LARGE SPACE ANTENNA TECHNOLOGY APPLIED TO RADAR-IMAGING, RAIN-RATE MEASUREMENTS, AND OCEAN WIND SENSING

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Large Space Antenna Systems Technology - 1984
December 4-6, 1984

ABSTRACT

During the last decade, the utility of spaceborne microwave remote-sensing systems for ocean windspeed measurement, ocean wave-imaging and sea-ice studies has been demonstrated. Development of large space antennas offers some interesting possibilities for rain-rate measurements, ocean and ice studies, and radar imaging.

The joint use of active and passive sensors using the 15-m antenna for ocean, ice, and soil moisture studies; rain-rate measurements; and radar imaging is considered. Verification of the frequency-agile rain radar concept with Shuttle offers the possibility of much needed rain-rate statistics over the ocean.

1.0 INTRODUCTION

Significant progress has been made in recent years in the application of microwave sensors to oceanographic, sea-ice, soil-moisture and snow studies. Most of these were aimed at understanding the interaction of electromagnetic waves with ocean and terrain, and determining the optimum radar parameters. These studies have proven the utility of microwave sensors for surveying the Earth's resources.

The inherent limitation in spaceborne passive microwave systems is poor resolution; large antenna technology will allow the development of systems with smaller footprints. The only spaceborne microwave system currently offering high resolution is synthetic aperture radar (SAR). However, spaceborne SARs have some major disadvantages including high data rates and the large amount of processing required to produce images. Some of the operations associated with the survey and exploitation of natural resources require near-real-time information. The availability of large space antennas makes it possible to develop systems with modest usable resolutions and near-real-time processing capability.

In addition, a large space antenna offers an opportunity to measure precipitation using microwave systems from space. The attenuation experienced by the signal as it propagates through the rain can be estimated by a radiometer. The main problem with measurement of precipitation from space is separating the rain echo from that of the background. Backscatter from rain varies rapidly with frequency as opposed to a slower variation from terrain or ocean. Scattering from the atmosphere can be distinguished from that of the background by using two closely spaced frequencies and taking advantage of the rapid variation of atmospheric phenomena.

In this paper, the joint use of a radar/radiometer for monitoring sea-ice, ocean windspeed, soil moisture and rain-rate is considered.

2.0 LOW-POWER RADAR/RADIOMETER

During the last decade Moore and Fung [1] and Gray et al. [2] have demonstrated the usefulness of complementary active and passive microwave systems for measuring windspeed over the ocean, sea-ice concentration and type, and geological mapping. Most of these studies were conducted with a coarse-resolution radiometer and scatterometer or fine-resolution SAR. The footprint size of the radiometers used in these early studies was generally 2-4 times larger than that of the scatterometers. This made it difficult to examine the relationship between active and passive sensors and also introduced errors in the estimation of windspeed.

Development of a truly complementary sensor with similar resolution and coincident coverage will be useful in studying the application of such a sensor to the scientific and operational problems associated with sea ice, soil moisture and ocean studies.

During the last few years, the University of Kansas made several broadband radar backscatter measurements from sea ice [3] to define optimum radar parameters. The experimental results indicate that there was a significant contrast between first-year (FYI) and multiyear (MYI) ice at all frequencies in C, X and Ku bands, but negligible contrast at L-band, as shown in Figures 1a and 1b. The contrast between thin ice and multiyear ice also increased with incidence angle, as shown in Figure 2a.

The Canada Centre for Remote Sensing collected simultaneous active and passive signatures of sea ice with an airborne system during the last few years. The results of their investigations indicated that the ambiguity associated with an active sensor can be eliminated by using a passive sensor or vice-versa, as shown in Figure 2b.

Some of the ice parameters such as boundary positions, percentage of area covered, etc. can be determined with a modest resolution (about a 1-km) system. Although contrast between FYI and MYI for cross-polarization is greater than that for like-polarization, cross-polarized measurements from space are not given serious consideration because, since the cross-polarized scattering coefficient is significantly lower than that for like polarization, additional power is required. The power required to measure the cross-polarized scattering coefficient with large antennas is not as great. Therefore, large antenna technology will have significant impact on system design considerations for sea-ice monitoring.

Moore et al. [4] reported that large errors in the estimation of windspeed can occur because of variability of rain rates within a beam. Simulations were performed, assuming that only part of the radiometer footprint that overlaps the scatterometer footprint was filled with rain, as shown in Figure 3a. The results of these simulations are shown in Figure 3b. Therefore, errors associated with in-beam rain variability can be eliminated by using a scatterometer and radiometer with similar resolution. The 15-m diameter of the large antenna will allow the development of an active/passive system with similar resolutions for both sensors.

The low-power radar-radiometer combination can also be used in soil moisture studies. It was reported by Ulaby et al. [5] that radar backscatter is strongly correlated with moisture content at 4.5 GHz and incidence angles between 10° and 20°. Surface roughness has less effect at 4.5 GHz than at 1.5 GHz, as shown in Figure 4.

Shuttle-based modest resolution radar/radiometer systems will be useful for several remote-sensing experiments on a variety of targets. These experiments can verify the potential for higher orbit (up to synchronous) operational sensors.

No detailed study to define the optimum parameters for these systems has been conducted, but we believe the systems with parameters given in Table 1 can meet the needs for sea-ice, soil moisture and ocean studies.

TABLE 1
CW RADAR

Height		500 km
Wavelength		2 cm
Aperture Efficiency		60%
Noise Figure		3 dB
Required Signal-to-Noise Ratio		10 dB or more
Scattering Coefficient		-40 dB
Incidence Angle		40°
Filter Bandwidth		7 kHz
Along-track cell width		1.11 km
Across-track cell width		1.4 km
Transmitter Power		< 1.5 W
Sensor Package:		
Frequency	Radar	5 GHz
	Radiometer	15 GHz
Polarization	Radar	VV, VH
	Radiometer	VV, HH
Incidence Angle		40° or greater
Aperture		15 m for ice

The use of radar and radiometer with coincident beams based on the same antenna will permit easy development of modest resolution radar images within the radiometer beam, but images with considerably better resolution than those of the radiometer. For mapping applications of the radiometer this will allow better delineation of edges and regions of inhomogeneity within the radiometer beam. At the same time, it will permit use of the synergistic effects of combined radar and radiometer measurements of such parameters as sea-ice type and concentration, soil moisture, and oceanic patterns associated with internal waves and submarine topography.

This application is possible because the radar may use either range resolution or Doppler beam sharpening in the azimuth direction (or both) to produce small pixels within the footprint of the antenna, and therefore within the beam of the radiometer. With the high gain of the large pencil-beam antenna, the radar power requirement is extremely low; for a radar with the footprint determined solely by the beam (a beam-limited scatterometer) the required power is less than that of the local oscillator of the radiometer/radar receiver in low Earth orbit, and less than a watt at synchronous orbit. Doppler beam sharpening allows footprint widths within the beam down to about $\sqrt{\lambda R}$, where λ is the wavelength and R is the slant range. This improved resolution can be achieved with no increase in transmitter power and with a relatively simple processor. Range resolution can be improved at the expense of additional transmitter power, but improvements up to about a factor of 10 fail to raise the power much above that of the local oscillator in LEO and still result in power levels easily attained with solid-state transmitters in GEO with the 50-m or larger antenna.

3.0 RAIN RADAR

The need for global precipitation statistics in the study of weather and climate is well established [6]. Remote-sensing devices operating in the visible, infrared and microwave spectrum can be used for global precipitation measurements. Although visible and infrared systems are very useful in delineating areas of precipitation, these systems usually do not give satisfactory estimates of precipitation statistics [6]. Radar systems operating in the microwave spectrum have proven very useful for measuring rain rate over large areas, but the accuracy of radar rain gauges is not as good as that of conventional point rain gauges. It is, however, possible to measure the rain-rate statistics over a region of several thousand square kilometers, an almost impossible feat with point rain gauges. Microwave radiometers are also useful for measuring the rain rate, but the relationship between rain rate and the measured brightness temperature is difficult to interpret in areas of variable background emission. Also, the non-beam-filling effects introduced by the poor resolution of spaceborne passive systems introduces large errors.

The spaceborne microwave system with the greatest potential for globally measuring rain rate over both the ocean and land is a radar in combination with a radiometer. Two promising radar methods for measuring rain rate from space are: (1) surface target attenuation radar (STAR) [7] and (2) frequency agile rain radar (FARR) [8]. The STAR system is based on the assumption that the path-averaged rain rate can be determined by measuring the attenuation experienced by the signal as it propagates through rain. The calibration target for estimating attenuation is the surface. This requires measurement of backscatter from the surface through rain and under clear weather conditions. The major disadvantage of this method is that the scattering properties of the surface change in the presence of rain. Backscatter from the ocean is changed when the rain strikes the surface of the water. The scattering coefficient of terrain is also strongly influenced by the moisture content and presence of free water on the surface.

The frequency-agile rain radar uses two closely spaced frequencies to distinguish rain echo from that of the background. The backscatter from raindrops generally increases very rapidly, as shown in Figure 5, but backscatter from ocean or terrain increases slowly with frequency, as shown in Figure 6. The differential scattering coefficient can be considered proportional to the rain.

CW or pulse radars operating at 14 and 17 GHz can be used to measure the rain rate. Although the power requirement for CW radars is lower than that for pulse radars, their rain-rate retrieval algorithm is more complex. Since the concept of measuring rain rate from space is new and untested, further research is required to define optimum system parameters.

The pixel size to eliminate the non-beam filling effect in intense rain should not be more than 5 km. Therefore one of the main problems, the non-beam filling effect, can be eliminated by using a sufficiently large antenna. The availability of the 15-m antenna makes it possible to measure rain rate with spaceborne radar at lower orbits and the future availability of 50-m or larger antennas extends this possibility to synchronous orbits.

4.0 CONCLUSIONS

Use of a large antenna on a spacecraft will permit combined radar and radiometer measurements from both low Earth orbits and geosynchronous orbits that can significantly enhance our ability to measure parameters of the Earth's surface and atmosphere. The Shuttle is useful for testing these concepts, even though it is not a good vehicle for operational measurements of these parameters because of the short mission durations.

Radars and radiometers have both been shown useful for monitoring sea ice and soil moisture. Use of systems with coincident beams for the active and passive systems will permit synergistic use of these sensors to attain better results than possible with either alone. The large antenna will permit much finer resolutions for the radiometers than previously available, thereby making them more useful. It will also permit simultaneous use of radars with very low transmitted powers. The pixel size for the radar within the radiometer beam can be improved without increasing the power by Doppler beam sharpening and can be improved significantly with only a small increase in power by use of range resolution.

Measurements of the rainfall rate can be achieved by combined radar-radiometer methods using the fine resolutions attainable with the large antenna. With smaller antennas, rainfall measurements are difficult because cell sizes are typically under 10 km and often under 5 km; the large antenna permits narrow enough beams to overcome this problem. Synergistic radiometric and radar measurements using multiple frequencies for both will improve the accuracy compared with that attainable with either sensor alone and at a single frequency.

Many of the techniques for Earth and atmosphere observation presented here can be tested using the 15-m antenna on the Shuttle, although operation will require longer missions at higher altitudes. Since many of these concepts have been studied only in minimal detail, more extensive studies, simulations and, in some cases, aircraft tests are called for so that the tests using the Shuttle may achieve optimal results.

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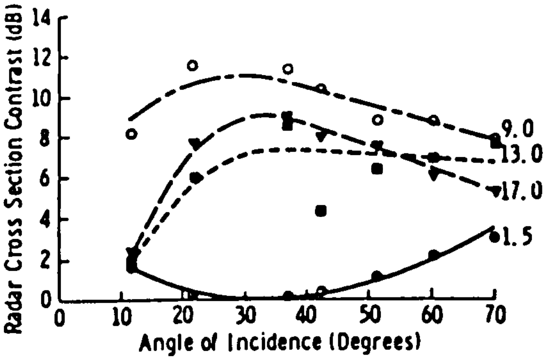
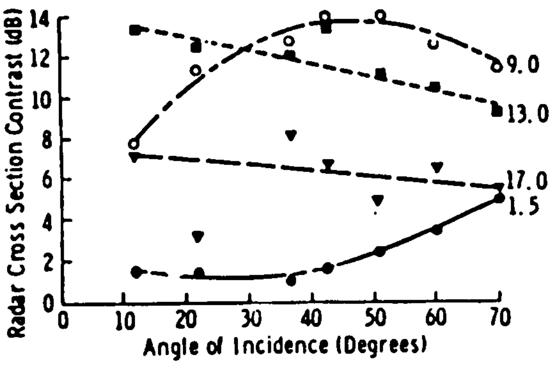
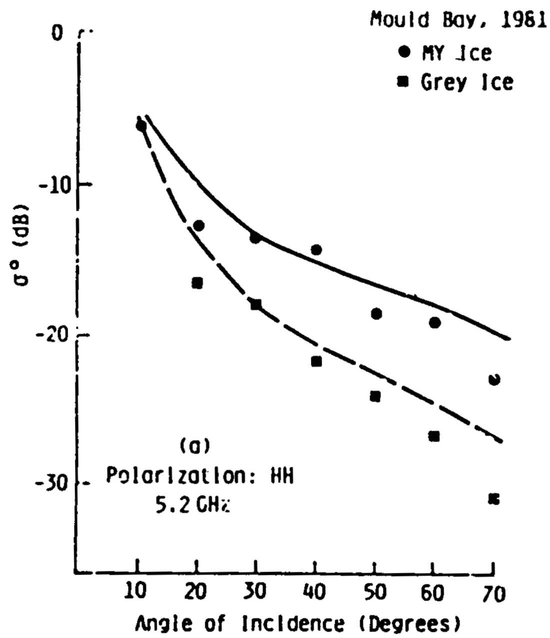


(a)



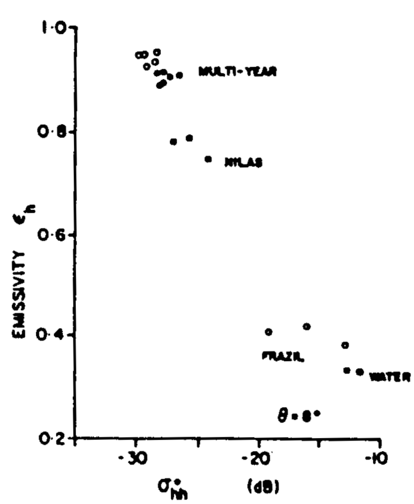
(b)

Figure 1. Difference between radar cross section of thick first-year and multiyear ice at 1.5, 9.0, 13.0, and 17.0 GHz with (a) vertical polarization and (b) cross polarization (ref. 3).



(a)

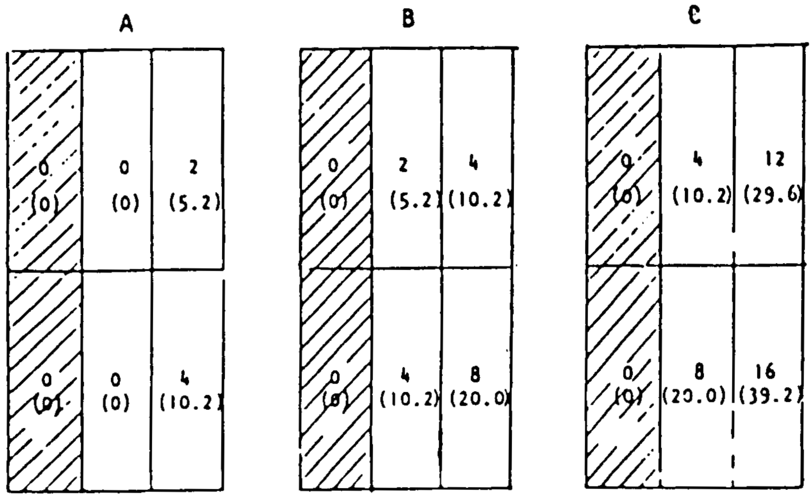
Scattering coefficient of thin ice and multiyear ice at 5.2 GHz (ref. 9).



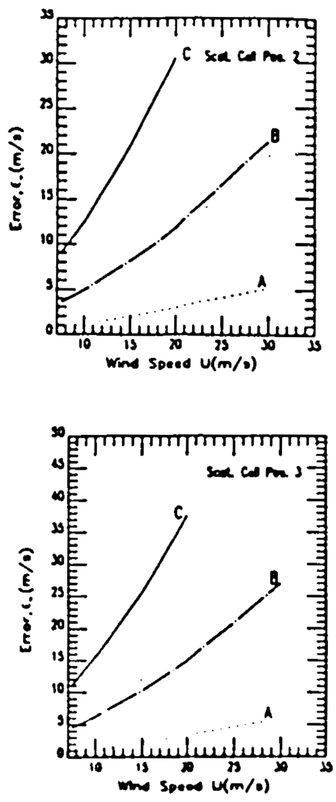
(b)

Comparison of passive and active signatures of sea ice (ref. 2).

Figure 2. Scattering coefficient of thin ice and multiyear ice and comparison of passive and active signatures of sea ice.



(a)



(b)

Figure 3. Errors in scatterometer-radiometer wind measurement (ref. 4).

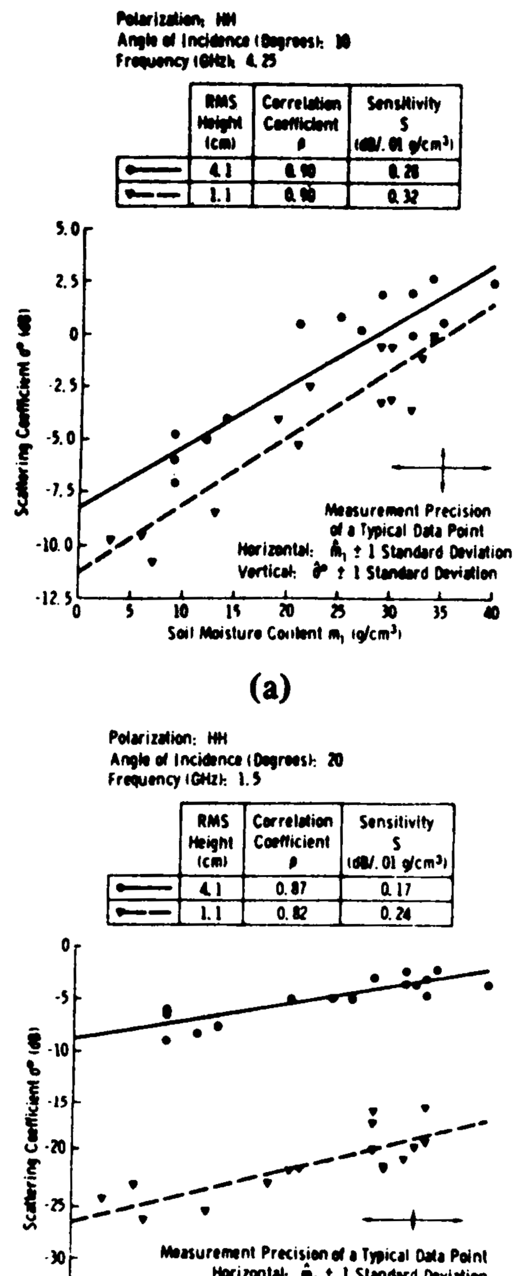


Figure 4. Comparison of the backscatter response to m_1 of a smooth surface and a rough surface of (a) $\theta = 10^o$, f = 4.25 GHz and (b) $\theta = 20^o$, f = 1.5 GHz (ref. 5).

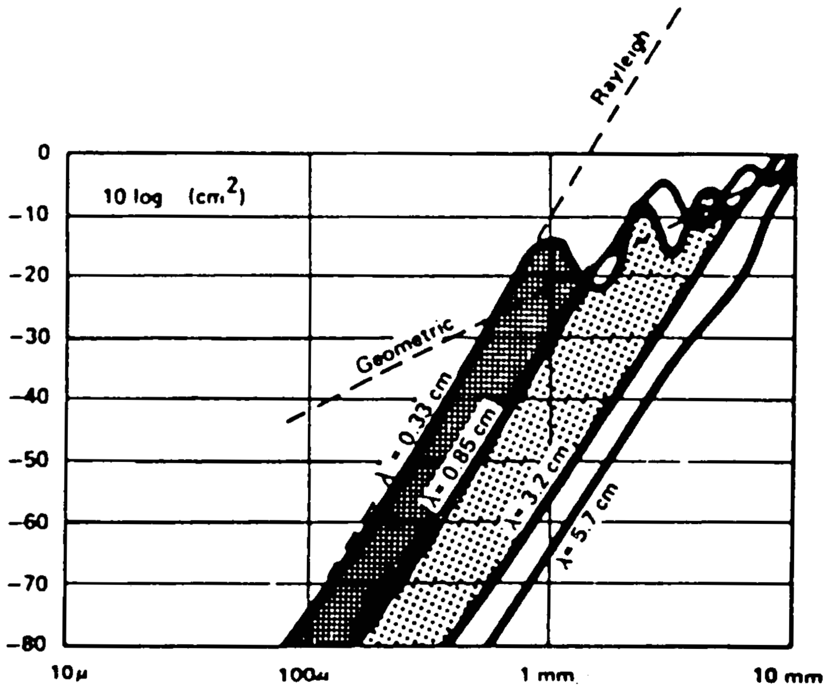


Figure 5. Backscattering cross section of water spheres as a function of diameter for the radar wavelengths (ref. 10).

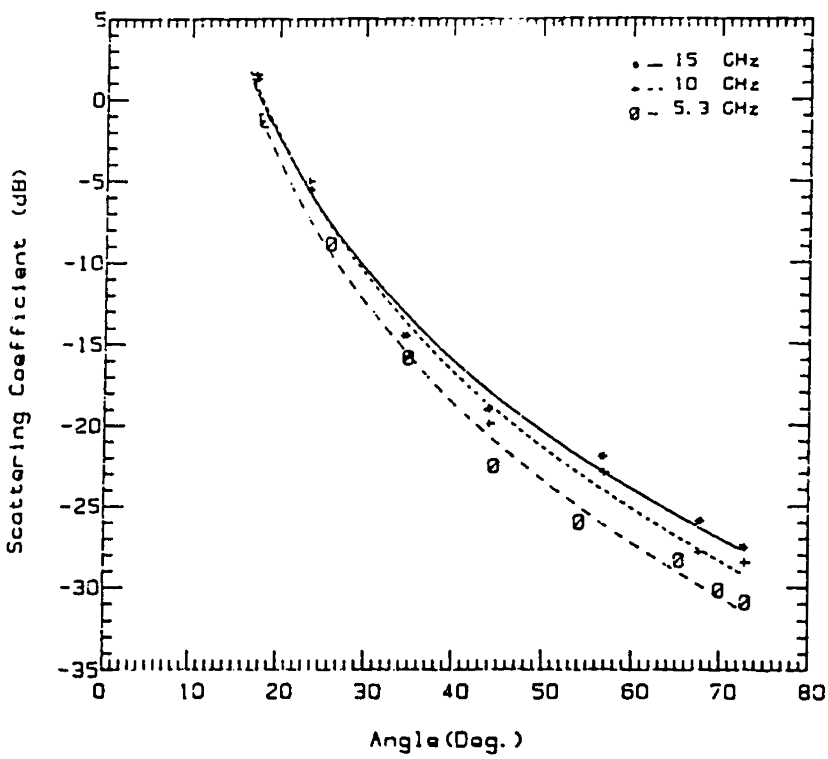


Figure 6. Angular response of scattering coefficient at U = 6.5 - 8.3 m/sec crosswind, VV-Pol., January 28, 1984.