

A First Look at the Potential of Remote Sensing of the Ocean

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Analysis has indicated that enormous economic benefits would result from an operational satellite system able to sense ocean surface conditions remotely on a global scale. This has been corroborated by SEASAT, which explored the potential of microwave instruments to obtain data for meteorological, navigational, oceanographic, and geodetic applications.

Introduction

This is a time of disenchantment with the nation's space program. The landing of the first men on the moon inspired pride in our nation's resolve and technology but provided few direct benefits to justify the billions in cost. Moreover, after that incredible technological feat, Viking's data showed Mars to be lifeless, thus disillusioning generations of science fiction fans.

In direct counterpoint, SEASAT was launched in June of 1978 to explore the potential of an operational satellite to remotely sense ocean surface conditions on a global scale. The effort contained little of Viking's (or of science fiction's) glamor but held real potential for directly benefiting commerce and everyday life.

The sea covers more than 70% of our planet. There are vast regions where man seldom ventures—areas where huge currents flow unseen, storms are born and mature, and fleets of icebergs drift uncharted. The U.S. Coast Guard goes to considerable trouble each year to locate and track icebergs and to warn ships of their approach to shipping lanes. Remote sensing gives easy access to these regions at a reasonable cost.

The huge schools of fish that swim the seas are a primary source of food for mankind. Some species are restricted to oceanic regions where the temperature varies no more than two degrees. Thus, currents like the Gulf Stream, that meander and change course and size, affect fishing as well as weather and shipping. El Niño, a warm current that flows south along the coast of Ecuador, usually

begins just after Christmas. In exceptional circumstances, it may extend down the coast of Peru to 12°S latitude. When that happens, plankton and fish are killed in vast numbers, devastating the fishing industries of many nations. Large concentrations of dinoflagellates (single-celled sea creatures) increase the fish kills, perhaps because of toxins they carry. The water turns a color similar to that of the "red tides" along the southern California and western Florida coasts. Remote sensing can plot the vagaries of temperature profiles and currents, providing useful information to the fisheries management centers that need it.

The sea is an energy storehouse and a huge weather machine. Because it is a better absorber and storer of solar energy than either the land or the atmosphere, it gives vast amounts of energy to the atmosphere.

The construction, installation, and operation of offshore oil and gas platforms are expensive and weather dependent. New platforms can be erected only during calm weather. Because the task takes many days, meteorologists push their capabilities to the limit to predict extended periods of calm. During storms and even when storms approach, the platforms often must be shut down, their pumping gear disconnected, and their crews evacuated in order to protect drillers and prevent blowouts. The satellite system could provide information about storms to help reduce the cost of drilling operations. It could also provide wave data that would allow ship design and construction to be improved, cutting down the annual toll of shipping taken by storms.

The greatest and most controversial potential benefit of SEASAT is in improved weather forecasting. Periodic sampling and rapid dissemination of ocean-surface data would provide a powerful new input for weather-prediction algorithms. Although the improvement in weather prediction to be achieved by using the new data has not yet been determined, SEASAT will certainly improve the forecasting of the U.S. Fleet Numerical Weather Center, whose forecasts are available to ships of all nations so that they can steer clear of storms.

The operational SEASAT system was conceived by the National Aeronautics and Space Administration (NASA) to provide the remote sensing of ocean data that will allow these benefits to be realized. SEASAT, the first spacecraft in the program, has demonstrated the concept that microwave sensors in space can indeed provide accurate, understandable, and unambiguous information directly usable by oceanographers and meteorologists as well as by government, commercial, and industrial users of the oceans.

SEASAT was launched into an 800-km near-polar orbit. The vehicle orbited the earth 14 times each day, scanning 95% of the ocean surface every 36 hours. The spacecraft's power system failed in October 1978, terminating its mission, although the 100 days of data collected are still being processed. The mission is considered a success because enough data were obtained to permit the measurement capabilities of the sensors to be evaluated.

The Sensors

SEASAT carried four microwave sensors and one optical sensor (Fig. 1) that measured winds, waves, and surface temperatures (Table 1).

The radar altimeter, developed at APL, operates by means of a short pulse radiated from a parabolic antenna pointed at the satellite subpoint (Fig. 2). The sensor's precise time discrimination allows the distance from the satellite to the ocean surface to be measured with a precision of 10 cm. The rough surface of the sea shapes the leading edge of the return pulse, allowing a processor in the sensor to determine the significant wave height directly below the satellite. (The companion article in this issue describes the altimeter and the results it obtained in SEASAT.)

The spacecraft's synthetic aperture radar (SAR), developed by the Jet Propulsion Laboratory (JPL), provides all-weather imagery of ocean waves, ice

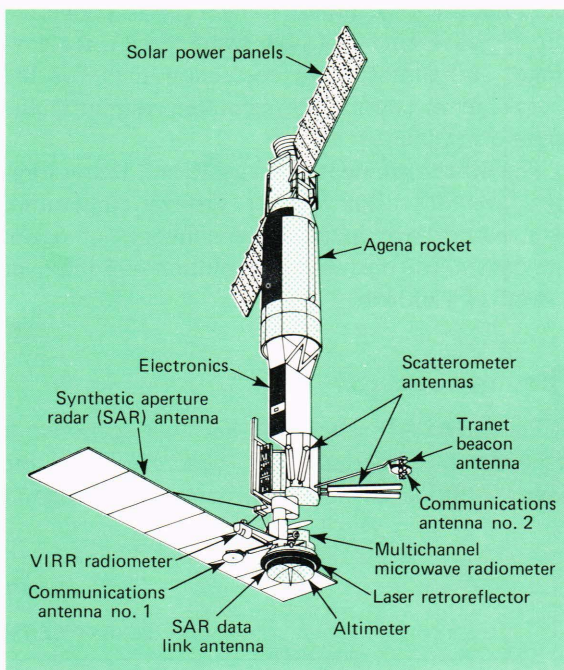


Fig. 1—SEASAT.

fields, icebergs, ice leads, and coastal conditions with a resolution of 25 m over a 100 km swath. Because of the high data rate of the SAR, it was operated only in real time and while it was in line of sight of tracking stations equipped to receive and record the data. APL developed both the spacecraft and ground station portions of the SAR's data link and is currently involved in several experiments with the flight data. (The next issue of the *APL Technical Digest* (Vol. 16, No. 4) will describe in detail the instrument, the data link, and the results obtained from the SEASAT data.)

The windfield scatterometer uses four fan-beam phased arrays to illuminate 500-km-wide swaths on either side of the satellite ground track. The two fan beams on each side are aligned orthogonally to each other, allowing orthogonal measurements of the ocean backscatter. As surface winds increase, the sea becomes rougher or choppier and the orthogonal backscatter measurements allow wind speed and direction to be calculated. The scatterometer was developed by the Langley Research Center of NASA and was built by the General Electric Co.

The microwave radiometer uses a scanning parabolic antenna to measure microwave surface brightness over a 920 km swath. The 10 measurements of the instrument (two polarizations at five frequencies) are processed to obtain surface tem-

perature, foam brightness (which can be converted into a measurement of high wind speed), ice coverage, and atmospheric correction data for the active radars (by measuring water content in the upper atmosphere).

The fifth instrument, the visible and IR radiometer, provides clear-weather surface-temperature data, cloud cover patterns, and images of ocean and coastal features with a resolution of 5 km over a swath of 1500 km.

The Spacecraft

The SEASAT spacecraft has two sections: a standard bus module that accommodates the power, attitude, orbit adjust, data, and command

systems; and a custom sensor module that integrates the sensors and houses the thermal-control and tracking systems.

The bus module is a Lockheed Agena, a spacecraft that has flown more than 300 missions. The Agena power system provided 626 W average and 1180 W peak in-orbit electrical power. The tri-axial attitude system provided approximately 0.5° control. Tape recorders allowed global storage of all but the data from the SAR.

Comparison of SEASAT and Surface Truth Data

NASA and the National Oceanic and Atmospheric Administration (NOAA) sponsored a

Table 1
SEASAT SENSOR MEASUREMENTS

<i>Sensor</i>	<i>Experiment Team Leader</i>	<i>Measurement Objectives</i>
Short-pulse radar altimeter	Byron Tapley, University of Texas	Significant wave height over the range 1-20 m to an accuracy of 10%. Satellite height relative to the sea surface to a precision of 10 cm. Satellite ephemeris determinations to less than 2 m globally, with a goal of 10-20 cm locally.
Windfield scatterometer	Willard Pierson, City University of New York	Sea surface wind speeds over the range 4-20 m/s to an accuracy of 2 m/s. Wind direction to an accuracy of 10%.
Scanning multifrequency microwave radiometer	Duncan Ross, Atlantic Oceanographic and Meteorological Laboratory (NOAA)	Sea surface temperature to an absolute accuracy of 2°C. Sea surface wind speeds over the range 7-50 m/s to an accuracy of 2 m/s or 10%. Atmospheric attenuation and refraction corrections for the windfield scatterometer and the short-pulse radar altimeter.
Synthetic aperture imaging radar	Paul Teleki, U.S. Geological Survey	Wavelength and direction for ocean waves greater than 50 m in wavelength. Sea ice, land, and coastal images to a resolution of 25 m.
Visual and infrared radiometer	Paul McClain, National Environmental Satellite Service (NOAA)	Visual and infrared images for feature recognition support of the microwave sensors. Clear air sea-surface temperature measurements for comparison with the scanning multifrequency microwave radiometer.

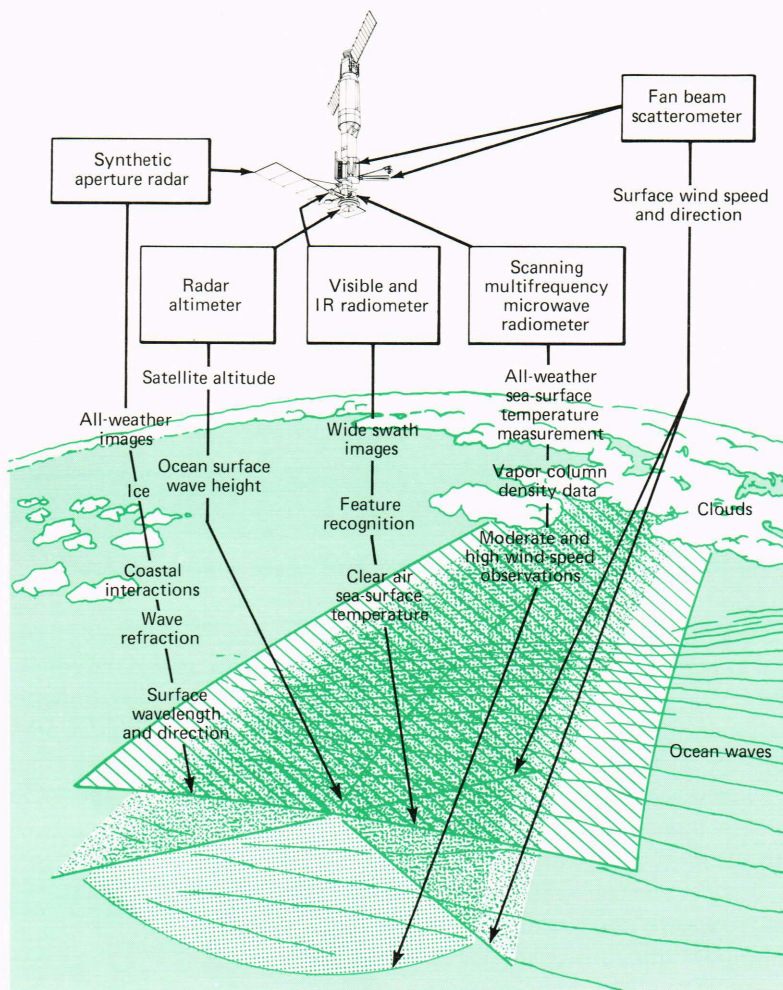


Fig. 2—SEASAT sensor coverage.

workshop at JPL (January 22-26, 1979) where SEASAT remote-sensing data were compared with surface truth data collected from buoys and ships in the Gulf of Alaska in September 1978.¹ The workshop was the first large-scale comparison of such data. It concluded that the SEASAT system would yield extremely important data for meteorology, climatology, navigation, and numerous oceanographic and geodetic applications.

The findings of the workshop on the altimeter and the SAR are reported in this issue and in the companion issue, respectively. The workshop's conclusions concerning the other three sensors are described in the following sections.

¹ SEASAT Gulf of Alaska Workshop Report (Draft), Jet Propulsion Laboratory Document 622-101 (1979).

The Windfield Scatterometer

The scatterometer data, processed by means of three different wind vector algorithms, were compared with surface truth consisting of windfields generated by a man/machine meteorological analysis as well as by spot observations from well-calibrated meteorological buoys and oceanographic research vessels. Statistics for the scalar differences between the scatterometer and surface-truth wind speed and directions were compiled for various categories of radar parameters (e.g., polarization, incidence angle) and surface conditions (e.g., wind speed). These statistics were weighted by the quality of the surface truth, by the estimated accuracy of the wind speed and direction, and by the atmospheric transmissibility derived from satellite IR and visible cloud imagery.

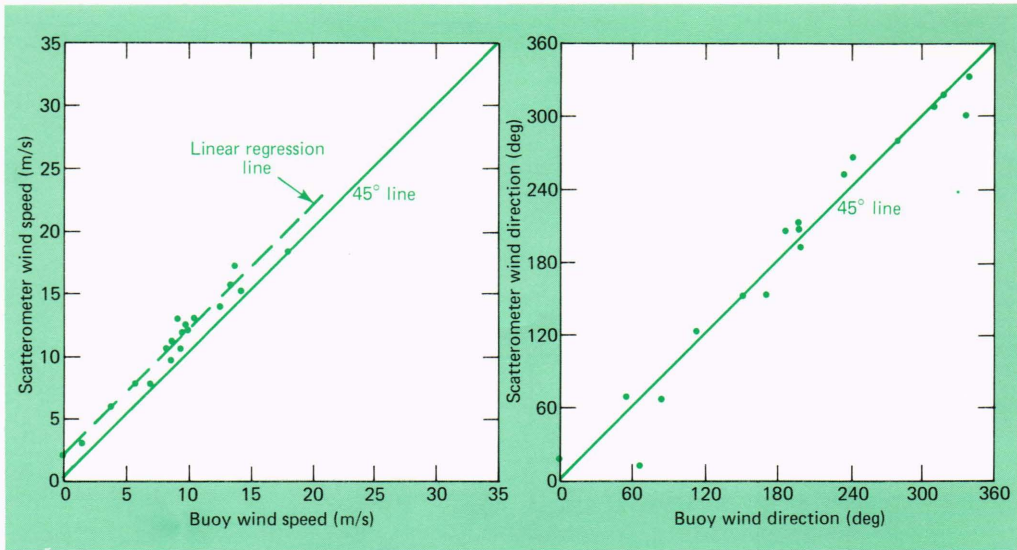


Fig. 3—Comparison of scatterometer wind speed with buoy reports.

Results of this comparison indicated that all scatterometer algorithms, based on prelaunch aircraft scatterometer data, were biased 0.5 to 3 m/s high compared to surface-truth wind speeds, and that the standard deviations of this bias were about 2 m/s. For wind direction, biases for the scatterometer were less than 10° with standard deviations about this mean of approximately 20° .

For example, a comparison of scatterometer wind speed with buoy reports indicates a bias of 1.9 m/s with a standard deviation of 1.8 m/s (Fig. 3). The wind direction comparison indicates very little bias between the scatterometer and buoy reports.

The results indicate that after refinement of the geophysical algorithms, the scatterometer will meet its prelaunch specification of ± 2 m/s or 10% (whichever is greater) in wind magnitude and $\pm 20^\circ$ in direction.

Scanning Multifrequency Microwave Radiometer

The microwave radiometer results were encouraging, especially considering the immaturity of the data-processing algorithms.

For open ocean cells with highest-quality surface truth, where no rain is indicated by the algorithms, the radiometer's wind determinations exhibit standard deviations of about 3 m/s about a bias near 1.5 m/s. The surface-truth estimates are probably accurate to ± 2 m/s. This suggests that the design goal of ± 2 m/s accuracy in wind speed meas-

urement can be reached. Possibly only higher-quality surface-truth data, combined with algorithm refinement and recalibration, are required. Both of the algorithms used in the workshop track the relative changes in wind speed (Fig. 4), although both algorithms, especially the Wilheit algorithm, ex-

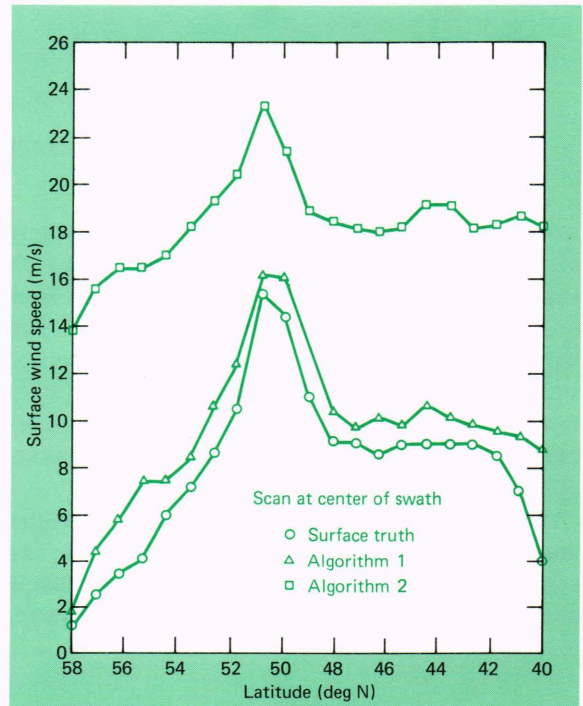


Fig. 4—SEASAT microwave radiometer (SMMR) wind comparison.

hibit significant bias. However, in portions of data passes with rain (Fig. 5), both algorithms fail to provide reasonable relative or absolute measure of the wind speed.

The determination of sea surface temperature using the radiometer had biases of 3 to 5°C. The stability of the temperature estimates over the nine-day period provides encouraging evidence that the instrument operates well under a variety of changing meteorological conditions. The temperature data from three SEASAT radiometer passes (Fig. 6) indicate temperatures several degrees lower than the surface truth published by NOAA's National Marine Fisheries Service. When the 3 to 4°C cold bias is removed, the radiometer estimates agree with the surface truth to about ±1.5°C. The accuracy of sea-surface temperature measurements is expected to degrade under the heavy rainfall conditions marked with an "R" in Fig. 6.

Visible and Infrared Radiometer

The radiometer operated for the first 61 days of the SEASAT lifetime. The visual and thermal images were adequate for meeting the objectives of identifying cloud, land, and water features. The radiometer was developed for the Improved TIROS Operational Satellite (ITOS) and was incorporated on SEASAT to support data processing and interpretation for the microwave sensors.

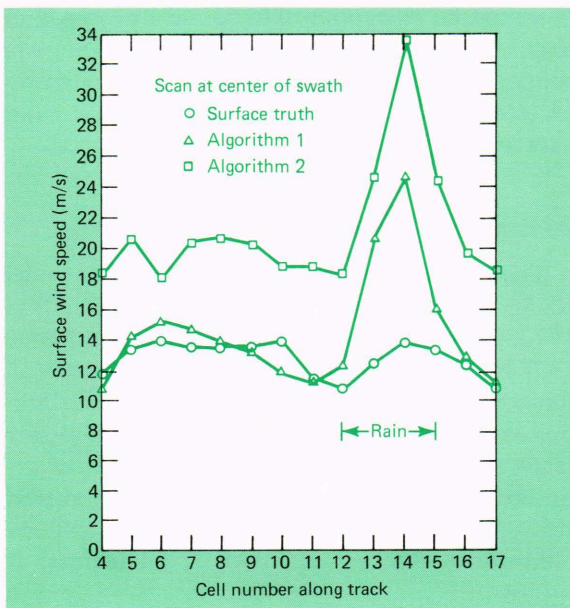


Fig. 5—The effect of rain on SEASAT microwave radiometer wind algorithms.

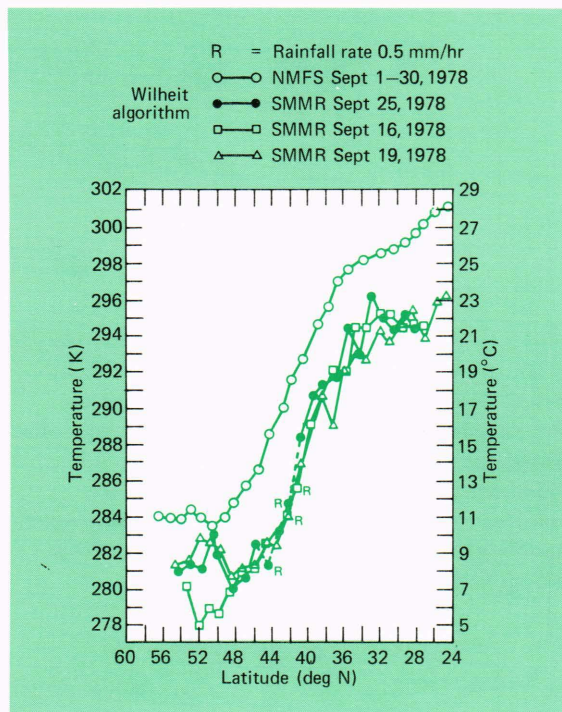


Fig. 6—Comparison of National Marine Fisheries Services (NMFS) sea temperature analysis with microwave radiometer data.

The Future of the SEASAT Program

NASA funding limitations have delayed the development of the operational system until 1981 or 1982. The planned program, the National Oceanic Satellite System (NOSS), is a joint NASA, NOAA, and Department of Defense (DoD) effort. It includes a four ton spacecraft with one ton of extended-lifetime SEASAT sensors, carried by a NASA Multimission Modular Spacecraft (MMS) bus module. The spacecraft will be launched by the space shuttle and will be able to relay data through the Tracking and Data Relay Satellite (TDRS) to a dedicated ground processing facility at the TDRS ground station. Data products will be available in near real time as required by NASA, NOAA, and DoD users.

Acknowledgment

In order to put the APL effort in context, this introductory article described the program segments done at organizations other than APL. To this end, it draws heavily on direct excerpts from NASA publications, particularly the Gulf of Alaska SEASAT Experiment Workshop report.