REFLECTANCE OF ICE AND SEAWATER AT MILLIMETER WAVELENGTHS

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ABSTRACT

Measurements of reflectance of sea water and ice at 100 GHz, 140 GHz, and 180 GHz are reported. Results are compared with recent dielectric property models derived from data at other wavelengths.

INTRODUCTION

Measurements of the dielectric properties of sea water and ice reported here were stimulated by the increased interest in millimeter wave radiometry for measurements in the earth's atmosphere. The dielectric properties of sea water have been measured to high accuracy at frequencies from dc to the microwave region as well as in the optical and infrared regions of the spectrum. Measurements in the millimeter wave region are few and of limited accuracy.

Measurements of the dielectric properties of water and ice at longer wavelengths provide a basis for extrapolation of these properties through the millimeter wavelength region. Unless additional sources of dispersion occur, as eventually occur in the submillimeter region, these extrapolations should be substantially correct. A means of substantiating the extrapolated values or improving them if necessary is desired.

Reflectance measurements are useful for this purpose, providing reproducible data with a minimum of measured properties and corrections. Such measurements are cost effective, easily implemented, and useful over a wide range of wavelengths. Measurements of normal incidence reflectance are used to obtain the index of refraction $\underline{n} = n - i\,k$. Both reflectance and phase information are required for an unambiguous determination, but accurate phase measurements are not essential. We find the frequency and temperature dependence of the index of refraction as determined by extrapolation from longer wavelengths gives a satisfactory fit to the data.

As a check on our assignment of refractive index values, reflectance at oblique angles of incidence was measured. The quantities n and k contribute to reflectance in varying amounts depending on the angle of incidence and polarization. Normal incidence measurements had the highest accuracy and were always used to determine dielectric properties.

Reflectance measurements compare power reflected from a water or ice surface with power reflected from a surface of liquid mercury. The reflectance of liquid mercury can be taken as unity to a very good approximation. Because of the high absorption coefficient of water at millimeter wavelengths, the reflection coefficient is determined by the front surface only. In contrast, the low absorption coefficient of ice at millimeter wavelengths required use of absorber in the container and surfaces oriented so as to eliminate unwanted contributions to the reflected energy. An ice prism was also used, the deviation of the incident radiation by the prism being a measure of the dielectric properties.

Klystrons served as power sources with a varacter doubler added to the system for measurements at 180 GHz. Fluctuations in klystron output power were the main limitation to measurement accuracy.

MEASUREMENTS

Reflectance at normal incidence was measured for fresh water at temperatures between 0°C and 50°C. Table I lists experimental values of reflectance of a fresh water surface at 20°C for three frequencies in the millimeter wavelength region. Values for the dielectric constant ($\varepsilon' - i\,\varepsilon''$) and refractive index as determined from a modified Debye equation to match reflectivity are included.

The reflectance of ice at 99 GHz was found to be 7.85%. This result corresponds to a dielectric constant of 3.17 and a refractive index of 1.78. Absorption in ice is negligible in this frequency region. Measurements at 136 GHz and 183 GHz using an ice prism also give a refractive index of 1.78 indicating no dispersion through the short millimeter region.

The variation of reflectance with temperature is shown in Figures 1 and 2. Error bars indicate standard deviation for a series of measurements taken at a specific temperature.

These results were obtained using fresh water. In order to verify that they are also representative of sea water, a solution representing the organic content of sea water and one representing the ionic content of the sea were prepared. Comparison with the normal incidence reflectance of fresh water showed differences less than the standard deviation of one percent or less. Samples of sea water from the Gulf of Mexico were compared with fresh water. The reflectance ratio was 0.9996 ± 0.0040. The ionic conductivity of the sea becomes small in the centimeter region, and negligible in the millimeter region. Effects of organic matter on dielectric properties of sea water are generally unknown.

DISCUSSION AND ANALYSIS

Measured reflectance in Figures 1 and 2 is compared with values calculated from recent dielectric property models for water by Ray [1] and by Mason, Hasted, and Moore [2]. The major difference between the three models is allowance for a small spread in relaxation times in the Cole-Cole equation (C-C) and

TABLE I

REFLECTANCE, RELATIVE DIELECTRIC CONSTANT,
AND INDICES OF REFRACTION FOR WATER AT 20°C

FREQUENCY GHZ	R %	ε'	ε''	n	k
103.8	39.2	7.16	11.82	3.24	1.82
135.6	34.1	6.33	8.96	2.94	1.52
183.3	30.1	5.85	7.13	2.74	1.30

a different temperature dependence of the high frequency dielectric constant in the model by Ray (R) from the Debye (D) and Cole-Cole models. Work at lower frequencies plus some data in the submillimeter region makes it a near statistical certainty that there is some spread in relaxation times of the water molecule at these frequencies and temperatures. We find that the Cole-Cole and Debye models differ by less than one percent in reflectance calculated for the short millimeter wavelength region. The Cole-Cole model appears to offer the best fit overall, while both the Cole-Cole and Debye equations are more satisfactory than the Ray equation over the range of frequency and temperature reported here.

The results of Cumming [3] at a wavelength of 3.2 cm give a value of 1.78 for the refractive index of ice. No absorption bands or dispersion are expected in the millimeter-centimeter wavelength region. Thus our results in the short millimeter wavelength region are in agreement with Cumming, and show no temperature dependence between -15°C and 0°C.

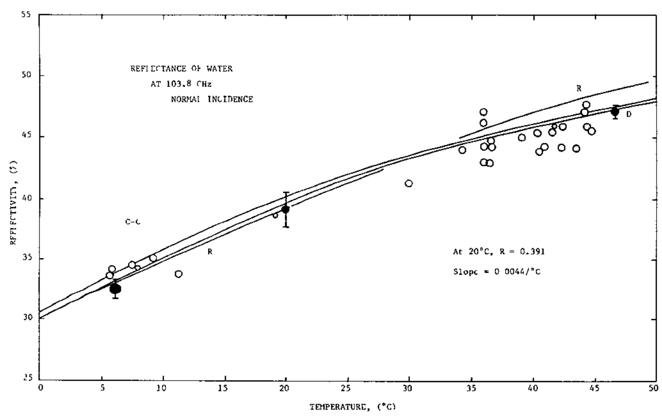

Figure 1. Reflectivity of Water at Normal Incidence at a Frequency of 103.8 GHz. The Value Obtained at 20°C Represents an Average of 122 Measurements. The Experimental Results Are Compared with Reflectivity Calculated from the Cole-Cole (C-C) and Debye (D) Models [2] and the Model of Ray (R) [1]. Small Circles Represent Typical Individual Measurements.

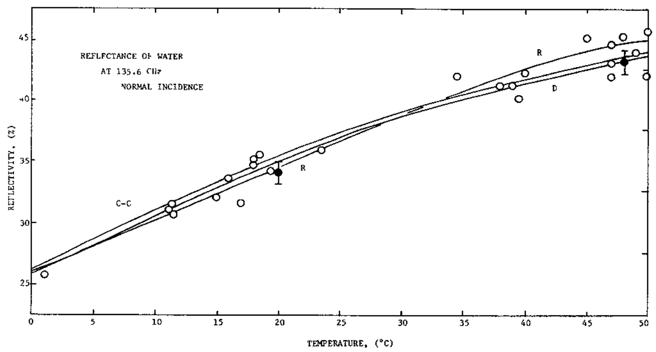

Figure 2. Reflectivity of Water at Normal Incidence at a Frequency of 135.6 GHz. The Value Obtained at 20°C Represents an Average of 49 Measurements, while the Value at 48°C Represents 79 Measurements. The Curves were Calculated from Cole-Cole (C-C) and Debye (D) Models [2] and the Model by Ray (R) [1]. Individual Measurements are Represented by Small Circles.

REFERENCES

1. P. S. Ray, "Broadband Refractive Indices of Ice and Water", Appl. Optics, 11, pp. 1836-1844, 1972.
2. P. R. Mason, J. B. Hasted, and L. Moore, "The Use of Statistical Theory in Fitting Equations to Dielectric Dispersion Data", Adv. In Molecular Relaxation Processes, 6, pp. 217-232, 1974.
3. W. A. Cumming, "The Dielectric Properties of Ice and Snow at 3.2 Centimeter", J. Applied Physics, 23, pp. 768-773, 1952.

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