# PASSIVE AND ACTIVE MICROWAVE SENSORS IN SATELLITES FOR REMOTE SENSING OF THE EARTH

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ABSTRACT

Microwave sensors which can operate day and night, and through clear and adverse weather have very high potential in inferring oceanic wind field, precipitation, and sea ice. Both passive radiometry and active radars can be operated from satellites.

## Introduction

Extensive operational use is being made of sensors borne by satellites to observe the physical parameters of earth. Visible and near infrared wavelength sensors provide useful data during daylight and under clear weather conditions. Far infrared sensors can operate day and night and can penetrate some haze. At millimeter and microwave lengths, passive and active sensors can operate day and night and can detect signals passing through clouds and rain.[1,2] The principal disadvantage of a microwave sensor is its relatively coarse spatial resolution capability due to finite antenna beamwidth. This problem will be partially offset by the advent of the Shuttle which will permit the launching of satellites with very large antennas. Fine resolution can be achieved now by a microwave synthetic aperture radar,[3,4] however, such a system usually entails considerable complexity and wide data bandwidth.

From microwave sensor data, geophysical parameters such as oceanic wind speed and direction, precipitation over ocean and land, and sea ice detection and age can be inferred. Other parameters which can be inferred include soil moisture, sea surface temperature, water vapor, and atmospheric profiles. The early work with microwave sensors used aircraft and terrestrial platforms. Since the 1973 SKYLAB Program additional microwave sensor data have been obtained from sensors on satellites. A very sizable data bank has been amassed from all of these sources, and more data is being generated from the NASA Nimbus-7 Program. This paper is concerned with satellite-borne microwave sensors which offer the possibility of global observations on timely and potentially economical bases. A large number of papers on microwave remote sensing have appeared in the literature and only a few are listed here to provide the reader with a starting point.

## Ocean Wind Field From Scatterometry

Over 30 years ago airborne radar signals were observed from oceanic surfaces roughened by the wind. At high incidence angles, upwind returns were stronger than downwind returns, and both of these were stronger than cross-wind returns. The higher wind speeds caused increased radar return for incidence angles greater than $15^o$, but for angles less than about $10^o$ higher wind speeds caused reduced radar return. Further data and analyses have been reported.[5] The sensitivity of the radar back scattering to wind speed decreases at the higher wind speeds.

Measurements employing a 13.9 GHz scanning pencil-beam radiometer scatterometer carried on the SKYLAB satellite in 1973 were reported.[6] The antenna beam footprint size on the ocean was several kilometers, and the data confirmed expected results. A passive radiometer operated on a time-shared basis provided some atmospheric correction due to rain encountered along the beam propagation path.

Efforts were expended by NASA Langley Research Center to design an operational satellite scatterometer to infer oceanic wind fields.[7] The scatterometer uses four fan beams, two on either side of the SEASAT satellite. Two beams map the region forward of satellite nadir and two beams map the rearward region. The wide dimensions of the fan beams are oriented vertically and these vertical planes are arranged symmetrically in azimuth with yaw angles of $\pm 45^o$ and $\pm 135^o$ from the satellite flight vector. The four fan beams are electronically switched in sequence to map a 1900-km wide swath. The ocean surface resolution cell size is about 50 km and this size is determined in azimuth by the thin fan beam, and in range by Doppler filters. Each ocean surface cell is viewed from two headings and from these measurements, the wind direction and speed can be inferred. The SEASAT satellite carrying this scatterometer was successfully placed in orbit in June 1978 and the scatterometer operated from July 6th to October 10th.

## Ocean Wind Speed From Radiometry

Radiometry is based on the observation that an object at absolute temperature $T_o$ with surface emissivity $\epsilon$ greater than zero emits noise-like thermal radiation at all wavelengths. The radiometric temperature is $T_A = \epsilon T_o$. The ocean surface is characterized by an emissivity that is typically about 0.3 but can vary over a wide range depending on surface roughness, incidence angle, polarization and wavelength of the radiometer. Other oceanic parameters that affect $T_A$ are salinity, physical temperature and foam coverage. A substantial amount of data has been collected using radiometers mounted on a high tower and in aircraft.[8]

A 19.35 GHz radiometer employing a phased array antenna has been operating from the Nimbus-5 spacecraft launched in 1972. A $1.4^o$ pencil beam is electronically scanned cross track passing through satellite nadir. A 37 GHz radiometer employing a phased array antenna has been operating from the Nimbus-6 spacecraft launched in 1975. This antenna aperture plane is almost vertical, and the plane normal lies in the satellite orbit plane. The radiated beam is squinted away from aperture normal. The pencil beam, approximately $1^o$, is electronically scanned in azimuth by $\pm 35^o$ from the orbit plane but maintains a constant incidence angle of $50^o$ at the earth surface. Sabatini, et al,[9] have examined the 37 GHz radiometric data and conclude that the brightness temperature increases with oceanic wind speed as expected. Unfortunately a calibration error has prevented an absolute determination.

Since the radar cross section of a wind blown sea surface is heading dependent, the surface emissivity should also be heading dependent, in principle. Radiometric measurements do not substantiate this hypothesis[10] probably because the emissivity difference is too small.

The effect of clouds prevailing along the beam propagation path depends upon its attenuation.[11] At the higher microwave frequencies cloud effects are usually not negligible and must be considered in data reduction.

A mechanically scanned multi-channel microwave radiometer has been developed for satellite application.[12] One such instrument was mounted on SEASAT-A satellite and launched in June 1978. The frequencies are 6.6, 10.69, 18.0, 21.0 and 37.0 GHz. The offset-fed paraboloidal antenna has a 79 cm diameter radiating aperture. The scanning antenna beam axis follows a conical surface. The earth incidence angle is constant at 50°. The azimuth scan angle range is 50°. Another such instrument is operating from Nimbus-7 spacecraft but the azimuth scan angle range is biased to one side of the spacecraft. This instrument is collecting radiometric data from oceanic surfaces.

## Precipitation Over Ocean

Inasmuch as precipitation attenuates microwave signals it will also emit microwave radiation.[2] Higher precipitation rates emit greater amounts of radiation so that a microwave radiometer offers the possibility of inferring precipitation rates remotely.[13] At light precipitation rates, the amount of attenuation is small so that the precipitation is partially transparent to microwave signals. This implies that the background may contribute to the power detected by the radiometer. Since the amount of radiation from the ocean is typically much lower than that from the land, the problem of detecting precipitation over ocean is a much simpler one. Precipitation over land is discussed in the next Section.

The radiometric brightness temperature of precipitation is the product of its emissivity and its physical temperature. Usually the physical temperature is estimated based on either historical data or extrapolated from local measurements. The radiometric temperature detected by a radiometer mounted in a satellite is composed of three principal components, viz., emission from the rain, emission from the ocean surface attenuated by the rain, and downward radiation from the rain reflected by the ocean and attenuated by the rain. To determine the contribution due only to precipitation, a dual-polarized multiple-frequency radiometer is used.[12]

Savage, et al,[14] has shown that at low precipitation rates over the ocean, the radiometric temperature increases with precipitation rate. At some higher rate, the temperature reaches a peak value established by the physical temperature of the rain. Above this rate, the radiometric temperature slowly decreases. The rain rate for peak radiometric temperature decreases approximately as the square of the radiometer wavelength.

The use of satellite-borne radiometric measurements to infer precipitation over oceans has been discussed.[13] A considerable increase in the data bank is expected from the scanning multi-channel microwave radiometers on SEASAT-A and Nimbus-7.[12]

## Precipitation Over Land

As stated earlier, the detection of precipitation over land by a satellite-borne radiometer entails radiation from the land background. The physical temperature of rain may be about 280°K, and the radiometric temperature of the land background may also have about the same value. The capability of discerning precipitation over land requires a difference in these two temperatures, and to achieve this objective, consideration is given to polarization effects, different frequencies, and different observation angles. The problem has been examined and some measurements from satellites have been reported.[14] Rodgers, et al,[15] have discussed statistical observations which can generally distinguish among classifications of wet soil, dry soil and rain by comparing horizontal and vertical polarization temperatures measured by the 37 GHz radiometer on Nimbus-6.

## Detection and Age of Sea Ice

Sea ice can be detected by both radiometers and scatterometers[16]. The emissivity of sea ice is near unity when fresh and it decreases with ice age. This general characteristic is independent of radiometer wavelength and geometry. The spatial resolution depends on antenna beamwidth and range. Radiometric observations of sea ice have been reported.[17] Scatterometric detection of shorefast and floating sea ice has been reported.[18] Fine resolution in range can be achieved by the use of short transmitted pulses, and the ultimate in azimuth resolution can be achieved by the use of a synthetic aperture radar.[3] To determine sea ice boundaries, adequate contrast with the surrounding sea is required.

## Data Reduction

Radiometric and scatterometric measurements depend on many geophysical parameters. To deduce or infer the geophysical characteristics from microwave engineering units requires a sufficient number of independent quantities, some of which are obtained from measurements and the remainder from a data bank.[19] With suitable models and auxiliary input data, the geophysical quantities can be computed and identified with geographic coordinates and time.[20] See Figure 1. A maximum likelihood estimator is a suitable algorithm because of the nonlinear relationships between geophysical parameters and microwave sensor responses.

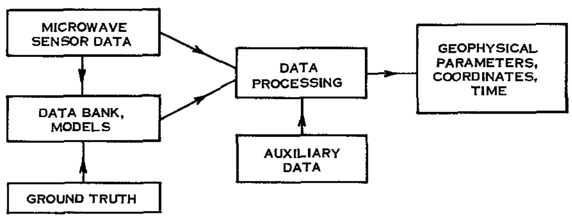


Figure 1. Data Processing

## Conclusion

Microwave sensors on satellites offer an invaluable capability of providing global measurements on a timely basis from which geophysical parameters are inferred. A large amount of data currently exists in the data bank, and more microwave data are being collected from satellites to enlarge the data bank. The trend of larger antennas for radiometers using the Shuttle launching facilities offer significant improvements in the future.

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