Particulate Properties of the Dead Sea Retrieved by the Physical Optics Method

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***Abstract*— It is a well-known fact that the Dead Sea located in Jordan, Israel is one of the saltiest lakes in the world, whose salinity is approximately 30%. Such a huge salinity makes it almost biologically lifeless. However this lake contains large quantities of different minerals and some quantity of dissolved organic matter. Minerals of the Dead Sea are important for medicinal and cosmetics purposes. Unfortunately, the Dead Sea is slowly drying up and soon it will no longer be around in years to come. We can help preserve the Dead Sea and it's important that we use its wealth more rationally to prevent or delay its death. Thus it is imperative that we find answers to the following questions: Which minerals are exactly dispersed within the water? What are the minerals concentration and their vertical and horizontal space distribution? We must find if this solution is unique and stable?**

***Keywords*— Excel, Attenuation, Absorption, Scattering, Back Scattering**

I. INTRODUCTION

A. *Overview*

In the spring of 2004 a scientific team was organized and sent to carry out the first optical expedition to the Dead Sea. This team consisted of several American and Israeli scientists. Such inherent optical properties such as absorption and attenuation spectra were measured by the WET Labs Inc. Absorption and attenuation meter ac-9 ("a" = absorption, "c" = attenuation, "9" = number of wavelengths: 412, 440, 488, 510, 532, 555, 650, 676, 715 nm) and backscattering spectra were measured at 660 nm by the WET Labs ECO-VSF optical instruments. The Expedition team collected dissolved organic matter that was retrieved by using special filters with diameters of 0.2 υm. Thus knowing standard values of pure water absorption coefficient, the suspended matter ("particles") absorption spectra were determined by the simple subtraction ($a_{part} = a_{total} - a_{dis} - a_{water}$). Similarly, dissolved matter suspended matter scattering spectra were determined by $b_{part} = b_{total} - b_{water}$. From the law of energy conservation we can determine now that particulate attenuation as $c_{part} = a_{part} + b_{part}$.

B. *Methods*

We used the optical method to conduct research about the Dead Sea because it allows us to collect data faster than using physical samples. Using physical samples can take a longer amount of time to collect and study. The optical method allows us to use non-contact methods to get the physical, logical, and chemical estimations of the Dead Sea. The optical method allows us to process the sample data faster than using any other method available.

C. *Data Visualization*

Data Visualization is making data in its raw format available in a visual representation of information, data, or knowledge. Data Visualization is used in the areas of teaching, research and development. The Ocean Optic team goal was to answers to these questions: Which minerals are exactly dispersed within the Dead Sea? What are the mineral concentrations and their vertical and horizontal space distributions? Find if this solution is unique and stable? Also we needed to display the data collected by the Optical Expedition Scientific team in 2004. The team made scatter plots to demonstrate the mineral concentrations and the vertical and horizontal space distributions as seen in figures 1-10. We used Microsoft Excel to create all the graphs.

D. *Data Collection*

The purpose of data collection is to acquire information to keep on file, to reach decisions about important issues, and to pass on information to other people. The Optical Expedition Scientific team collected the data in 2004 that was used by our team to conduct this research. The Optical Expedition Scientific team collected dissolved organic material by using special filters with diameters of 0.2 υm. The team also measured inherent optical properties such as absorption and attenuation. The data was collected and put into an excel datasheet. The Ocean Optics Team took this data and used mathematical formulas in excel to find the answers to our questions stated above in the overview.

II. DEAD SEA

A. Overview

In order to understand our research it is imperative that you have some knowledge about the Dead Sea. The Dead Sea is a hyper saline terminal lake located in the Dead Sea Rift Valley. The lake is 50 km long (not including the Southern evaporation ponds), up to 16 km. The Dead Sea is distinguished for being located at the lowest place on Earth as well as being the deepest (328 m) hyper saline lake (approximately 280%). Reduced fresh water from the Jordan river and surrounding fresh water springs since the 1960's has caused the lake surface level to drop due to evaporation at an average rate of 1 m/yr and in 2005 it had dropped to 418 m. Other notable features include the extraordinary density (1.236 kg L-1) and its almost complete lack of life within, except for infrequent short periods of dense microbial blooms, both due to its hyper-salinity. The lack of phytoplankton makes the Dead Sea a unique "environmental laboratory" for aquatic optical studies. The Dead Sea's environmental climate has year-round sunny skies and dry air with low pollution. It has less than 100 millimetres (3.94 in) mean annual rainfall and a summer average temperature between 32 and 39 °C (90 and 102 °F). Winter average temperatures range between 20 and 23 °C (68 and 73 °F). The region has weakened ultraviolet radiation and an atmosphere with high oxygen content due to the high barometric pressure. The sea affects temperatures nearby because of the effect a large body of water has on a climate. During the winter, sea temperatures tend to be higher than land temperatures, and vice versa during the summer months. This is the result of the water's mass and specific heat capacity.

III. MICROSOFT EXCEL

A. Overview

Microsoft Excel 2008 is a software package that can be used to create and format spreadsheets. Excel is also used to analyse and share data in a reasonable form. This project used Excel to calculate and manage collected data as well as create scatter plots as seen in figures 1-10. In addition the team utilized Excel to analyse the mineral concentrations of the Dead Sea at multiple depths.

B. Capabilities

Microsoft Office Excel 2008 is the Mac version of Microsoft Excel 2007. It has the same capabilities as the Window version of Microsoft Excel 2007. It has an increased row amount to one million, and the column amount has expanded to sixteen thousand. Excel quickly formats cells and tables. Excel can create many different charts including radar, scatter, and line. Sorting and filtering are two important basic features that organize and locate data. Excel also allows the input of formulas. Formulas are equations that perform calculations on values in a spreadsheet.

IV. METHODOLOGY

A. *Statement of Problem*

We have three different optical spectra for each depth: a_{part} (λ,z), a_{part} (λ,z), a_{part} (λ,z) and the one vertical profile of backscattering coefficient: b_{bpart}(660 nm, z), where l is a wavelength (in nanometres) and z is a depth (in meters). All this data may be found in the Excel file named 2004 Optical Expedition. We are trying estimate some optical disperse information from this data. The parameters are as follows:

1) The real part (n_{part}) of the complex refractive index of the particles $m_{part} = n_{part} - k_{part}$
2) The imaginary part (k_{part}) of the particulate complex refractive index
3) The number of particles in the unit volume (numerical concentration) N_{part}
4) The volume part of particles in the unit volume (volume concentration) C_v
5) A particles mass in the unit volume (mass volume concentration) TSM (Total Suspended Matter)

Also we need to check whether the solution is unique or if it has multiple solutions or the solution does not exist at all.

B. *Setup of Problem*

The original data collected by the Optical Expedition Team in 2004 consisted of seventeen thousand forty eight different values. There was a lot of information to process and calculate in a short amount of time. So we choose to take a maximal and minimal depth average. We took the average depth at different depth intervals. This allowed us to speed up the calculation and information process inside of excel. We also choose two different values of D_{max} to test and see if the solution was unique or stable. Once we took the average depth and choose the two values of 10 and 50 for the D_{max}. After we established these values and averages we started to conduct our research.

C. Solution

There are many different ways to find the solution of the task. We used a simplified version to solve the problem. The solution still remains precise and stable enough. We assumed that all particles are spheres or, more exactly hypothetical spheres with some effective diameter, optical properties of which are the same as optical properties of real particles. Usually, in the disperse optics literature the ratio of the mean volume of all particles to the mean surface of these particles is considered as effective diameter which is sometimes designated as $D_{32.}$ In ocean optics literature it is usually accepted to describe a particle size distribution (PSD) by the simple differential hyperbolic function (Junge's Law):

$$f(D) = \alpha D^{-\mu} \qquad D \in [D_{\min}; D_{\max}]$$

(1)

Where α and μ the factor and slope of the PSD, respectively; D_{min} and D_{max} are the minimal and maximal diameters of the PSD. For PSD expressed by Eq. (1), an effective diameter (you can find a definition of "effective diameters" and general equation for it in: Mitchell, 2002) may be expressed as follows:

$$D_{32} = \frac{\int_{\mathrm{D_{min}}}^{\mathrm{D_{max},}} \mathrm{D}^3 f(D)dD}{\int_{\mathrm{D_{min}}}^{\mathrm{D_{max},}} \mathrm{D}^2 f(D)dD} = \frac{(\mu-3)(D_{\max}^{4-\mu} - D_{\min}^{4-\mu})}{(\mu-4)(D_{\max}^{3-\mu} - D_{\min}^{3-\mu})}$$

(2)

Further, it follows from the calculations performed by the rigorous solution of the Maxwell's electromagnetic equations (Mie theory) that for ensemble of the spherical particles following to Eq. (1), the n_{part} may be presented as (*Twardowski et al.*, 1999):

$$n_{part} = 1 + B_{part}^{0.5377+0.4867(\mu-3)^2}\left[1.4676 + 2.2950(\mu-3)^2 + 2.3113(\mu-3)^4\right.$$

(3)

Where B_{part} is the probability of backscattering:

$$B_{part} = \frac{b_{b,\,part}}{b_{part}}$$

(4)

And m is related with the slope g of the power spectral dependence of c_p(l) (c_p(l)=al^{-g}) by equation (*Boss et al.,* 2001):

$$\mu = \gamma + 3 - 0.5\exp(-6\gamma)$$

(5)

B_{part} may be assumed to be spectrally independent. Thus, the optical properties B_{part} and n_{part} may be derived straightforward from the data. We used the wavelength of 660 nm for calculation of particulate scattering and backscattering probability assuming the power spectral dependence for b_{part}.

The particulate absorption and particulate attenuation may be expressed through the relationships:

$$a_{part}(\lambda) = \frac{1.5C_v Q_a(\lambda)}{D_{32}}$$

$$c_{part}(\lambda) = \frac{1.5C_v Q_c(\lambda)}{D_{32}}, \qquad (6)$$

Where Q_a and Q_c are the spectral efficiency factors for absorption and attenuation, respectively. In turn, Q_a and Q_c in the first approximation can be determined from the anomalous diffraction theory (*van de Hulst*, 1981; *Morel and Bricaud,* 1981, 1986):

$$Q_a = 1 + \frac{2\exp(-\rho')}{\rho'} + \frac{2[\exp(-\rho') - 1]}{(\rho')^2}$$

(7)

$$Q_c = 2 - 4\exp(-\rho\tan\xi)\left[\frac{\cos\xi\sin(\rho-\xi)}{\rho} + \left(\frac{\cos\xi}{\rho}\right)^2\cos(\rho-2\xi)\right] + 4\left(\frac{\cos\xi}{\rho}\right)^2\cos 2\xi$$

. (8)

Here spectral structural parameters r, r′ and x (We omitted the spectral dependence in Eq. 7 and 8 for simplicity) are defined as follows:

$$\rho(\lambda) = \frac{2\pi D_{32} n_w(\lambda)(n_{part} - 1)}{\lambda}$$

(9)

$$\rho'(\lambda) = \frac{4\pi D_{32} n_w(\lambda) k_{part}(\lambda)}{\lambda}$$

(10)

$$\xi(\lambda) = \arctan\left[\frac{0.5\rho'(\lambda)}{\rho(\lambda)}\right]$$

(11)

The table below yields the spectral refractive indices n_w (l) for the Dead Sea waters needed for calculations:

λ	412	440	488	510	532	555	650	676	71
n_w(λ)	1.395	1.392	1.388	1.387	1.386	1.385	1.381	1.380	1.

Thus, from Eq. (2)-(11) follows that the system of regulating equations contains the following unknown parameters: C_v, D_{max} and k_{part} (l), which may be derived (or not derived) from this system. Two remaining types of concentrations may be found from the following equations:

$$TSM = \rho_{part} C_v \qquad (12)$$

$$N_{\mathrm{part}} = \frac{6}{\pi}\mathrm{C_v}\frac{(\mu-4)(D_{\max}^{1-\mu} - D_{\min}^{1-\mu})}{(\mu-1)(D_{\max}^{4-\mu} - D_{\min}^{4-\mu})}$$

(13)

Where the density of mineral particles r_{part} (expressed in kg/L) may be related to n_{part} by the empirical equation (*Woźniak and Stramski,* 2004):

$$\rho_{\text{part}} = \frac{n_{part} - 0.7717}{0.1475}. \quad (14)$$

V. OUTCOME

A. *Results*

Through our research we have found that this problem does have a mathematical solution. The solution was not unique and we found out all of our parameters as such as absorption, attenuation, backscattering, n_p, k_p, D_{32}, C_V, N_{part}, r_{part}, and TSM as seen in Figures 1-10. In the figure 1 graph you can see how particles are absorbed in the water. As the depth increases the particles are less absorbed. In the figure 2 and 3 graphs we can see particulate attenuation and particulate backscattering. As you can see there is a sharp and drastic change in the attenuation in the first fifty meters. Also the backscattering graph shows a sharp change in the backscattering of particles in the first fifty meters. As seen in most graphs in figures 1-10 we can see most of the activity happening in the first fifty meters of the ocean. As we go deeper in the Dead Sea we see less activity.

B. *Data Visualization*

Upon completing the project our data could now be visualized. The data was visualized by graphs using excel as seen in Figures 1-10.

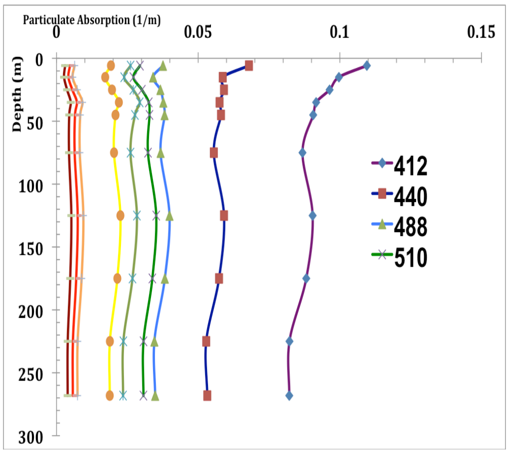

Figure 1: Graph of Particulate Absorption

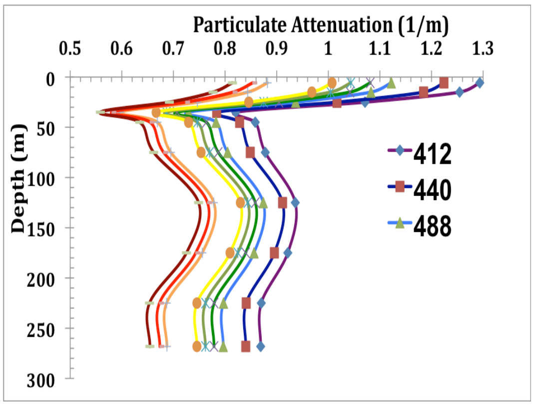

Figure 2: Graph of Particulate Attenuation

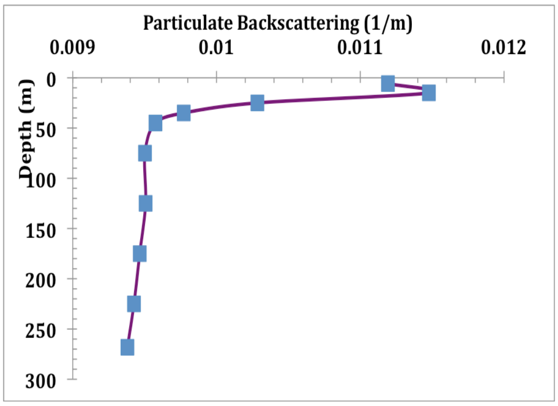

Figure 3: Graph of Particulate Backscattering

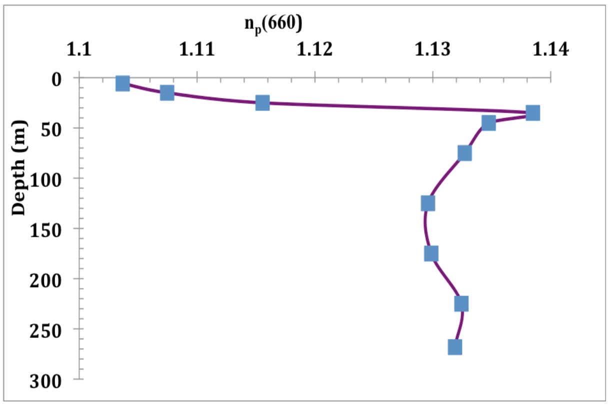

Figure 4: Graph of Real Part of Refractive Index

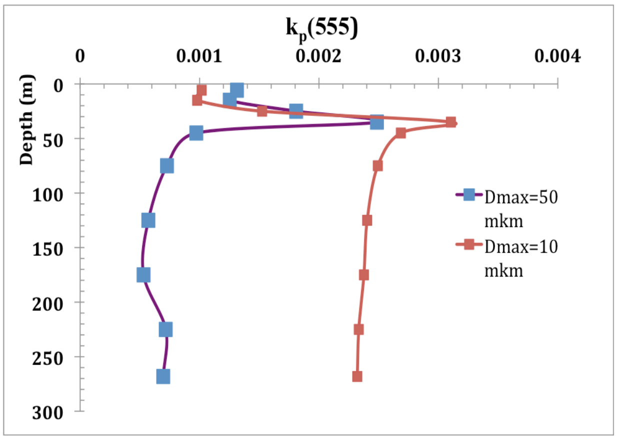

Figure 5: Graph of Imaginary Part of Refractive Index

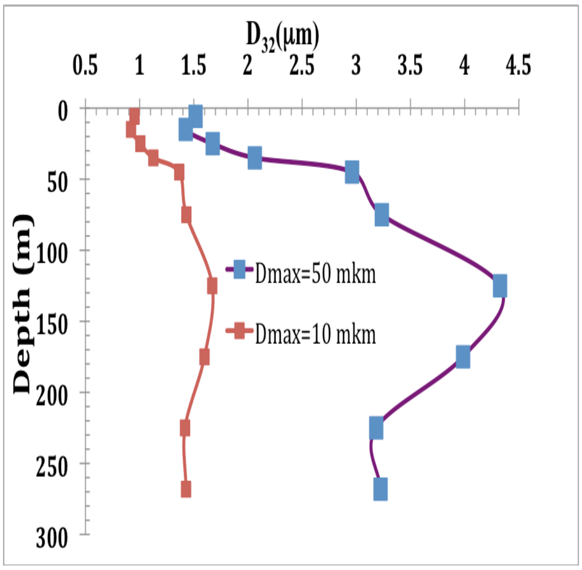

Figure 6: Graph of Refractive Diameter

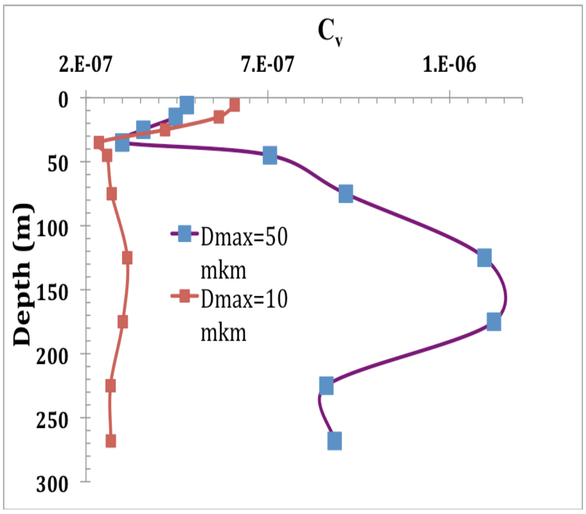

Figure 7: Graph of Efficiency Absorption & Attenuation Factor

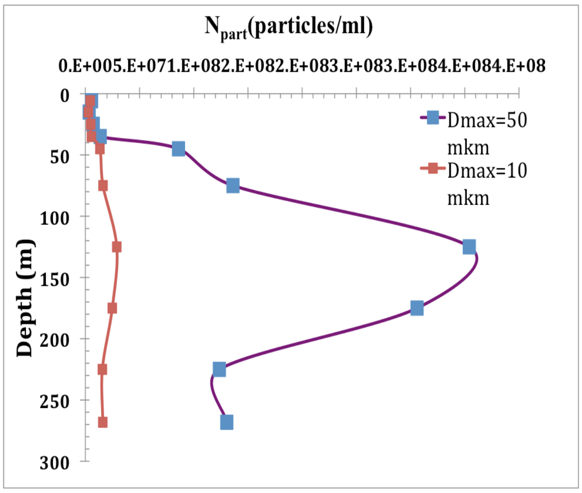

Figure 8: Graph of Particles in Unit of Volume

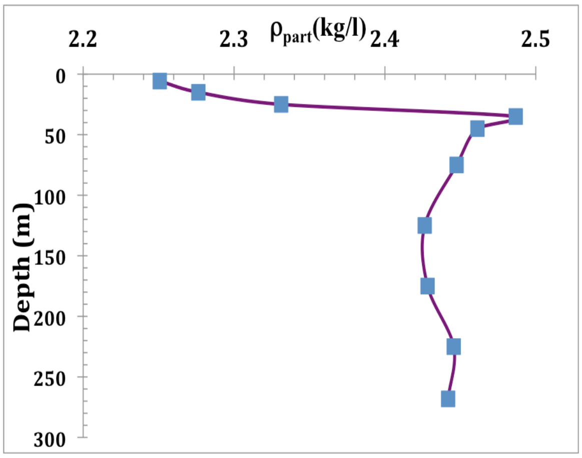

Figure 9: Graph of Structure Parameter

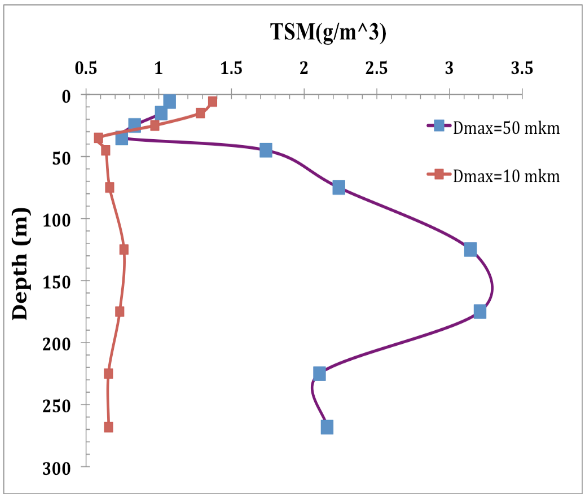

Figure 10: Graph of Total Suspended Matter

VI. FUTURE WORK

In this research the data that was utilized was averaged into ten minimal and maximal depths because there was not enough time to compute all seventeen thousand forty eight-depth increments. In the future this data could be utilized to provide and even more accurate visual by using all seventeen thousand forty eight-depth increments. By using all of the data we will get a better understanding of the Dead Sea.

VII. CONCLUSIONS

A. *Acknowledgements*

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