New dielectric measurement data to determine the permittivity of seawater at 1.413 GHz

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1. INTRODUCTION

This paper describes the new measurements - made in 2010-2011 - of the dielectric constant of seawater at 1.413 GHz using a resonant cavity technique. The purpose of these measurements is to develop an accurate relationship concerning the dependence of the dielectric constant of seawater on temperature and salinity for use by the Aquarius inversion algorithm. Aquarius is a NASA/CONAE satellite mission launched in June of 2011 with the primary mission of measuring global sea surface salinity with a 1.413 GHz radiometer to an accuracy of 0.2 psu.

A brass microwave cavity resonant at 1.413 GHz has been used to measure the dielectric constant of seawater. The seawater is introduced into the cavity through a capillary glass tube having an inner diameter of 0.1 mm. The change of resonant frequency and the cavity Q value are used to determine the real and imaginary parts of the dielectric constant of seawater. Measurements are automated with Visual Basic software developed at the George Washington University.

In this paper, new results from measurements made since September 2010 will be presented for salinities of 30, 35 and 38 psu with a temperature range of 0^{o}C to 35^{o} C in intervals of 5^{o} C. These measurements are more accurate than earlier measurements made in 2008[1]. The new results will be compared to the Klein-Swift (KS) and Meissner-Wentz (MW) model functions. The importance of an accurate model function will be illustrated by using these model functions to invert the Aquarius brightness temperature to retrieve the salinity values. The salinity values will be compared to co-located insitu data collected by Argo buoys.

2. RESONANT CAVITY TECHNIQUE

The resonant cavity technique has been used in the past to make highly accurate dielectric measurements. After introducing the seawater sample into the cavity, the seawater perturbs the fields inside the cavity, causing a change in both the resonant frequency and the cavity Q. If the perturbation is small, the dielectric constant of the seawater can be retrieved by using the following perturbation relations:

$$\varepsilon' - 1 = 2C\Delta f / f_o \quad , \quad \Delta f = f_o - f$$

$$\varepsilon'' = C\Delta(1/Q) \quad , \quad \Delta(1/Q) = 1/Q - 1/Q_o$$

where ε' and ε'' are the real and imaginary parts of the relative dielectric constant of the seawater sample respectively and C is a calibration constant. The variables f and Q are the resonant frequency and the quality factor of the cavity after the sample has been introduced into the cavity. In this work the measurements made by Gregory and Clark of the dielectric constant for methanol at 20°C are employed as the reference liquid to determine the calibration constant C in the above formulas.

3. DESCRIPTION OF THE NEW MEASUREMENTS

Over the past year and a half, the measurements made in 2008 have been repeated with more accuracy, and the measurement range has been increased to include 0°C and 5°C. It has been observed that the measurement of the calibration constant can be improved by using methanol in a capped bottle. When methanol is exposed to air it accumulates water that changes its dielectric constant. By using a capped bottle, the variance of the methanol measurements has been reduced to 0.23% compared with a variance of 0.76% found in 2008[1]. In addition, the variance in the seawater measurements is decreased by allowing the cavity temperature to stabilize for a longer period after it has been changed. After a change in cavity temperature of 5°C, for example, the system is allowed to stabilize for more than three hours. As a result, the average variance for all seawater measurements is reduced to 0.22 compared with 0.45 in 2008[1]. Finally, an oxidizing acid (chromic/sulfuric) has been used to dissolve particles blocking the capillary tube. To protect the system, all brass and nylon parts have been replaced by stainless steel and Teflon parts respectively.

4. MEASUREMENT RESULTS

Selected results for 30psu seawater are presented in Figs 1a and 1b. In these figures

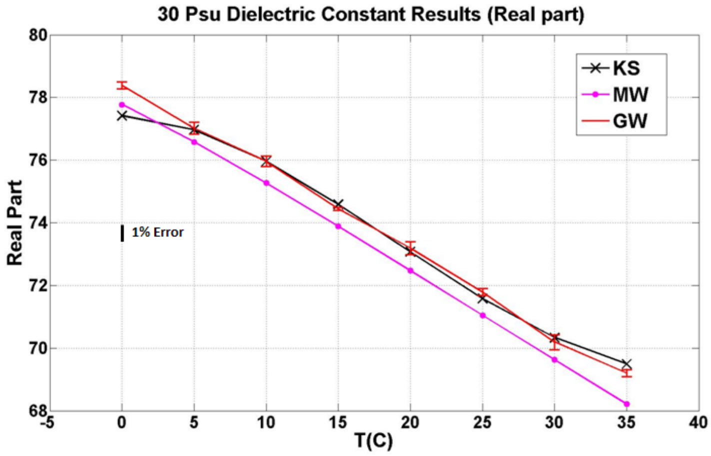

Fig. 1a Real part of the dielectric constant (ε') of 30 psu seawater

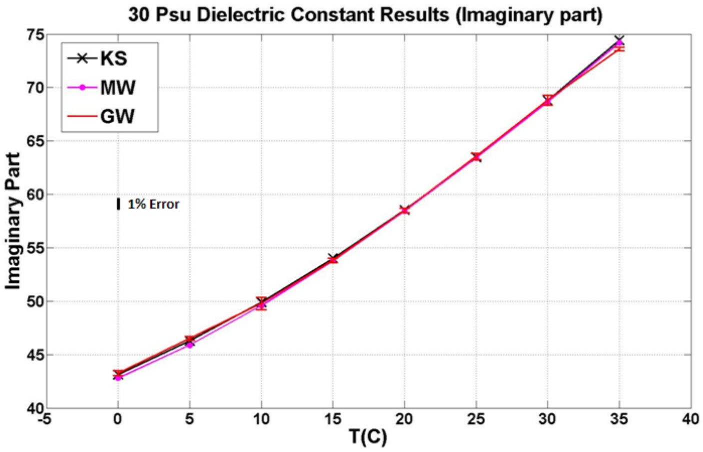

Fig. 1b Imaginary part of the dielectric constant (ε'') of 30 psu seawater

the red line represents the George Washington (GW) curves, and each of the points on the red curves are based on real data. Each point represents the average result for three or more measurements. The black line represents KS model and the pink line represents MW model. For the real part of seawater dielectric constant, it is seen that the GW curve matches KS model very closely from 5°C to 35°C, however at low temperatures the GW curve is about 1-2% bigger than the KS model results. The GW curve is parallel to the MW curve and about 1% bigger for all temperatures. For imaginary part, GW curve matches the other two curves closely from 0°C to 30°C and is slightly lower at high temperatures.

Table 1a and Table 1b show the error analysis of the GW measurements in 2011-2010 and 2008. The total uncertainty is based on three terms that can be represented by the formula:

$$\sigma_\varepsilon^2 = \sigma_\varepsilon^2(SW) + \sigma_\varepsilon^2(C_M) + \sigma_\varepsilon^2(C_{ref})$$

where $\sigma_\varepsilon^2(SW)$ is the uncertainty from seawater measurements; $\sigma_\varepsilon^2(C_M)$ is the uncertainty for the methanol measurements, and $\sigma_\varepsilon^2(C_{ref})$ is the uncertainty of the reference liquid (methanol) measurements. From the tables, it can be seen that the total uncertainty of ε' has been reduced to 0.26 from a value of 0.75 obtained in 2008[1], and the total uncertainty of ε'' has been reduced to 0.42 from a value of 0.73 obtained in 2008[1].

Real Dielectric Constant Uncertainty					
Temp	**σ_ε(SW)**	**σ_ε(C)**	**σ_ε(ref)**	**σ_ε(total)**	**σ_ε(2008)[1]**
0	0.12	0.17	0.14	0.25	-
5	0.14	0.17	0.14	0.26	-
10	0.10	0.17	0.14	0.24	0.62
15	0.20	0.16	0.13	0.29	0.67
20	0.12	0.16	0.13	0.24	0.63
25	0.14	0.16	0.13	0.24	0.7
30	0.22	0.15	0.12	0.29	0.86
35	0.14	0.15	0.12	0.24	1.02
Average				0.26	0.75

Table 1a The comparison of ε' uncertainty between new and old measurements

Imaginary Dielectric Constant Uncertainty					
Temp	**σ_ε(SW)**	**σ_ε(C)**	**σ_ε(ref)**	**σ_ε(total)**	**σ_ε(2008)[1]**
0	0.09	0.19	0.08	0.22	-
5	0.22	0.20	0.09	0.31	-
10	0.19	0.22	0.1	0.31	0.44
15	0.28	0.24	0.11	0.38	0.62
20	0.32	0.26	0.12	0.43	0.53
25	0.37	0.28	0.13	0.48	0.68
30	0.50	0.31	0.14	0.60	1.03
35	0.48	0.34	0.15	0.61	1.06
Average				0.42	0.73

Table 1b The comparison of ε'' uncertainty between new and old measurements

5. REFERENCES

[1] R. Lang, C. Utku, Y. Tarkocin and D. Le Vine, "*Accurate Measurements of the Dielectric Constant of Seawater at L Band*," NASA Technical Memo NASA/TM-2010-215861, Oct. 2010.