Status of the SeaWinds Scatterometer on QuikScat

D. G. Long

Brigham Young University, Electrical and Computer Engineering Dept.
Provo, Utah 84602 USA

ABSTRACT

The QuikScat satellite carrying the SeaWinds Scatterometer was developed as a replacement mission for the aborted Japanese Advanced Earth Observation System-I (ADEOS-I) mission carrying the NASA Scatterometer. Like NSCAT, SeaWinds is an active microwave remote sensor designed to measure winds over the ocean from space. SeaWinds can measure vector (speed and direction) winds over 95% of the Earth's ice-free oceans every day, a significant improvement over previous scatterometers. Such data is expected to have a significant impact on weather forecasting and will support air-sea interaction studies. SeaWinds will also fly aboard the ADEOS-II sensor scheduled for launch in Nov. 2000.

QuikScat was successfully launched on June 19, 1999, though as of this writing the instrument has not been turned on. This paper provides a brief overview of the SeaWinds instrument and discusses new applications of scatterometer data for the study of land and ice.

Keywords: scatterometry, radar scattering, SeaWinds, NSCAT, winds, wind measurement, tropical vegetation, polar ice

1. INTRODUCTION

In August 1996 the Japanese Advanced Earth Observation System-I (ADEOS-I) spacecraft was launched. Designed for a 3 to 5 year mission, the mission prematurely terminated after the catastrophic failure of the solar array after only 9 months of operation. The NASA Scatterometer (NSCAT)[1] was one of the key instruments aboard ADEOS-I. A follow-on scatterometer, known as SeaWinds, is planned for flight on ADOS-II with a launch in late 2000.

The enormous success of NSCAT lead to interest in a replacement scatterometer mission, known as QuikScat. Using spare parts from the SeaWinds scatterometer mission, a second SeaWinds instrument was hurriedly prepared for rapid launch. Though somewhat delayed from its original launch date in late 1998 due to launch scheduling delays in unrelated missions, QuikScat was successfully launched on June 19, 1999. SeaWinds on QuikScat represents the latest in a series of U.S.-developed Ku-band scatterometers, starting with the Seasat scatterometer (SASS) in 1978.

This paper provides a brief overview of SeaWinds and the status of the QuikScat mission. The paper is organized as follows. First, a brief description of SeaWinds is provided and the instrument calibration and validation plans are discussed. Finally, new applications for scatterometer data for studies of land and ice are briefly described.

2. PRINCIPLES OF SCATTEROMETRY

A wind scatterometer is microwave radar designed to measure near-surface wind velocity over the global oceans under all-weather conditions. Winds drive oceanic motions on scales ranging from surface waves to basin-wide current systems. Winds also modulate air-sea fluxes of heat, moisture, gases, and particulates, regulating the crucial coupling between atmosphere and ocean. Scatterometers are the only remote sensing systems able to provide accurate, frequent, high-resolution measurements of ocean surface wind speed and direction in both clear-sky and cloudy conditions. As such, they will continue to play an increasingly important role in oceanographic, meteorological, and climate studies during the next decade.

Spaceborne scatterometers measure microwave power reflected from the ocean's surface. Wind produces waves which modify the radar cross section of the ocean and hence the magnitude of backscattered power. Scatterometers measure this backscattered power, allowing estimation of the normalized radar cross-section (σ^o) of the sea surface.

Correspondence: Email: long@ee.byu.edu; Telephone: 801-378-4383; Fax: 801-378-6586

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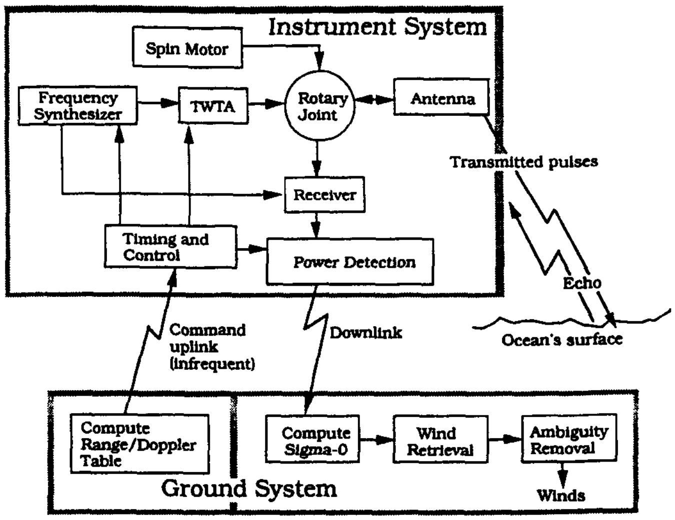

Figure 1. Conceptual block diagram of the SeaWinds system.

Using measurements of σ^o at a single point obtained from different azimuth angles, the near-surface wind speed and direction is estimated with the aid of a geophysical model function. To enable accurate wind estimates scatterometers are designed to make precision σ^o measurements with accuracies of the order of one or two tenths of a dB. For a detailed tutorial on the principles of wind scatterometry the reader is referred to Ref. 1.

3. SEAWINDS SYSTEM DESIGN

The SeaWinds system consists of a spaceborne segment (the SeaWinds instrument) and a ground processing system. A conceptual block diagram of the SeaWinds system is shown in Fig. 1. In this paper we focus primarily on the instrument segment. QuikScat is illustrated in Fig. 2. The SeaWinds dish antenna is visible at the bottom of the spacecraft.

Unlike previous scatterometers, which are based on fan-beam antennas such as NSCAT, SeaWinds is a dual-beam, conically-scanning scatterometer.[2,3] The two beams operate at different incidence angles and different polarizations. Because inner and outer scans overlap as the spacecraft propagates, backscatter measurements are obtained from both scans at cross-track distances less than the radius of the inner scan. Furthermore, each scan images a point on the surface twice – once when the ocean location is "ahead" of the subsatellite point, and once when the satellite has passed the subsatellite point. Thus, four backscatter measurements (2 different azimuths at each of two different incidence angles) are obtained for each point within the inner scan radius. Outside of the inner scan region, only two measurements are obtained. Figure 3 illustrates the SeaWinds observation swath.

By combining the backscatter measurements for each ocean location, the surface wind velocity can be estimated as in classical fan-beam scatterometry. However, the scanning scatterometer concept has several advantages over traditional fan-beam instruments. For example, since wind retrieval from low incidence angle σ^o is very inaccurate, fan-beam scatterometers have wide nadir gaps where the wind cannot be accurately estimated due to the low incidence angles of the observations. The scanning geometry of SeaWinds enables observation of σ^o at a uniform high incidence angle, resulting in high directional and speed accuracy in the wind estimates. Further, because measurements are made at only a small number of incidence angles, the model function does not need to be known over a wide range of radar parameters, simplifying the geophysical modeling problem. On the other hand, the wind retrieval algorithm is somewhat more complicated due to the varying azimuth angle geometry variation over the swath. The wind estimate accuracy varies somewhat over the swath with the most accurate measurements in the swath regions between the near-nadir swath center and the edge of the swath center.

Two different types of σ^o measurements are reported by SeaWinds. These are termed 'eggs' and 'slices'.[3] The instantaneous antenna footprint defines the spatial extent of the egg measurements while range/Doppler processing is used to resolve the footprint into smaller areas in the slice measurements.[3] Previous scatterometers have used

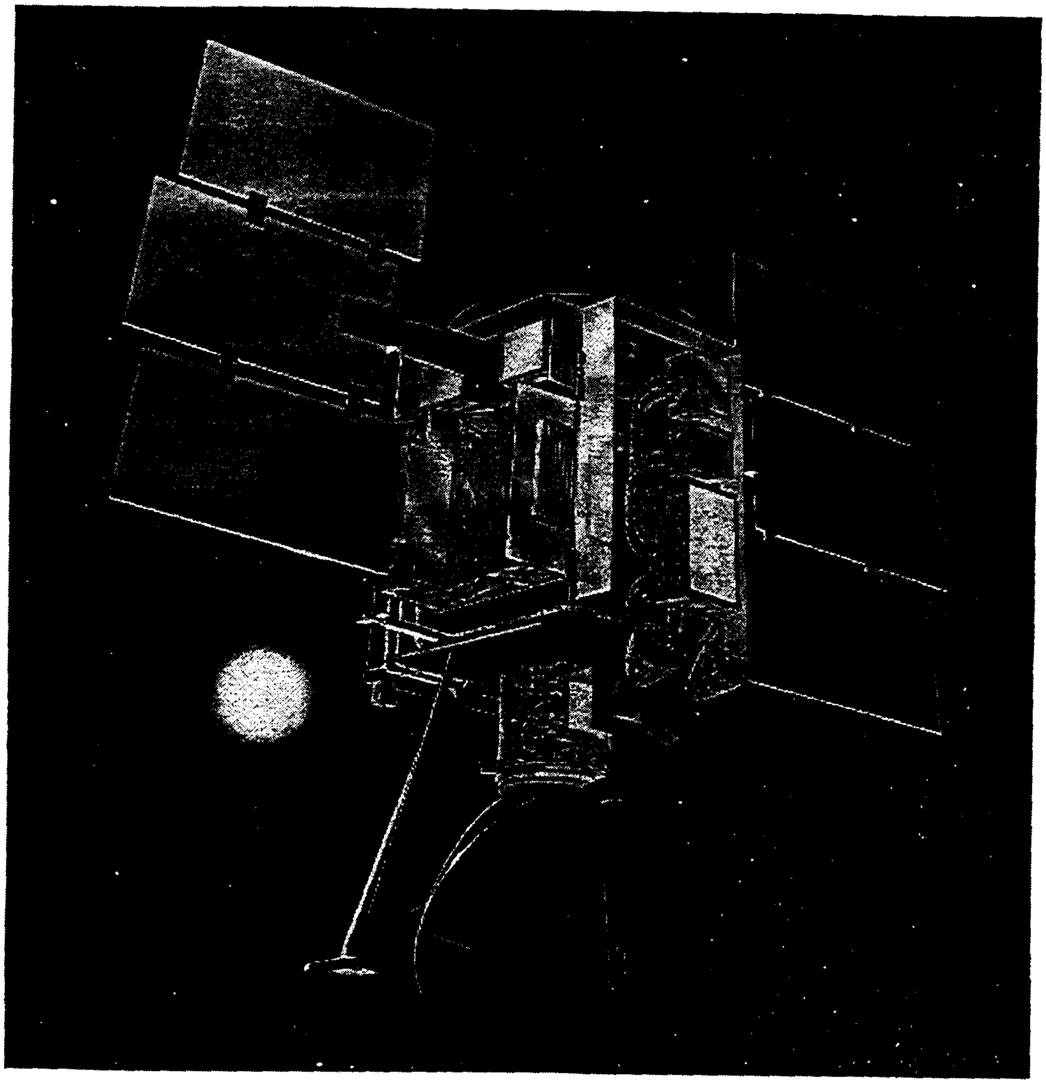

Figure 2. Artist's conception of the QuikScat satellite in orbit. (courtesy of JPL/NASA)

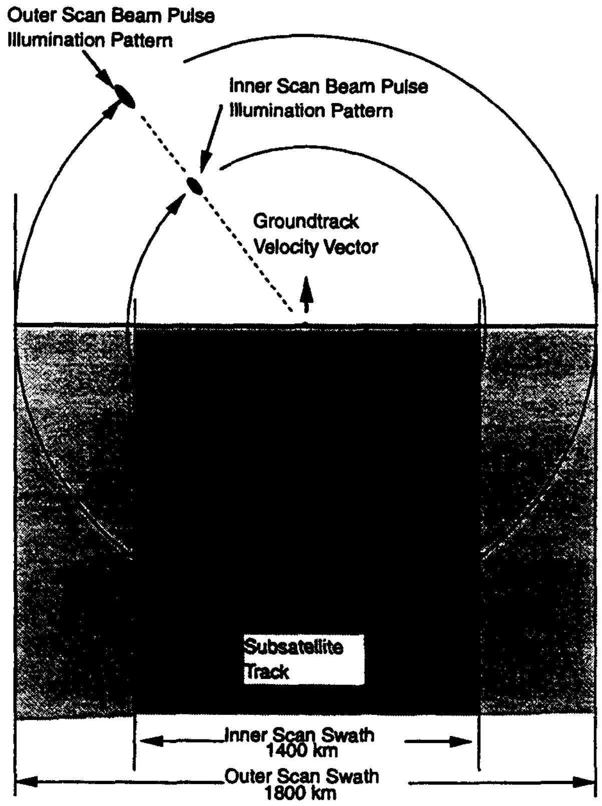

Figure 3. SeaWinds coverage swath.

Doppler filtering (SASS and NSCAT) or range gating (the scatterometer mode of the European Earth Remote Sensing Satellites [ERS-1 and ERS-2] Advanced Microwave Instrument) to achieve spatial resolution. σ^o measurements corresponding to the 8 center slices of the antenna illumination footprint and their sum are reported. The individual slices are approximately 7 × 40 km. The antenna beamwidths are 1.8° × 1.6° and 1.7° × 1.4° for the inner and outer beams respectively, resulting in elliptical 3 dB footprints of 34 × 44 km and 37 × 52 km and defining the resolution of the egg measurements. The along track spacing between rotations is approximately 22 km.

The peak antenna gains for each beam are 38.5 and 39 dBi while the antenna rotation rate is 18 rpm about nadir. The inner beam is horizontally polarized while the outer beam is vertically polarized. Using linear frequency modulation (LFM) with a bandwidth of 375 kHz bandwidth, the SeaWinds transmitter emits 1.5 ms long pulses at a pulse repetition frequency (PRF) of 185 Hz. The pulses alternate between inner and outer beams, resulting in an effective PRF of 92.5 Hz for each beam. With a pulse time of flight to the surface of 7.3 and 8.3 ms for the inner and out beams, respectively, several pulses are in flight at a time. The along-scan distance between pulse footprints is 15 and 19 km, respectively, so there is significant overlap in the 3 dB antenna/pulse footprints between pulses and scan rotations. The peak transmit power is approximately 110 W and the center frequency is 13.402 GHz. The transmit frequency is shifted to compensate for the expected Doppler shift in the received signal so that the return echo comes back at an offset frequency of nominally 0 Hz. After reception and amplification, the signal is digitized and "dechirped" by digitally mixing with an LFM reference chirp. The resulting signal is processed using an FFT to extract range and Doppler information. The noise-only measurement bandwidth is 1 MHz.

4. SEAWINDS CALIBRATION/VALIDATION

Precise calibration (on the order of a few tenths of a dB) of the scatterometer σ^o measurements is required to achieve the desired wind measurement accuracy. This level of precision in radar calibration is difficult to achieve using pre-launch calibration alone so an intensive post-launch calibration campaign is planned for shortly after launch.

Following the successful precedent set by the NSCAT Cal/Val activities,[4] an intensive initial intensive calibration activity is planned for the first two months after instrument turn-on and check-out. A preliminary scientific data set will then be released to the Science Working Team (SWT) to support validation activities.

Three approaches to post-launch calibration are planned: 1) a calibration ground station (CGS), 2) homogeneous extended-area targets such as tropical rain forests, and 3) comparison of SeaWinds observed σ^o measurements and estimated winds with model winds and values of σ^o computed from them. The receive-only CGS is in White Sands, New Mexico. Approximately twice each day, the CGS will observe overflights of the SeaWinds instrument. It will accurately measure the received signal timing, power, and Doppler shift during the pass. This data will be used to verify instrument operation, spacecraft attitude, and antenna calibration parameters.

Extended area targets such as tropical rainforests have proven effective in calibrating previous scatterometers.[4,5] Rainforests provide large, homogeneous areas with stable σ^o responses, enabling validation of the system calibration. During the SeaWinds initial calibration/validation period σ^o measurements collected over selected extended area targets will also be used to validate the ground processing algorithms for computing σ^o from the power measurements as well as verifying system pointing and spacecraft attitude.[4] Long-term measurements will assist in the evaluation of the gain stability.

5. LAND AND ICE APPLICATIONS OF SCATTEROMETER DATA

Unlike previous fan-beam scatterometers which measure σ^o over a wide range of incidence angles, SeaWinds will observe σ^o at only two incidence angles, nominally 38° and 53°. However, SeaWinds will sample the surface much more densely than previous scatterometers. As a result, resolution enhancement algorithms can be more effectively applied to SeaWinds data. The coarse resolution (nominally 25 km) of the SeaWinds measurements, while suitable for ocean wind measurement, can be a significant limitation in the application of scatterometer data to land and ice studies. To ameliorate this limitation, resolution enhancement algorithms can be applied to the data. The dense, overlapping SeaWinds 'slice' measurements are particularly well-suited for the application of the Scatterometer Image Reconstruction (SIR) algorithm,[6] which is predicted to achieve a resolution enhancement of SeaWinds data to better than 6-8 km.[3] Enhanced resolution images of σ^o generated from SeaWinds data with the aid of the SIR algorithm will be used in a variety of non-ocean applications. Some of these are described below.

While originally designed for wind observation, NSCAT data has been successfully being used in a variety of studies over land and ice.[13] In particular, NSCAT has proven to be very useful in polar ice studies.[7,9] Scatterometer data has also been used for tropical vegetation studies.[8,12]

In Ref. 9 NSCAT data is used to map the extent of sea-ice over the 9 month NSCAT mission. This algorithm has been extended for use with QuikScat data[10] and will be applied for studies of sea ice dynamics and mapping. Scatterometer data is ideal for this application since it does not depend on solar illumination and provide rapid, global coverage. Further, active microwave signals can be very effective in discriminating geophysical ice characteristics.[7]

The rapid repeat coverage of scatterometer data can be a valuable asset in many studies. Due to the sensitivity of σ^o to moisture content in surface snow layers, scatterometer data is an effective tools for monitoring the onset of summer melt in the polar regions.[7] This sensitivity can be exploited in other ways as well. As an illustrative example of an innovative use of scatterometer data for global monitoring consider Figure 4. This figure shows a sequence of enhanced resolution images of the incidence angle normalized σ^o ($\mathcal{A}$) over iceland during a portion of 1996 from Julian day 261 through 327. Each image is made from 6 days of v pol NSCAT data.

At the start of the analysis period in late summer, snow covering the Icelandic icecaps contains significant liquid water, resulting in a low backscatter value. As the season progresses, lowering temperatures freeze liquid water, resulting in significantly increased backscatter values which show up as light patches in the images. The largest of these patches corresponds to the Vatnajoekull icecap at the right center of the island. As can be seen in the image sequence, there is a gradual increase in σ^o of the icecaps from JD 261 through 327, with some interruptions due to warm fronts passing over the island and, in the case of the Vatnajoekull icecap, the eruption of a subglacial volcano in the Grimsvotn caldera underlying the icecap. On Sept 29, 1996 (JD 303) a volcanic eruption began in a crater beneath the Vatnajoekull icecap, resulting in the formation of a large subglacial lake in the Grimsvotn caldera and thinning the ice cover over the caldera. On Nov. 5 (JD 310) water flowed for several days from beneath the glacier, dramatically flooding Skeidara river and draining the subglacial lake. These events cause a small, but visible, perturbation in the observed backscatter values. Further analysis continues.

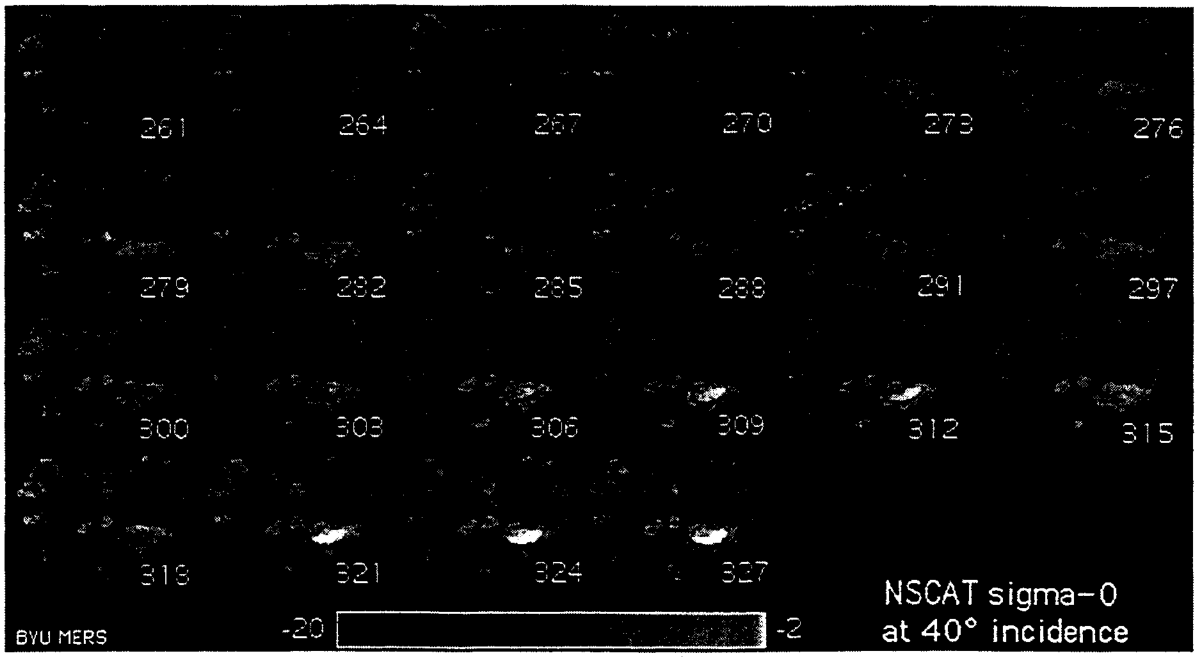

Figure 4. NSCAT image time series of Iceland in 1996.

6. CONCLUSION

Scatterometers can provide frequent global measurements of vector winds of unprecedented accuracy. Although originally designed for measuring ocean winds, scatterometer data has proven to be useful in studies of polar ice and vegetation. The SeaWinds on QuickScat replacement mission will continue the NSCAT Ku-band scatterometer time series of earth observations begun in 1978 with Seasat. SeaWinds' wide swath and frequent revisit time for measuring ocean winds is expected to significantly improve weather forecasting skill. The data will also be important in climate forecasting, air/sea interaction, and land/ice studies. Both NASA and the European Space Agency have in place mature programs for scatterometer missions through the first part of next decade. The next U.S. scatterometer will be the primary SeaWinds mission aboard ADEOS-II, currently scheduled for launch in late 2000.

REFERENCES

1. F.M. Naderi, M.H. Freilich, and D.G. Long, "Spaceborne Radar Measurement of Wind Velocity Over the Ocean – An Overview of the NSCAT Scatterometer System," *Proc. IEEE*, vol. 79, no. 6, pp. 850–866, 1991.
2. M.W. Spencer, C. Wu, and D.G. Long, "Tradeoffs in the Design of a Spaceborne Scanning Pencil-beam Scatterometer,"*IEEE Trans. Geosci. Remote Sens.*, Vol. 35, No. 1, pp. 115-126, 1997.
3. M.W. Spencer, C. Wu, and D.G. Long, "Improved Resolution Backscatter Measurements with the SeaWinds Pencil-Beam Scatterometer," in review, *IEEE Trans. Geosci. Remote Sens.*, 1999.
4. W. Tsai, J.E. Graf, C. Winn, J.N. Huddleston, R.S. Dunbar, M.H. Freilich, F.J. Wentz, D.G. Long, W.L. Jones, "Post-launch Sensor Verification and Calibration of the the NASA Scatterometer," *IEEE Trans. on Geosci. Rem. Sens.*, vol. 35, pp. 1517-1542,1999.
5. D.G. Long and G.B. Skouson, "Calibration of Spaceborne Scatterometers Using Tropical Rainforests," *IEEE Trans. Geosci. Remote Sens.*, vol. 34, no. 2, pp. 413–424, 1996.
6. D. Long, P. Hardin, and P. Whiting, "Resolution Enhancement of Spaceborne Scatterometer Data," *IEEE Trans. Geosci. Remote Sens.*, vol. 31, pp. 700–715, 1993.
7. D.G. Long and M.R. Drinkwater, "Cryosphere Applications of NSCAT Data," *IEEE Trans. Geosci. Remote Sens.*, vol. 35, pp. 1671-1684, 1999.
8. D.G. Long and P.J. Hardin, "Vegetation Studies of the Amazon Basin Using Enhanced Resolution Seasat Scatterometer Data," *IEEE Trans. Geosci. Remote Sens.*, Vol. 32, No. 2, pp. 449-460, 1994.

9. Q.P. Remund and D.G. Long, “Polar Sea Ice Extent Mapping Using Ku-Band Scatterometer Data,” *J. Geophys Res*, May 1999.
10. Q. P. Remund and D. G. Long, “Antarctic Ice Edge Detection Using NSCAT Data,” in Earth Observing Systems II, William L. Barnes, Ed., *Proc. SPIE Vol. 3117*, pp. 72-80, San Diego, California, 27 July - 1 August, 1997.
11. Q.P. Remund and D.G. Long, “Sea Ice Mapping Algorithm for QuikScat and SeaWinds,” *Proc. IGARSS '98, Seattle*, pp. 1686-1688, Washington, 6-10 July, 1998.
12. P.J. Hardin and D.G. Long, “Characterization of Global Vegetation Using Reconstructed NSCAT Imagery,” in *Proc. SPIE 3119*, San Diego, California, 27 July - 1 August, 1997.
13. D.G. Long, “NSCAT Views Land and Ice,” *Proc. Int. Geosci. Remote Sens. Sym.*, pp. 1973-1975, Seattle, Washington, 6-10 July, 1998.