on for the European wind scatterometers, Can. J. Remote Sensing, **28**, 3, 404-412.

Klaes KD, Cohen M, Buhler Y, Schlüssel P, Munro R, Luntama JP, Engeln, O'Clerigh E, Bonekamp H, Ackermann J & Schmetz J (2007) An Introduction to the EUMETSAT Polar System, Bulletin of the American Meteorological Society, **88**, 7.

Lecomte P & Wagner W (1998) ERS Wind Scatterometer Commissioning and in-flight Calibration, in Proc. Workshop on Emerging Scatterometer Applications: From Research to Operations, ESA-ESTEC, ESA-SP-424, 261-270.

Stoffelen A, (1999) A simple method for calibration of a scatterometer over the ocean, J. Atm. & Oceanic Technology, **16**, pp 275–286.

Wilson JJW et al (2010) Radiometric calibration of the advanced wind scatterometer carried onboard the Metop-A satellite, IEEE Trans. Geosci & Rem. Sensing, **48**, 8, pp3236-3255.