High Resolution Surface Backscatter Measurements with the *SeaWinds* Pencil-Beam Scatterometer

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Abstract— A technique employed to extract higher resolution backscatter measurements from the *SeaWinds* pencil-beam scatterometer system is described. The unique methodology necessary to achieve very high radiometric accuracy for such measurements is discussed.

INTRODUCTION

To continue and expand upon the foundation provided by the recent flight of the NASA Scatterometer (NSCAT), NASA is developing the *SeaWinds* instrument which is scheduled to fly on the *Quikscat* mission in November 1998, and on the Second Japanese Earth Observation Satellite (ADEOS-II) to be launched in early 2000. In a significant design departure from previous "fan-beam" scatterometer systems, *SeaWinds* will be a "pencil-beam" system. Pencil-beam systems employ a single, approximately 1 m parabolic dish which is conically scanned about the nadir axis to provide multiple azimuth measurements [3] [4] (see Fig. 1). A key advantage to pencil-beam systems is that, because of their more compact design, they are much easier to accommodate on spacecraft without the necessity of complex deployment schemes or severe field-of-view constraints. In an era where smaller space missions with faster development times are often mandated – as is the case with the *Quikscat* mission, for example – such a reduction in payload size is highly desirable. An additional advantage to pencil-beam systems is that because they measure ocean backscatter at a constant incidence angle suitable for wind retrieval, there is no "nadir gap" in swath coverage as there is for fan-beam systems. The resulting contiguous swath offers a significant improvement in Earth coverage. For these reasons, the pencil-beam design has been adopted for NASA scatterometers into the next century.

The adoption of the pencil-beam approach, however, has presented system designers with new challenges as well. One design challenge, largely unanticipated until the success of the recent NSCAT mission, is the coarser spatial resolution of the pencil-beam footprint obtainable with a 1 m parabolic dish as compared to the smaller σ_0 cells collected by NSCAT. As originally envisioned, the

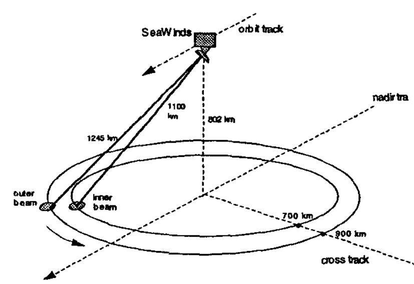

Figure 1: *Fig. 1: SeaWinds Measurement Geometry*

SeaWinds instrument would collect aperture limited resolution σ_0 measurements – approximately 20 by 30 km ovals spaced at 20 km intervals on the Earth's surface [3]. This sampling strategy was demonstrated to meet key requirements for global synoptic wind speed and direction measurements. The higher resolution σ_0 cells – approximately 7 by 20 km – obtained with the NSCAT system, however, have proven to be enormously useful in new science applications. As an example, high resolution wind fields exhibiting detailed mesoscale phenomena have been constructed. Higher resolution σ_0 measurements also allow winds to be retrieved closer to coastlines and open the possibility of spaceborne monitoring of coastal phenomena.

In addition to high resolution wind estimation, NSCAT σ_0 measurements also have found wide applicability in land and ice studies [1]. Through a technique know as enhanced resolution imaging, multiple passes of overlapping scatterometer data over the same region are combined to solve for higher resolution images of the under-

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lying backscatter. The resolution achievable is limited by the narrowest dimension of the measurement cell. For NSCAT, this limiting resolution is approximately 8 km. To extend the high resolution imaging capability demonstrated by NSCAT into the pencil-beam era, it is clearly desirable to identify and implement techniques to improve the beam resolution beyond the simple aperture limit.

IMPROVED RESOLUTION APPROACH

Doppler and/or range information in the returned radar echo can be used to achieve resolution beyond the simple aperture limit. Existing hardware constraints make simultaneous range/Doppler resolution unachievable for *SeaWinds*, but higher resolution may be obtained in one dimension by performing either pure Doppler or pure range filtering. For *SeaWinds*, the range resolution approach was selected, rather than a Doppler resolution approach, to form the σ_0 cells. This selection insures that an optimal number of "looks" can be obtained for each σ_0 cell – an important consideration in minimizing measurement variance due to fading and thermal noise. Range filtering also allows the shape of the σ_0 cells to maintain approximately the same geometry with respect to the viewing direction as a function of antenna scan position.

To achieve range resolution, the transmit pulse is modulated with a linear chirp. The nominal 1.5 ms pulse and 250 kHz/ms chirp rate yield a signal with a bandwidth of 375 kHz. The return echo is downconverted, A/D converted, and digitally "de-ramped" or "de-chirped" by mixing with a chirped reference function. At this point in the processing, the signal has an approximately 40 kHz bandwidth with each frequency corresponding to a given range line (plus a Doppler offset) within the antenna footprint. An FFT is applied to obtain the total detected energy at each range location. The FFT periodogram bins are summed to yield σ_0 resolution "slice" measurements which are telemetered to the ground. The resolution slice is illustrated conceptually in Figure 2. The narrow dimension of the slice is approximately 8 km., and the long dimension of the slice is approximately 20 km. Thus, the slices have approximately the same dimension as the NSCAT fan-beam cells. *SeaWinds*, however, has the advantage of providing a much denser sampling of the surface for each measurement pass.

σ_0 CALIBRATION

Although the above described range resolution approach is common to many radars, a unique aspect of wind scatterometery is the desire for extremely high radiometric measurement precision. In order to track climatological trends, it is desirable to insure that σ_0 measurements are repeatable to within 0.2 dB over the life of the mission. This is challenging for any radio frequency device, and is particularly challenging for the *SeaWinds* high resolution measurements. The response of the range filtering processor, the effect of the rapidly scanning antenna beam during the pulse and round trip flight to the surface, and the spacecraft attitude and orbit must all be carefully taken into account.

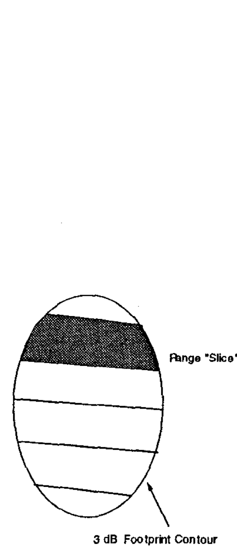

Figure 2: *Fig. 2: Conceptual Diagram of Range Resolution Slice*

The value of σ_0 for the jth slice is obtained from

$$\sigma_0 = \frac{P_s^j}{X} \tag{1}$$

where P_s^j is the echo return energy in the slice (minus an estimate of the thermal noise power), and X is the radar calibration parameter. For the *SeaWinds* processor, X is given by

$$X = C^2 \sum_{k=k_s}^{k_e} \sum_{i \in \mathcal{I}} \left| \sum_{n=0}^{N-1} B_i(t_{bs} + nT) e^{2\pi j (f_{b,i} T - \frac{k}{N}) n} \right|^2 . \tag{2}$$

Here, the k summation is performed over all periodogram bins that constitute the slice, the i summation is over all independent, infinitesimal surface scattering elments in the field of view of the radar, the n summation is over the signal samples input to the FFT, t_{bs} is the time (relative to the onset of the transmit pulse) corresponding to the first signal sample, $f_{b,i}$ is the de-chirped baseband frequency of a specific surface scattering element, T is the sample period and N is the total number of samples. The windowing function $B_i(t)$ is given by

$$B_i(t) = G(t) \left(\frac{\delta A_i}{r_i^4} \right)^{\frac{1}{2}} [p(t - t_{d,i}) g_i(t) g_i(t - t_{d,i})]^{\frac{1}{2}} . \tag{3}$$

where $G(t)$ is the receive gate window, δA_i is the area of each surface element, r_i is the slant range to each surface

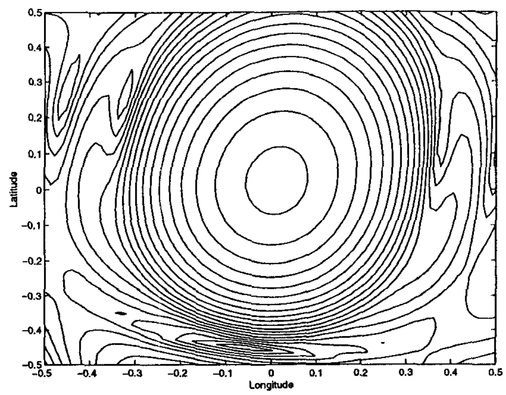

Figure 3: *Fig. 3: Spatial Response of Antenna Footprint (3 dB Contours)*

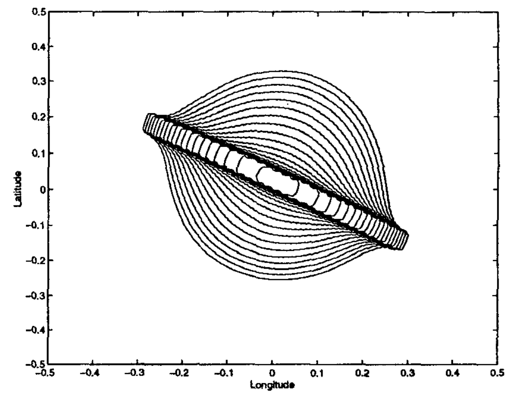

Figure 4: *Fig. 4: Example Spatial Response of Range Resolved σ_0 slice (3 dB Contours)*

element, $p(t)$ is the transmit signal power envelope, $g_i(t)$ is the normalized antenna gain at each surface element at time t, and $t_{d,i}$ is the round trip flight time of the pulse to each surface element. The parameter C^2 represents geometry independent radar parameters, and is given by

$$C^2 = \left(\frac{\lambda^2}{(4\pi)^3}\right)\left(\frac{E_t G_r G_p^2}{L_{sys}}\right) \quad (4)$$

where λ is the transmit wavelength, G_r is the total receiver gain, G_p is the peak antenna gain, and L_{sys} is total two-way system loss.

σ_0 CELL SPATIAL RESPONSE

Using the result in Eq. (1), it is useful to define the spatial response of a specific slice on the Earth's surface, S, at a surface element located at position $\vec{l_i}$:

$$S(\vec{l_i}) \propto \frac{1}{\delta A_i} \sum_{k=k_s}^{k_e} \left| \sum_{n=0}^{N-1} B_i(t_{bs} + nT) e^{2\pi j (f_{b,i} T - \frac{k}{N}) n} \right|^2 \quad (5)$$

Figure 3 is an example of the spatial response of the antenna beam projected on the surface with no range slicing employed. Figure 4 shows an example spatial response of range filtered slice. Note the sharp manner in which the response falls off in the range dimension. Even though the processor induced side lobes are very low, the calibration goals require that this spatial response be carefully integrated for each slice.

SUMMARY

The above described technique for enhancing the resolution of *SeaWinds* measurements has been implemented by retro-fitting the digital sub-system with the appropriate modifications to transmit pulse generation and signal processing. One of the new challenges of this approach, accurate σ_0 cell calibration, has been briefly described. The Ku-Band wind scatterometery data base is scheduled to resume in November 1998 with the launch of the *Quikscat* spacecraft.

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