DEBYE DIELECTRIC MODEL FUNCTION FOR SEAWATER BASED ON EXPANDED L-BAND MEASUREMENT DATA SET

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ABSTRACT

New seawater dielectric measurements have recently been made over a broad range of salinities and temperatures at the George Washington University (GW). These measurements have been used to refine the existing dielectric model function of seawater for salinity retrieval. The mathematical structure of the new model function has been investigated to: (a) look for a physical basis for the mathematical form; and (b) to optimize the accuracy of data fitting. The Debye model has been chosen to represent the dielectric constant of seawater as a function of salinity (S), temperature (T) and frequency (f). The retrieved salinity using the Debye model has good agreement with the in-situ data collected by Argo floats. The global differences in retrieved salinity and in-situ data will be presented at the meeting.

Index Terms— Ocean salinity, L-band, Dielectric model function

I. INTRODUCTION

Ocean salinity scientists need a dielectric model function for expressing the fundamental relationship between the seawater dielectric constant, salinity (S) and physical temperature (T). The model function bridges the gap between the observed ocean brightness temperature (T_B) and the ocean salinity.

The model function has been developed from lab data. A transmission-type microwave cavity is employed to measure the dielectric constant of seawater at L-band [1]. The seawater is introduced into the cavity via a capillary tube. The cavity is then immersed in a coolant and the temperature of the system is kept constant by a circulator. The real and imaginary parts of the seawater dielectric constant are determined by the change in the cavity's resonant frequency and Q-factor when the seawater enters the cavity.

Based on the measurements made before 2017, a seawater dielectric model, now denoted as GW2017, was developed and applied to retrieve sea surface salinity (SSS) [2]. The GW2017 is formed by a third-order polynomial in S and T. The salinities were retrieved from surface brightness temperatures observed during the Aquarius mission (Aquarius data from 2011 - 2015) by using the GW2017, Klein-Swift [3] and Meissner-Wentz [4] model functions.

The retrieved SSS is then compared with in-situ values observed by Argo floats. Although the GW2017 has the best agreement in average [2], a dispersion has been found in its behavior for different salinities as a function of temperature. This dispersion undermines the performance of model function in salinity retrieval. See retrieval results for GW2017 shown in Fig.1 for the global difference between retrieved salinity and in-situ values.

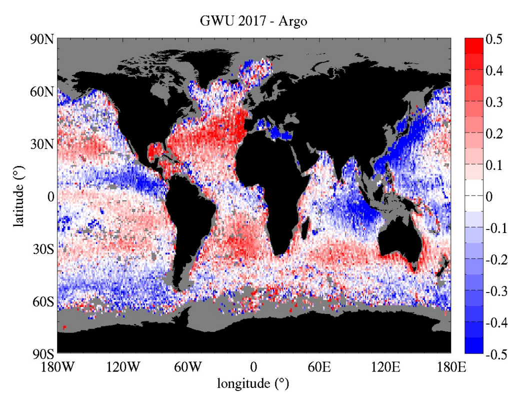

Fig. 1 Global difference between the retrieved salinity and in-situ data from GW 2017 model

The polynomial expression of GW2017 has in total 32 unknown coefficients that need to be determined for real and imaginary part (16 coefficients for each).

Because of the large number of unknown coefficients, the resultant model function has suffered from over-fitting; this is the main reason for undermining its performance in salinity retrieval. In this paper, a Debye model function is proposed. Its three real parameters (relaxation time, static dielectric constant and conductivity) are determined using the GW data. Each unknown parameter is determined using fewer unknown coefficients then employed in the GW2017 model. This more physically based model function has much less dispersion between salinities and, as a result, has better performance in salinity retrieval.

II. NEW MODEL FUNCTION

Since 2017 new seawater dielectric measurements have been made based on an upgraded system [5] to expand the dataset. The increase in the data set and the decrease in the number of unknown coefficients using the Debye model will reduce the possibility of over-fitting.

Measurements have been made for seawater samples with 10, 20 and 34 psu from 0° C to 30° C with a 5° C interval; the measurements also include 36 psu from 10° C to 30° C. Additional measurements were made below 5° C with finer temperature steps to improve the accuracy of model function at low temperature [6]. Besides the seawater measurements, distilled water measurements have been made from 0° C to 35° C with a 5° C interval. The dielectric constant of distilled water provides an important reference to the development of seawater Debye model function.

The GW new model function has the Debye expression which is given as:

$$\varepsilon_{sw}(S,T) = \varepsilon_{\infty} + \frac{\varepsilon_{s-dw}(T) R_{sw/dw}(S,T) - \varepsilon_{\infty}}{1 + j\omega\tau(T)} - \frac{j\sigma(S,T)}{\omega\varepsilon_0} \quad (1)$$

where ε_0 is the dielectric constant of free space; $\varepsilon_{s-dw}(T)$ and $\tau(T)$ are the static dielectric constant and relaxation time of distilled water respectively; $R_{sw/dw}(S,T)$ is an additional term in the static dielectric constant of seawater due to the presence of ions; ε_{∞} is the high frequency dielectric constant, $\sigma(S,T)$ is the conductivity of seawater and ω is the angular frequency.

In the process of determining the unknown coefficients, the value of the relaxation time, $\tau(T)$, and the static dielectric constant of distilled water, $\varepsilon_{s-dw}(T)$, are determined such that they agree with the results of distilled water measurements. This later procedure reduces the number of coefficients needed and insures that the model function for seawater reduces to the model function for distilled water when S=0. The static dielectric constant of seawater is determined by the ratio of the real part of the dielectric constant of seawater to distilled water. The conductivity term is determined from the imaginary part of the measured seawater dielectric constants. Note that the relaxation time of seawater is assumed to be the same as distilled water. This is because τ is based on the inertial properties of the water molecules; the addition of salt has a small effect because of the large mass of water molecules compared to salt ions [7].

III. RESULTS AND DISCUSSIONS

Compared with GW2017 model, the new model, i.e. GW2019, avoids the over-fitting issues by increasing the size of dataset and decreasing the number of unknown coefficients in each fitting process. The GW2019 Debye model function, as a result, is more stable than GW2017 model.

Tests have been done to validate the stability of the model function. A virtual dataset has been developed by generating random numbers from the normal distribution having mean values and standard deviations that are similar to those of the measured data set. Based on the virtual dataset, a new model function has been developed. The difference between the virtual model function and the actual model function has been found and plotted in Fig.2.

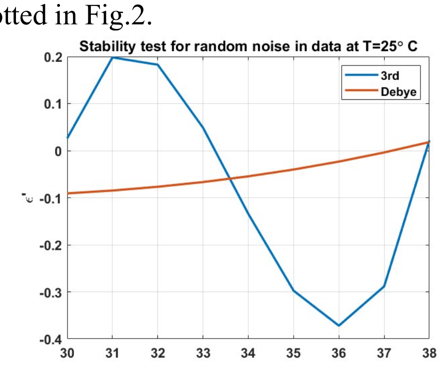

Fig. 2 Stability test for random noise in data

In Fig. 2, the blue curve represents the difference in the real part of the dielectric constant between the virtual and measured model function for the 3rd-order polynomial model; the red curve represents the difference for Debye model based on extended dataset. The test is done for the model function at 25° C. It is seen that the 3rd-order polynomial model is very sensitive to the noise in data. The Debye model, on the other hand, stays quite stable when the data is perturbed.

The brightness temperature (T_B) obtained from different model functions have also been plotted for an idealized flat surface case. It is known that the KS model function does not have a significant dispersion between different salinities when they are employed in salinity retrieval. The difference in T_B between the GW2019 and the KS model functions will provide an indication of the performance of GW2019 in salinity retrieval. The results are shown in Fig. 3.

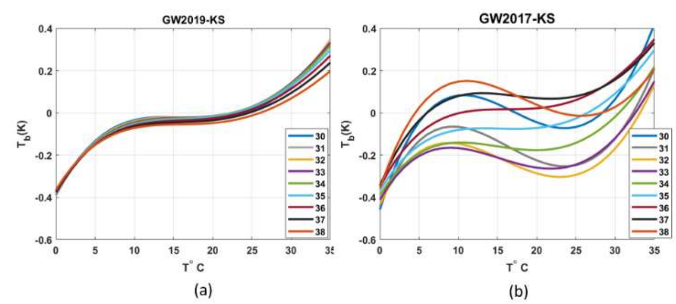

Fig. 3 Difference in brightness temperature between the GW models and the KS model

It is seen that the GW2019 model has a much more consistent behavior between different salinities compared with GW2017 model. Note that it doesn't mean that the GW2019 is the same as the KS model, significant difference as a function of temperature still exists between these two model functions. These results indicate that GW2019 will have a better performance on salinity retrieval. The global map of the retrieved salinities from GW2019 model and the comparison between the in-situ data and retrieved results will be presented at the meeting.

IV. CONCLUSIONS

A new GW model function has been developed using a Debye form. Additional seawater dielectric measurements have been made to improve the coverage in the ranges of S and T. The expanded dataset and the choice of Debye expression together avoid the over-fitting issue that existed in our previous model function. The new model, as a result, has a more stable performance in salinity retrieval. Compared with other existing models, the retrieved salinity using GW2019 model indicates better agreement with the in-situ data from Argo floats. The new model function and its application on salinity retrieval will be further discussed at the meeting.

V. REFERENCES

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