Undergraduate Research Experience in Ocean, Marine, and Polar Science

URE OMPS 2010

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.

Introduction

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 $c_{part} = a_{part} + b_{part}$.

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.

Data Visualization

We needed to display the data collected by the Optical Expedition Scientific team in 2004. This project used Excel to calculate and manage collected data as well as create scatter plots. We used Microsoft Excel to create all the graphs.

The Optical Expedition Scientific team collected dissolved organic material by using special filters with diameters of 0.2 um. The team also measured inherent optical properties such as absorption and attenuation. 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.

Dead Sea

The Dead Sea is a hyper saline terminal lake located in the Dead Sea Rift Valley. The lake is 50 km long and up to 16 km wide. 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%).

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.

Statement of the Problem

We are trying estimate some optical disperse information from the data and to check whether the solution is unique, if it has multiple solutions, or the solution does not exist at all.

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)

Setup of the Problem

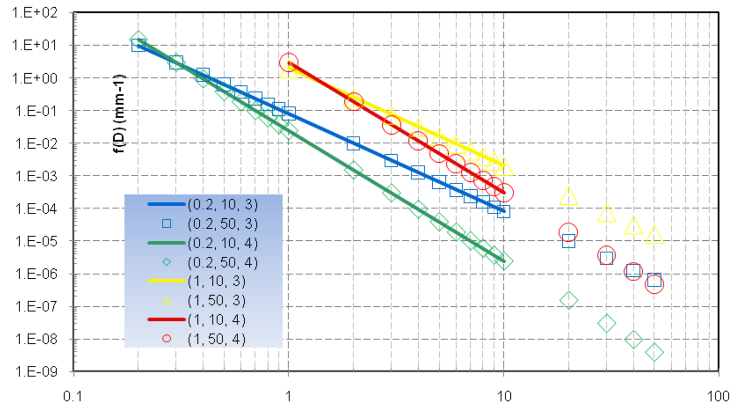
The data collected consisted of 17,048 different values. We choose to take a maximal and minimal depth average and the average depth at different depth intervals. We also choose two different values of D_{max} to test and see if the solution was unique or stable. Once we took the average depth and choose the two values of 10 and 50 for the D_{max}.

Depth_min (m)	Depth_max (m)	Depth_mean (m)
1.5	10.000	5.8
10	20.000	15.0
20	30.000	25.0
30	40.000	35.0
40	50.000	45.0
50	100.000	75.0
100	150.000	125.0
150	200.000	175.0
200	250.000	225.0
250	286.317	268.2

Solutions of the Problem

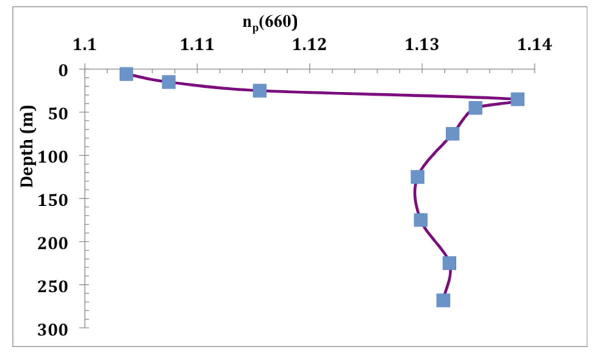
There are many different ways to find the solution of the task. We used a simplified version to solve the problem. The solution still remains precise and stable enough. We assumed that all particles are spheres or, more exactly hypothetical spheres with some effective diameter, optical properties of which are the same as optical properties of real particles.

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



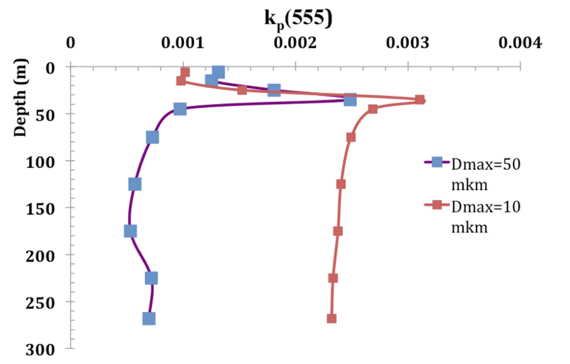
γ	μ
0.741	3.736
0.761	3.755
0.687	3.679
0.628	3.616
0.512	3.488
0.486	3.459
0.391	3.344
0.417	3.376
0.496	3.471
0.498	3.472

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



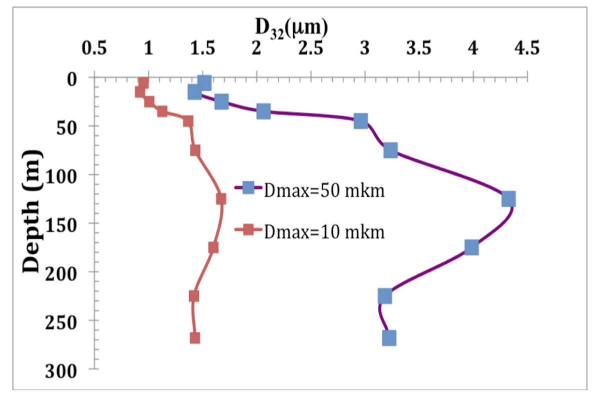
$n_p(660)$
1.104
1.107
1.116
1.138
1.135
1.133
1.130
1.130
1.132
1.132

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



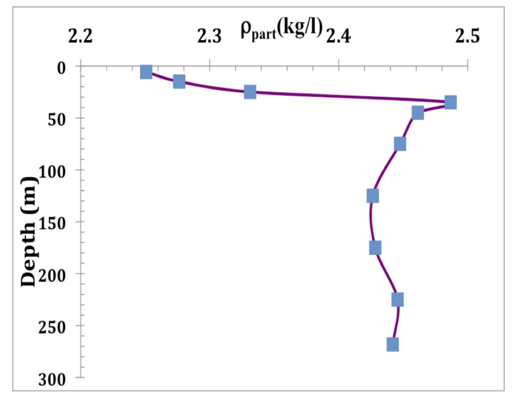
$k_p(555)$	$k_p(555)$
1.313E-03	1.017E-03
1.253E-03	9.797E-04
1.809E-03	1.524E-03
2.485E-03	3.105E-03
9.727E-04	2.686E-03
7.273E-04	2.493E-03
5.712E-04	2.403E-03
5.311E-04	2.376E-03
7.166E-04	2.333E-03
6.960E-04	2.321E-03

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



D_{32}	D_{32}
1.517	0.953
1.426	0.921
1.675	1.007
2.063	1.127
2.961	1.366
3.236	1.432
4.327	1.670
3.986	1.599
3.184	1.419
3.224	1.429

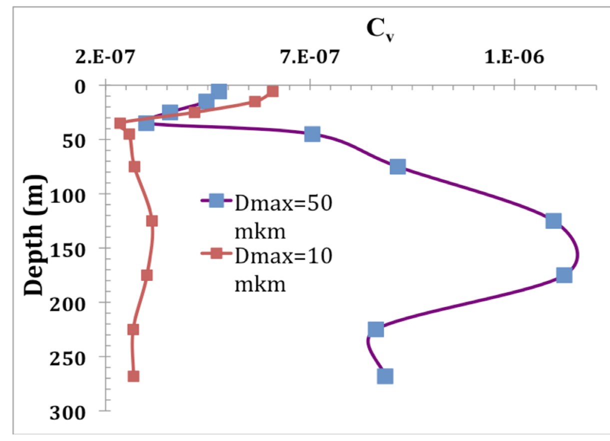
$$\rho(\lambda) = \frac{2\pi D_{32} n_w(\lambda)(n_{part} - 1)}{\lambda}$$



r(0.555)	r(0.555)
2.466	1.550
2.402	1.552
3.035	1.824
4.481	2.447
6.256	2.885
6.734	2.979
8.792	3.394
8.116	3.256
6.611	2.947
6.666	2.954

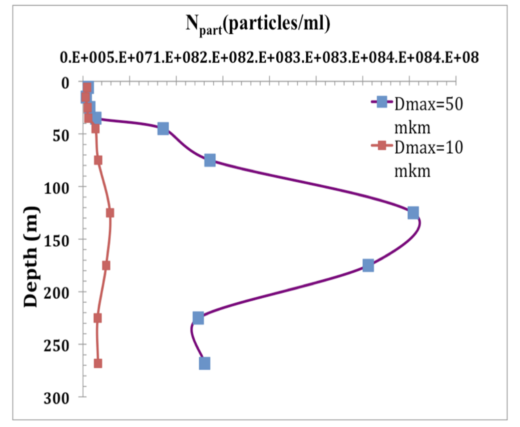
$$Q_c = 2 - 4\exp(-\rho\tan\xi)\left[\frac{\cos\xi\sin(\rho-\xi)}{\rho} + \left(\frac{\cos\xi}{\rho}\right)^2\cos(\rho-2\xi)\right] + 4\left(\frac{\cos\xi}{\rho}\right)^2\cos 2\xi$$

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



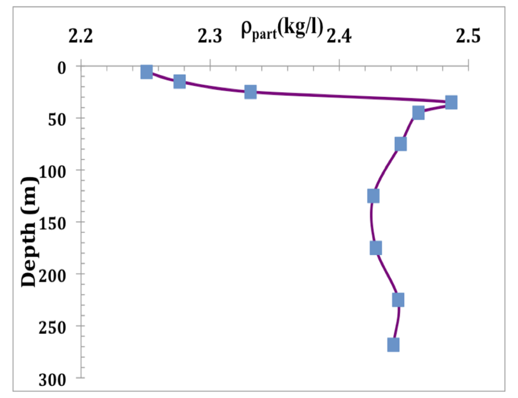
$C_V(Q_a)$	$C_V(Q_a)$
4.773E-07	6.088E-07
4.467E-07	5.653E-07
3.577E-07	4.173E-07
2.997E-07	2.354E-07
7.058E-07	2.580E-07
9.146E-07	2.706E-07
1.296E-06	3.135E-07
1.322E-06	3.012E-07
8.610E-07	2.676E-07
8.836E-07	2.683E-07

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



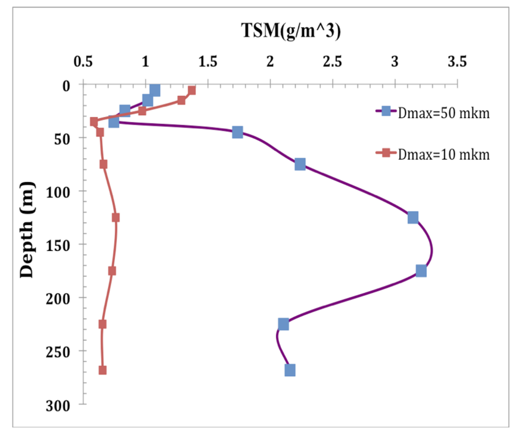
N_{part} (mL^{-3})	N_{part} (mL^{-3})
5.716E+06	4.452E+06
3.500E+06	2.788E+06
7.300E+06	4.947E+06
1.374E+07	5.623E+06
8.592E+07	1.338E+07
1.362E+08	1.629E+07
3.542E+08	2.897E+07
3.060E+08	2.483E+07
1.236E+08	1.569E+07
1.305E+08	1.605E+07

$$\rho_{part} = \frac{n_{part} - 0.7717}{0.1475}$$



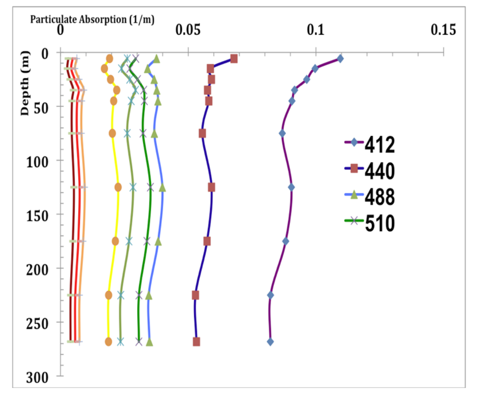
r_{part} (kg/l)	r_{part} (kg/l)
2.25	2.25
2.28	2.28
2.33	2.33
2.49	2.49
2.46	2.46
2.45	2.45
2.43	2.43
2.43	2.43
2.45	2.45
2.44	2.44

$$TSM = \rho_{part} C_v$$



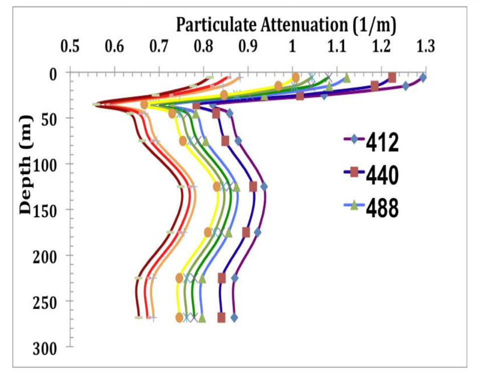
TSM (g/m^3)	TSM (g/m^3)
1.074E+00	1.370E+00
1.017E+00	1.287E+00
8.339E-01	9.728E-01
7.452E-01	5.854E-01
1.737E+00	6.349E-01
2.239E+00	6.623E-01
3.144E+00	7.607E-01
3.210E+00	7.314E-01
2.106E+00	6.544E-01
2.158E+00	6.552E-01

Displaying Absorption



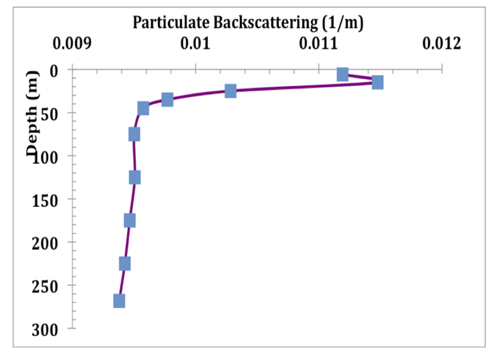
$a_p(412)$
0.110
0.100
0.096
0.092
0.091
0.087
0.090
0.088
0.082
0.082

Displaying Attenuation



$c_p(412)$
1.280
1.239
1.079
0.826
0.870
0.891
0.953
0.938
0.885
0.885

Displaying Backscattering



$b_p(412)$
1.171
1.140
0.982
0.734
0.780
0.804
0.862
0.850
0.803
0.803

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.

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.

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