# SeaWinds Beam and Slice Balance using data over Amazonian Rainforest

Josko Zec and W. Linwood Jones
Central Florida Remote Sensing Laboratory
UCF - Electrical and Computer Engineering Dept.
PO Box 162450
Orlando, FL 32816-2450, USA
Tel/fax (407) 275-4350 jzec@pegasus.cc.ucf.edu

David G. Long
BYU Department of Electrical and Computer Engineering
459 Clyde Building
Provo, Utah 84602

## I INTRODUCTION

Satellite scatterometers are spaceborne microwave radars designed to measure the earth's surface normalized radar cross section $\sigma^0$. This value is estimated by measuring the power reflected from the distributed (non-point) target area and inverting the radar equation [1]:

$$P_R = \frac{P_t L \lambda^2}{4\pi^3} \iint_A \sigma^0 \frac{G^2(x,y)F(x,y)}{R^4(x,y)} dA, \quad (1)$$

where $P_t$ is transmitted power, $L$ denotes system losses, $\lambda$ is wavelength of transmitted radiation, $G(x,y)$ is antenna gain at the point (x,y), $F(x,y)$ is Doppler gain at (x,y), $R(x,y)$ is slant range from antenna to the illuminated point (x,y), and $dA$ is infinitesimal rectangular area $dxdy$ centered around (x,y). In the $\sigma^0$ computation, integration is approximated by the pre-calculated calibration factor [1], which allows simple inversion of the above equation.

The primary application of a scatterometer is estimation of wind vectors over sea surface, but a variety of other geophysical parameters can be retrieved as well. To eliminate ambiguity in retrieved wind direction, multiple looks are required at the observed area. These looks are provided by multiple scatterometer antenna beams. To achieve desired accuracy of wind vectors and other retrieved geophysical products, antenna beams must be calibrated to within ± 0.2 dB. Pre-launch calibration alone is insufficient for such a level of beam balance. Post-launch calibration/validation activities are therefore required for scatterometer missions.

This paper describes beam balance procedure applied following the recent launch of the SeaWinds scatterometer on the QuikScat spacecraft. This work was similar to the NSCAT post-launch verification [2]. Following section is a brief description of the SeaWinds instrument. Calibration data set is introduced in section III. Azimuth beam balance and a comparison with preceding NSCAT instrument is presented in section IV. High-resolution slice-balance results are shown in section V. The paper concludes with a brief summary.

## II SEAWINDS INSTRUMENT

The SeaWinds instrument on the QuikScat spacecraft is the latest satellite scatterometer. Launched in June 1999, it is the first in a series of pencil-beam conical scanners that replaced previously flown fan-beam systems (SEASAT [3], ERS 1 and ERS 2 [4], and NSCAT [5]). The main advantage of a pencil-beam scatterometer is it's wider contiguous coverage, without a nadir gap that restricted the coverage of fan beam sensors. Pencil-beams are more compact, resulting in a 1-meter dish SeaWinds antenna, compared to six deployed 3-meter stick antennas for NSCAT. The rotating dish generates beams from two feeds: horizontally polarized inner beam at 46° incidence and vertically polarized outer beam at 54° incidence as shown in Fig. 1. This configuration results in a contiguous swath approximately 1800 km wide.

The baseline SeaWinds resolution is set by the 3-dB antenna beamwidth to produce an instantaneous field of view (IFOV) 26 X 36 km. This is worst than NSCAT sensor data resolution of about 7 X 25 km. To enhance the SeaWinds resolution, signal processing is employed to modulate the transmitted signal by a linear FM chirp signal at a rate of 250 kHz/ms [1]. The returned signal is range-gated into 12 "slices" within the IFOV. This enhancement increases the SeaWinds capability and thereby broadens its applications.

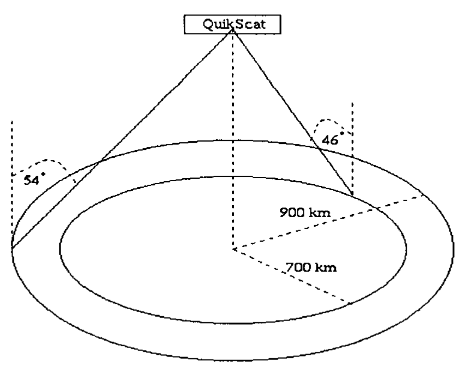


Fig. 1: QuikScat measurement geometry

## III SEAWINDS CALIBRATION DATA

The required high level of beam balance (within ≈ 0.2 dB) necessitates post-launch instrument verification and beam bias removal. Several methods have been used in the past, including ground stations, comparisons with model wind fields and homogenous land and ice targets. Extended-area isotropic land targets have been used during SEASAT [6,7] and NSCAT [2] beam balance campaigns. It is a simple and fast-converging method that relies on the temporal and spatial stability of a calibration target. Amazon rainforest has been the traditionally used scatterometer calibration site [2,6,7]. The vast area (≈ 3 million km$^2$) exhibits azimuth and polarization independent radar response. Backscatter data are accumulated over the region and filtered according to the rainforest mask shown on Fig. 2. This mask is generated from NSCAT measurements using the Scatterometer Image Reconstruction with Filtering (SIRF) algorithm [8]. It enhances scatterometer resolution using overlapping passes over the same area within a time frame in which the radar response of the area does not change. Accumulated measurements are regressed to produce linear $\sigma^o(\theta)$:

$$\sigma^o(\theta) = A + B(\theta - 40^o)\,, \qquad (2)$$

where $\theta$ is incidence angle (≈ 16-66° for NSCAT geometry). Therefore, coefficient $A$ is $\sigma^o$ at 40° incidence, while $B$ is $\sigma^o$ vs. $\theta$ slope. High-resolution SIRF pixels within $\bar{A} \pm 0.5$ dB are included in the mask in Fig. 2, where $\bar{A}$ is the mean response of the whole Amazon basin. A simple relative beam balance technique was proposed for NSCAT where $\sigma_i^o(\theta)$ for each antenna beam $i$, was forced to the mean response from all beams [2].

## IV AZIMUTH BEAM BALANCE

Previously NSCAT measured $\sigma^o$ over a broad range of incidence angles (typically 20 - 60°). Each beam provided looks at approximately constant azimuth angle with respect to the spacecraft velocity vector. Beam balance was achieved by comparing individual antennas to the mean of all. On the other hand, SeaWinds $\sigma^o$ 's are measured using beams at two constant incidence angles (46° and 54°, Fig. 1) while covering the entire range of azimuths while scanning. Because of the the incidence angle difference between the beams, relative

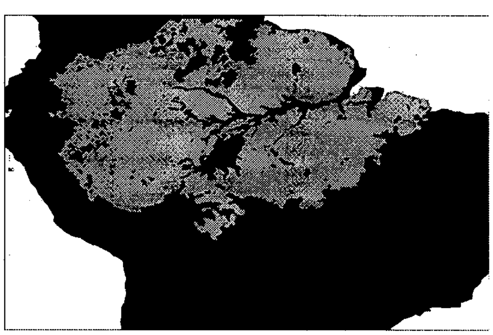

Fig. 2: Amazon mask for data filtering

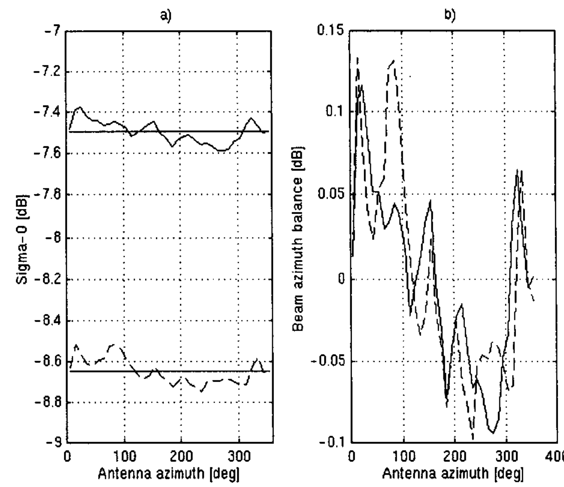


Fig. 3: QuikScat beam azimuth balance

balance by forcing beams to referent incidence angle response is not applicable. Without a suitable reference, QuikScat calibration data are used only for inspection of the $\sigma^o$ azimuth response. Based on QuikScat orbits 430-1200, at beam IFOV resolution, $\sigma^o$ azimuth response is within ± 0.1 dB of the mean as shown in Fig. 3. The left panel shows QuikScat inner and outer beam azimuth response compared with the mean response from all azimuths (horizontal line). The right panel emphasizes variation about the mean, confirming it is mostly within ± 0.1 dB. The diurnal effect of cell $\sigma^o$ is shown in Fig. 4 for data that are separated into ascending (≈ 6:30 local time) and descending (≈ 18:30) passes. A consistent difference of $\sigma^o_{asc} - \sigma^o_{dsc} \approx$ 0.5 dB is observed which may be attributed to varying geophysical conditions (e.g., leaf orientation and moisture content) between morning and evening.

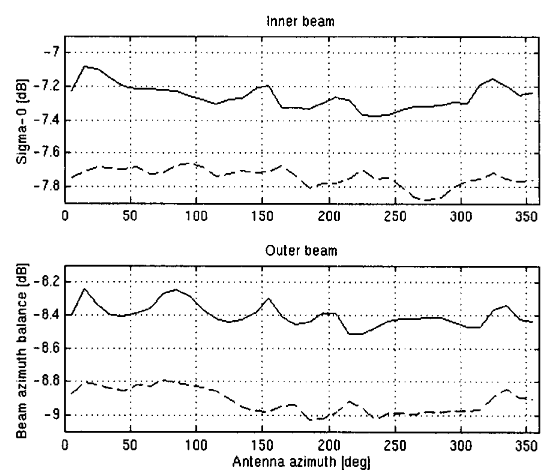


Fig. 4: Diurnal QuikScat response: ascending passes: solid line descending passes: --

## V SLICE BALANCE

Due to incidence angle differences between the two beams, the relative beam balance approach was not applicable for high-resolution slices [1]. Nevertheless they can be relatively balanced using the QuikScat slice data over a homogenous land target. The obvious reference is the corresponding low-resolution cell $\sigma^o$, to which all neighboring slices should converge in the mean. Because of the large density of $\sigma_s^o$ measurements (subscript $s$ denotes slice, $s$ = 1..8), a week's worth of QuikScat data (≈ 30 passes over Amazon) is enough to achieve covergence in $\delta_s = \sigma_s^o - \sigma_c^o$, where $\sigma_c^o$ is the cell $\sigma^o$ corresponding to slices $s$. The value of $\delta_s$ is, thus, slice bias that needs to be subtracted from $\sigma_s^o$ to balance all individual slices to the corresponding cell. With a small incidence angle correction applied, $\delta_s$ is calculated for QuikScat orbits between 430 and 1200, and results are shown in Fig. 5. A relatively balanced slice response is observed for all slices, except the outermost slice 8, which deviates as much as 0.5 dB from the cell $\sigma^o$ at azimuth angles close to 200°. This prompted reprocessing of $\sigma^o$ set with modified calibration table [1]. The modification applied to orbits 1200-1400 shows an improvement in the sense that the outermost slice bias is decreased to within 0.15 dB, as shown in Fig. 6. Based on this result, derived from the Amazon region, usage of the modified calibration table applied for reprocessed orbits 1200-1400 is recommended.

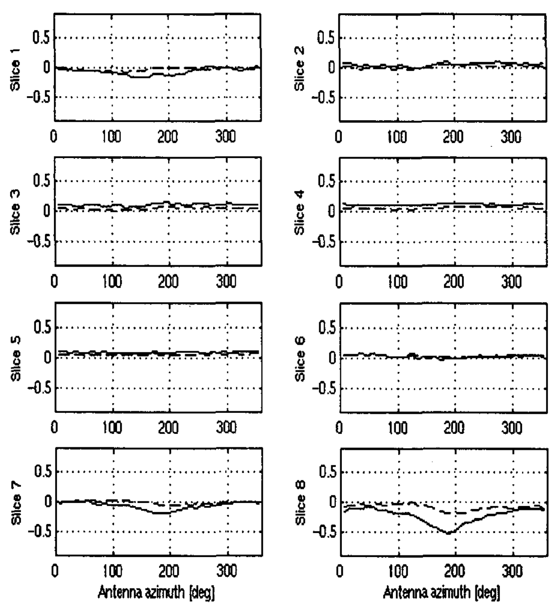


Fig. 5: QuikScat slice balance: Inner beam: solid line, Outer beam: dashed line

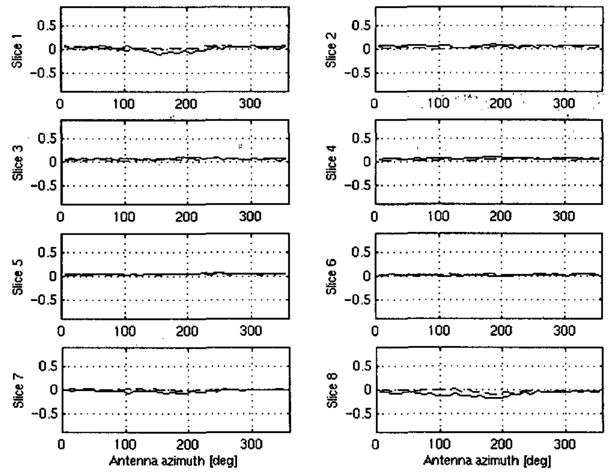


Fig. 6: QuikScat slice balance calculated from reprocessed data (orbits 1200-1400): Inner beam: solid line, Outer beam: dashed line

## V REFERENCES

[1] Spencer, M. W., Chialin Wu, and D. G. Long: Improved resolution backscatter measruements with the SeaWinds pencil-beam scatterometer, to appear in Trans. on Geoscience and Remote Sensing, 1999.

[2] Zec, J., D. G. Long, and W. L. Jones, NSCAT sigma-0 biases using homogenous land targets, J. Geophys. Res., Vol. 104, No. C5, May. 1999

[3] Grantham, W. L., E. M. Bracalente, W. L. Jones, and W. J. Johnson, The SEASAT-A Satellite Scatterometer, *IEEE J. Oceanic Engineering*, OE-2, pp. 200-206, (1977).

[4] Attema, E. P. W., The Active Microwave Instrument On-board the ERS-1 Satellite, *Proc. IEEE*, vol. 79, No.6 (1991).

[5] Naderi, F., M. H. Freilich, and D. G. Long, Spaceborne Radar Measurement of Wind Velocity over the Ocean - An Overview of the NSCAT System, *Proc IEEE*, vol. 79, no. 6, pp. 850-866, (1991).

[6] Birer, I. J., E. M. Bracalente, E. M. Dome, G. J. Sweet, and G. Berthold, σ° Signature of the Amazon Rain Forest Obtained from the Seasat Scatterometer, *IEEE Trans. Geoscience and remote Sensing*, Vol. Ge-20, no. 1, pp. 11-17 (1982).

[7] Long, D. G., and G. B. Skouson, Calibration of Spaceborne Scatterometers Using Tropical Rain Forests, IEEE Trans on Geoscience and Remote Sensing, Vol. 34, no. 2, pp. 413-424 (1996).

[8] Long, D. G., P. Hardin, and P. Whiting, Resolution Enhancement of Spaceborne Scatterometer Data, *IEEE Trans. Geoscience and Remote Sensing*, Vol. 31, no.3, pp.700-715 (1993)