Seasat Scatterometer: Results of the Gulf of Alaska Workshop

Abstract. *The Seasat microwave scatterometer was designed to measure, globally and in nearly all weather, wind speed to an accuracy of ± 2 meters per second and wind direction to ± 20° in two swaths 500 kilometers wide on either side of the spacecraft. For two operating modes in rain-free conditions, a limited number of comparisons to high-quality surface truth indicates that these specifications may have been met.*

The Seasat-A scatterometer system (SASS) is a microwave radar which was designed to provide global, day or night measurements of the synoptic-scale, ocean-surface vector winds. The physical basis for this technique is the Bragg scattering of microwaves from centimeter-length capillary ocean waves. The strength of the radar backscatter (σ^0) is proportional to the capillary wave amplitude, which is proportional to the wind speed near the sea surface. Moreover, the radar backscatter is anisotropic; therefore, wind direction can be derived from SASS measurements at different azimuths.

The SASS (*1*) incorporated four dual-polarized [vertical (V-pol) and horizontal (H-pol)] antennas, which produced an X-shaped pattern of illumination on the earth (Fig. 1). The satellite geometry required that both forward- and aft-looking antennas be used to obtain two independent radar measurements at the same ocean location. The Seasat implementation used antenna beams oriented 45° relative to the subsatellite track to yield observations that were separated in azimuth by 90°. Twelve Doppler filters were used to subdivide the antenna footprint electronically into resolution cells approximately 50 km on a side. In addition, three σ^0 measurements from incidence angles near nadir provided coverage (wind speed only) along the subtrack. The cover of this issue depicts a SASS-derived wind field for a port-side-only measurement mode. The satellite ground track is from south to north and lies between the wind field and land.

The SASS evaluation task group (*2*) has three candidate geophysical algorithms (*3*) for inferring ocean wind vector from σ^0 measurements. Although the candidate algorithms differ in approach, preliminary comparisons indicate that all give similar results; therefore, we present here the results from only one algorithm (*4*). Basic to all the geophysical algorithms is the empirical model function, which relates σ^0 to the wind vector as a function of incidence angle, azimuth angle, and polarization. The present model function was derived before launch from a limited data base of aircraft radar measurements and will be improved when Seasat data and suitable surface wind measurements are incorporated. Because of the harmonic nature of the model function, the geophysical algorithm recovers between one and four solutions for each grid point. These solutions are nearly equal in speed but vary widely in direction. This result, referred to as aliasing, necessitates further processing to yield the correct solution. For the present case (including the cover wind field), a priori knowledge of wind direction, from surface observations, permitted aliases to be removed.

The objective of the Gulf of Alaska Seasat Experiment (GOASEX) Workshop was to gather and process meteorological data on winds, sea-surface temperature, air temperature, and cloud cover so as to compare the meteorologically determined winds with the winds inferred from SASS. In the field of remote sensing, the measurements collected by other means (in situ instruments) are often referred to as surface truth, as if they were inherently more accurate than the remotely sensed quantities. However, a synoptic-scale wind determined from meteorological measurements at discrete points over the ocean surface has identifiable, and at times removable, sources of bias and random errors. Similarly, the SASS winds also have inherent biases and random errors. Therefore, the error statistics presented should be distributed to all sources.

The set of conventional meteorological products used in the GOASEX Workshop exceeded in both quality and quantity the usual data obtained from operational ocean weather analysis and forecasts. The surface truth data consisted of spot reports and calculated wind fields. The spot reports were from the National Oceanic and Atmospheric Administration (NOAA) national data buoys, the NOAA oceanographic vessel *Oceanographer*, the Canadian ocean weather station PAPA, and transient ships. Sources of bias in these wind observations are variations in anemometer height, the effects of atmospheric stability, the disturbance of the flow by the presence of the ship, and errors in anemometer exposure and calibration. Of these biases, the effects of variations in anemometer height and atmospheric stability have been removed by means of the Monin-Obukhoff theory (*5*) for the variation of the wind with height. Thus

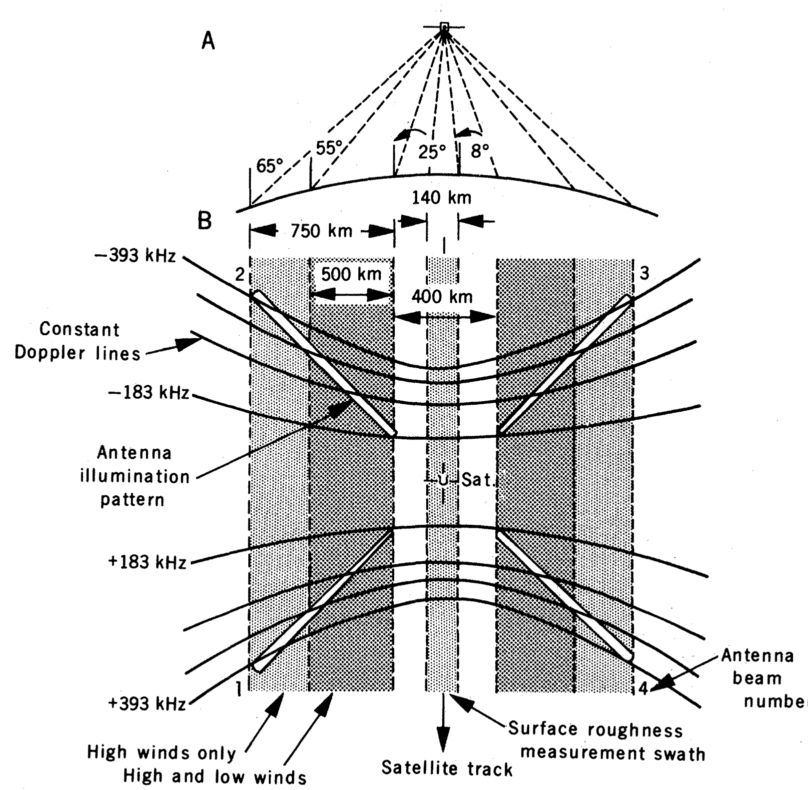

Fig. 1. SASS swath geometry: (A) side view, (B) top view. The instrument characteristics were as follows: 1459927 GHz; 100 W, peak radio-frequency power; electronic scan (15 Doppler cells); orthogonal measurement (azimuth); four antennas; dual polarization; and 0.5° by 25° antenna beam.

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the wind speed that has been used is the effective neutral stability wind at an anemometer height of 19.5 m (6). There was no reason to believe that the other biases in the spot reports were consistently high or low; therefore, it was assumed that these biases would average to only a small residual. Conventional anemometer measurements do not adequately separate the turbulent-scale and the synoptic-scale wind, and the random component of a speed and direction measurement is caused by the inadequate average of the anemometer time history. This random error dominates the errors in anemometer measurements and grows in direct proportion to the mean wind speed.

We made comparisons, using SASS winds with 85 spot reports subdivided into four categories: (i) buoys, (ii) ships with anemometers at known height, (iii) ships with anemometers at unknown height, and (iv) ships that made Beaufort wind estimates. For category (iii), an anemometer height of 26 m, based on the average for all ships operating in the Gulf of Alaska, was used. Winds for categories (i), (ii), and (iii) were corrected by means of the Monin-Obukhoff theory to yield 19.5-m effective neutral stability winds; Beaufort estimates, however, were used as reported. An example of results based on the use of buoys is presented in Fig. 2. Measurements along the subtrack were excluded from this analysis since a different algorithm was used for nadir cells. No attempt was made to separate any SASS data which may have been influenced by rain (7). SASS winds were biased high by 1.9 m/sec (8) with a standard deviation about this bias of 1.8 m/sec. Table 1 summarizes the statistics for the difference between SASS winds and spot reports for all categories.

Because the spot reports were widely scattered, wind fields were produced by kinematic analysis techniques (9) and planetary boundary layer models (10) to provide a large number of surface truth winds for comparison. Eight fields were produced which consisted of 19.5-m neutral stability wind vectors with spatial resolution on the order of 100 km over the entire SASS swath. The SASS geophysical algorithm combined all σ^0 measurements (typically 8 to 12) in a grid 1° in latitude and 1° in longitude to produce a wind vector plus aliases. The interpolated surface truth wind field was used to select the wind vector closest in direction. Next the scalar wind speed and wind direction differences were calculated, and the corresponding statistics for each field were compiled. The mean wind speed differences were typically 1.1 to 5.2 m/sec (SASS higher) with standard deviations about this mean of 1.4 to 3.5 m/sec. For wind direction, the means were less than 10° with standard deviations of approximately 20°. The surface truth values are not unbiased and are probably low by 1 to 2 m/sec because of the sparse spatial data density of spot reports and the smoothing procedure used. Moreover, for wind speeds the differences appeared to be proportional to the mean wind speed. Therefore, we calculated the error by normalizing the difference by the surface truth wind speed. Mean results are given in Table 2 for seven wind fields (11); these are consistent with those from the spot report comparison.

Finally, a qualitative comparison was made between SASS winds and the surface truth wind fields. The same general conclusions were drawn for wind speed; however, for the alias problem the comparison was viewed differently. If the SASS is to guess the wind direction, the more aliases that are produced, the better its chances are. Thus we believe that the error statistics presented earlier are optimistic in that they produce the smallest difference. A realistic assessment of the accuracy of the wind direction therefore awaits an alias-removal scheme. The lowest SASS winds correctly located high- and low-pressure centers that

Table 1. Difference between SASS winds and surface spot observation.

Polarization	SASS minus spot wind speed (m/sec): Mean error V & H	Mean error V	Standard deviation of error V & H	Standard deviation of error V	Number of samples	SASS minus spot wind direction (deg): Mean error V & H	Mean error V	Standard deviation of error V & H	Standard deviation of error V
Buoy	1.79	1.48	0.9	1.5	22, 14	2.33	0.36	16.2	18.6
Anemometer at known height	3.72		2.44		9	−13.9		17.9	
Anemometer at unknown height	3.0		2.69		24	3.34		22.92	
Beaufort	2.11		2.66		30	7.6		16	

Table 2. Comparisons of SASS winds with derived wind fields.

Polarization	Number of comparisons	Wind speed difference: Mean (m/sec)	Mean (%)	Standard deviation (m/sec)	Mean wind direction difference (deg)	Standard deviation (deg)
Vertical	443	3.02	24	2.55	1.1	17.3
Horizontal	133	3.35	30	2.19	1.8	17.9
V and H combined	307	2.70	23	2.38	1.3	18.0

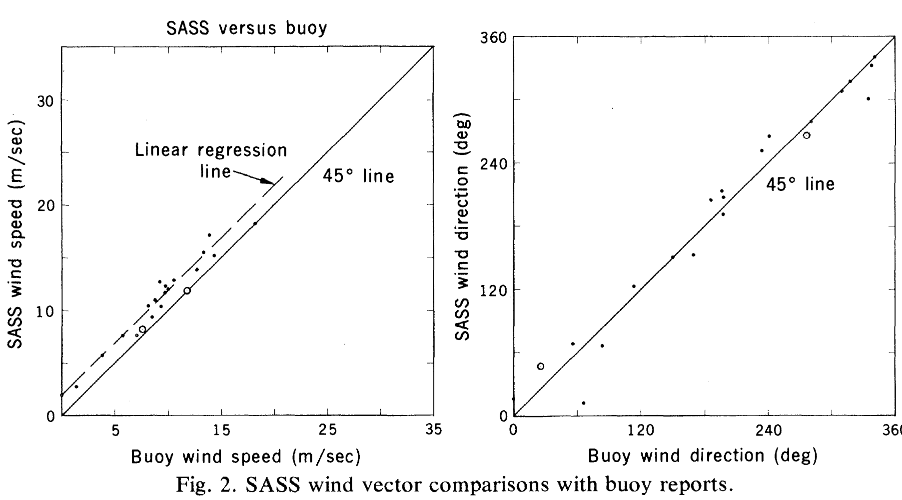

Fig. 2. SASS wind vector comparisons with buoy reports.

lie within the swath. Thus, it appears that such centers would be accurately positioned. This in itself would be a significant accomplishment, improving the numerical weather prediction in data-poor regions.

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References and Notes

1. W. L. Grantham, E. M. Bracalente, W. L. Jones, J. W. Johnson, *IEEE J. Oceanic Eng.* **OE-2**, 200 (1977).
2. An interdisciplinary panel of representatives of government, university, and private industry established by the Seasat Project Office to evaluate the data reduction-analysis algorithms for SASS.
3. Geophysical algorithms were developed by the Institute of Marine and Atmospheric Sciences, City University of New York; Center for Research, Inc., University of Kansas; and Frank J. Wentz and Associates, San Francisco.
4. W. L. Jones, F. J. Wentz, L. C. Schroeder, *AIAA J. Spacecraft Rockets* **15** (No. 6), 368 (1978).
5. A. S. Monin and A. M. Obukhoff, *Dokl. Akad. Nauk SSSR* **93**, 223 (1953).
6. The effective neutral stability wind is defined as the wind speed that would result from a given friction velocity if the atmosphere were neutrally stratified with an adiabatic lapse rate.
7. Atmosphere attenuation correction algorithms were not available for the Gulf of Alaska Seasat Experiment (GOASEX) Workshop. The result is that SASS winds during light to moderate rain may be biased in the low direction by several meters per second.
8. Results for the City University of New York algorithm (after adjusting the σ^0 model function) are +0.8 m/sec bias and 1.7 m/sec root-mean-square difference.
9. V. J. Cardone, in "GOASEX Workshop Report," G. H. Born, D. B. Lame, J. C. Wilkerson, Eds. (Report 622-101, Jet Propulsion Laboratory, California Institute of Technology, Pasadena, 1979) (internal document), vol. 2, pp. A-79 to A-87.
10. J. Overland and P. M. Woiceshyn, in *ibid.*, pp. A-88 to A-112.
11. Subsequent to the GOASEX Workshop, the Wentz model function was adjusted to remove biases. The result corresponding to V and H combined (23 percent before adjustment) is −3.2 percent (surface truth fields greater).
12. Portions of the research described in this report were carried out by the Jet Propulsion Laboratory, California Institute of Technology, under NASA contract NAS7-100.

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Seasat Scanning Multichannel Microwave Radiometer: Results of the Gulf of Alaska Workshop

Abstract. *The scanning multichannel microwave radiometer results for the Gulf of Alaska Seasat Experiment Workshop are quite encouraging, especially in view of the immaturity of the data-processing algorithms. For open ocean, rain-free cells of highest-quality surface truth wind determinations exhibit standard deviations of 3 meters per second about a bias of 1.5 meters per second. The sea-surface temperature shows a standard deviation of approximately 1.5°C about a bias of 3° to 5°C under a variety of changing meteorological conditions.*

The Seasat scanning multichannel microwave radiometer (SMMR) was flown to provide estimates of sea-surface temperature (SST) and surface wind speed (*1*), geophysical parameters of value in weather prediction, oceanographic research, and commercial operations. The accurate determination of these two parameters requires estimates of atmospheric water vapor and liquid water (clouds and rain). To provide these geophysical outputs, the SMMR measures Earth radiation with a scanning antenna operating at 6.6, 10.7, 18, 21, and 37 GHz at vertical and horizontal polarizations.

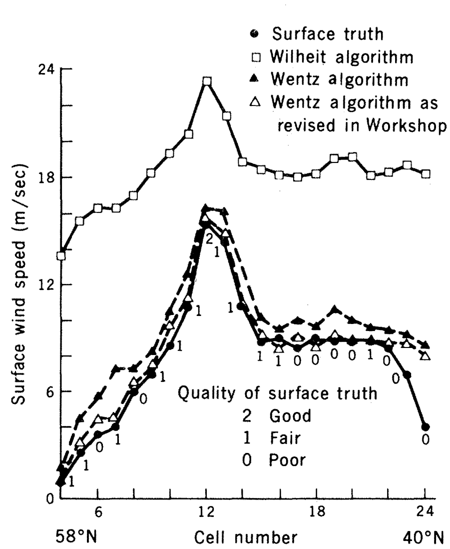

Fig. 1. Seasat SMMR wind comparison for revolution 1298; the scan was conducted near the center of the swath.

The SMMR scans to the starboard side of the spacecraft track and has a swath width of 600 km.

The antenna temperature measured by a radiometer system is the weighted integral of the brightness temperature distribution over all solid angles. The weighting is provided by the antenna patterns, which are peaked in the boresight direction and taper off rapidly away from the boresight to the lower sidelobe levels. The purpose of the antenna pattern correction (APC) algorithm (*2*) is to invert the antenna pattern effects, deriving brightness temperatures from measurements of the antenna temperature. In addition, the algorithm corrects for polarization mixing introduced by the scanning mode and averages the data onto Earth-located grids for geophysical data processing.

To provide an early data-processing capability for the SMMR, an interim version of the APC was developed which contains all the major corrections except sidelobe effects within the Earth-viewing region. In the open ocean away from land regions, it was anticipated that results accurate enough for an initial data evaluation would be obtainable with the APC interim version. The interim version has been used for the Gulf of Alaska Seasat Experiment (GOASEX) Workshop.

Two entry algorithms to retrieve geophysical parameters were investigated in the GOASEX Workshop. The Wentz geophysical algorithm (*3*) is based on a

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