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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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).
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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.
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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.

20 April 1979

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.

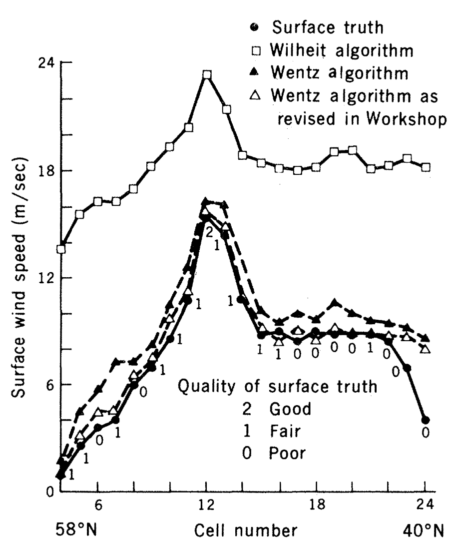

Fig. 1. Seasat SMMR wind comparison for revolution 1298; the scan was conducted near the center of the swath.

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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theoretically derived function for computing the brightness temperatures observed by the SMMR. This function depends on the SST, the sea-surface wind speed, the columnar atmospheric water vapor, and the columnar liquid cloud water. A nonlinear, iterated, least-squares estimator operates on this function to determine the several environmental parameters sensed by the SMMR. The Wilheit geophysical algorithm is based on statistical relationships between brightness temperatures and the geophysical parameters obtained from an ensemble of realistic SST values, wind speeds, atmospheric temperature profiles, water vapor profiles, and cloud models by multiple linear regression. One treats nonlinear features of the problem by relating a suitable function (not necessarily linear) of brightness temperature to the geophysical parameters and by using differing sets of regression coefficients which depend upon values of geophysical parameters determined in an initial calculation.

Table 1. Comparison of SMMR-derived surface wind speed against surface truth field data from kinematic analysis of revolutions 1135, 1212, 1292, and 1298.

Swath location	Bias (m/sec)	RMSD (m/sec)	δ (m/sec)	No. of samples
	Wentz algorithm versus category 2 surface truth			
Inner edge	2.83	4.41	3.66	7
Center scans	1.54	3.22	2.86	42
Outer edge	0.46	2.49	2.61	8
Overall	1.54	3.30	2.95 (2.93)*	57
	Wilheit algorithm versus category 2 surface truth			
Inner edge	10.56	10.95	3.13	7
Center scans	7.75	8.02	2.28	42
Outer edge	5.31	5.73	2.29	8
Overall	7.75	8.20	2.71 (2.40)*	57
	Wentz algorithm versus category 1 surface truth			
Inner edge	2.62	4.30	3.47	27
Center scans	2.28	4.18	3.52	96
Outer edge	0.78	3.21	3.20	18
Overall	2.16	4.09	3.49 (3.47)*	141
	Wilheit algorithm versus category 1 surface truth			
Inner edge	12.28	12.61	2.84	27
Center scans	8.51	9.07	3.14	96
Outer edge	4.58	5.60	3.21	18
Overall	8.73	9.51	3.77 (3.09)*	141

*Error residual after removal of cross-track-dependent biases.

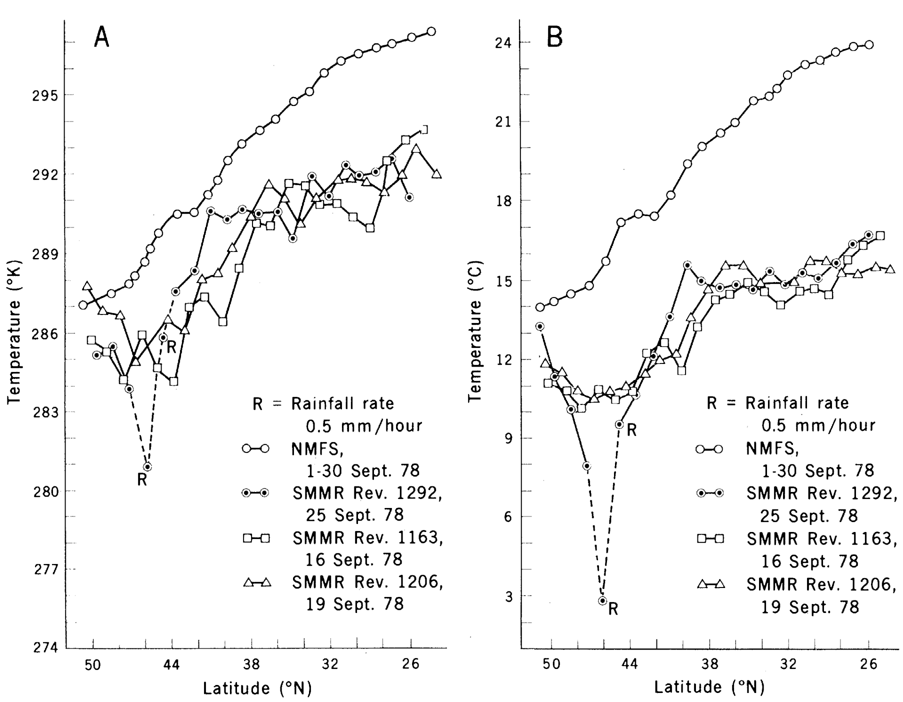

Fig. 2. Comparison of the NMFS sea temperature analysis with SMMR data from the east track for (A) Wilheit and (B) Wentz algorithms.

The GOASEX Workshop version of the SMMR algorithms can best be described as preliminary. The first geophysical outputs were produced in late November 1978. The data, from a pass over Hurricane Fico, uncovered a number of software errors and a few conceptual errors in the geophysical processing algorithms. During the 2 months available to produce data for the workshop, such errors were corrected where possible. However, the entry geophysical algorithms were not refined with the use of Seasat data in this process.

During initial evaluation activities, brightness temperature gradients from one edge of the swath to the other were observed in several of the passes, particularly for the 6.6-GHz channel. The geophysical algorithms interpret these gradients as variations due to wind speed or SST across the swath. In most cases, such variations were not found in surface truth, particularly in the SST. Potential causes for these cross-track biases are polarization cross-coupling, deviation of the spacecraft attitude from nominal (as assumed in the interim APC), and Faraday rotation. We circumvented this difficulty in the GOASEX Workshop by restricting evaluation to data sets having the same location in the swath (for example, near the center of the swath).

Wind speed data derived from the SMMR were evaluated on the basis of detailed studies of data from four GOASEX orbits characterized by a wide range of wind speeds and atmospheric conditions. These wind speeds were compared to the surface truth wind fields at roughly five points in the cross-track direction, three points near the center of the swath and one point at each edge. Figure 1 compares the surface truth wind speeds to winds computed by the entry algorithms. Both algorithms successfully track the relative changes in the wind speeds observed, although both algorithms, especially the Wilheit algorithm, exhibit significant bias.

Similar plots from other orbits revealed two additional features of the SMMR winds produced through both algorithms. First, the algorithms fail to provide reasonable relative or absolute measures of the wind speed when rain, as indicated by the algorithms and corroborated by satellite and ship data, was present. Second, an unrealistic variation in cross-track bias appears in the wind speeds. Possible reasons for the cross-track bias are given above.

The overall performance of the entry

algorithms demonstrated in the limited data set examined here is shown in Table 1. The statistics computed are (i) the mean difference or bias (SMMR minus surface truth), (ii) the root-mean-square difference (RMSD), and (iii) the standard deviation of the error about the mean, δ. The statistics are stratified by surface truth category, algorithm, and relative location within the swath. The inner edge is always located near the subsatellite track. Grid points near land and at points at which either algorithm indicated that rain was present were excluded. The surface truth data from kinematic analyses were categorized by estimated accuracy (primarily determined by spot report proximity and number) with categories 1 and 2 believed to be accurate to $\pm$ 3 and $\pm$ 2 m/sec, respectively.

This initial statistical evaluation is encouraging, in view of the fact that the algorithms have yet to be refined by the use of Seasat data. The systematic cross-swath variation in the wind speed bias is evident in both algorithms, although to a larger degree in the Wilheit algorithm. As the quality of the surface truth degrades, so does the error in the SMMR winds; this result suggests that already a significant fraction of the RMSD in wind can be assigned to the surface truth. This initial study suggests strongly that, with higher-quality surface truth data (as from data buoys) and further refinements of the entry algorithm, the Seasat SMMR design goal of a wind speed measurement capability of $\pm$ 2 m/sec can be met, at least under nonprecipitating conditions. Further evidence for this conclusion can be drawn from the plot (Fig. 1) of the Wentz winds resulting after changes suggested in the GOASEX Workshop were made. The bias for this near-center swath position has been effectively removed. Unfortunately, the bias is only reduced for cross-scan positions near the swath edges (not shown in Fig. 1).

The SST comparison data were taken from the September 1978 bulletin of the National Marine Fisheries Service (NMFS) (*4*). The accuracy of these data has been compared to higher-quality, expendable bathythermograph data (accurate to $\pm$ 0.2°C) collected on semimonthly aircraft flights. The comparison for 13 September 1978 shows the NMFS data biased high by 0.7°C with a standard deviation of 0.9°C, which is in agreement with the advertised accuracy of these data. Consequently, we believe that the NMFS data were adequate for the preliminary analysis presented here.

We evaluated SMMR-derived SST data for six Gulf of Alaska passes. Since the spacecraft was in a 3-day, repeat ground track orbit, the data consisted of two descending tracks separated by about 2000 km (referred to as east and west tracks), each of which was covered on three passes. The SMMR SST values were extracted from one of the cells closest to the center of the swath in an effort to minimize the cross-track bias problem. Figure 2 presents the data from six SMMR passes from the east track for both the Wilheit and Wentz algorithms; the NMFS analysis along each track is also plotted. In almost every case, the SMMR temperatures are low by several degrees or more. In addition, the Wentz algorithm yields increasing discrepancy toward the south. The Wilheit algorithm appears to successfully provide the meridional gradient. Means and standard deviations of SMMR SST values from this algorithm relative to the NMFS values for both east and west tracks are given in Table 2.

Table 2. Seasat passes used in the study of SMMR sea-surface temperature data. The mean and the standard deviation of the SMMR values (Wilheit algorithm) are given with respect to the monthly NMFS analysis.

Revolution	Date (1978)	T_{SMMR} minus T_{NMFS} (°C) Mean	Standard deviation	No. of samples
		West track		
1163	9/16	−4.1	1.3	21
1206	9/19	−3.5	1.4	22
1292	9/25	−3.2	1.8	18
		East track		
1164	9/16	−4.8	0.9	20
1207	9/19	−4.5	1.6	25
1293	9/25	−3.9	1.4	20

Once the cold bias (3° to 4°C) is removed, individual SMMR estimates are in agreement with the NMFS analysis to approximately $\pm$ 1.5°C. The stability of the SMMR SST estimates over the 9-day period (16 through 25 September 1978) is encouraging evidence that the instrument and the Wilheit algorithm are operating well over a variety of changing meteorological conditions. Significantly degraded accuracy was expected for retrievals of SST values under rainfall conditions exceeding 0.5 mm/hour. Points in Fig. 2 where the rain exceeded this amount are marked with an *R*. Only one point, for revolution 1292 at 46°N, indicates serious rain problems. This result suggests that 0.5 mm/hour may be too conservative a value.

The algorithms determined integrated atmospheric water vapor and altimeter path length corrections that are quite consistent with the limited surface truth provided by a set of radiosonde ascents over the Canadian ocean weather station PAPA, the National Oceanic and Atmospheric Administration research vessel *Oceanographer*, and Bermuda. This sample set, although insufficient for a full statistical evaluation, indicates that integrated water vapor agreed to within 0.3 g/cm^2 root-mean-square, and the altimeter path length correction was within 2 cm root-mean-square of radiosonde-determined values.

Probably because of biases in the brightness temperature input, both algorithms produce small negative integrated liquid water content in many cells. Surface truth data of this type were not available for comparison. The rain rate determinations of the two algorithms are consistent with each other. The rain pattern for the ascending 19 September 1978 pass is corroborated by ship reports in the vicinity of the front.

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