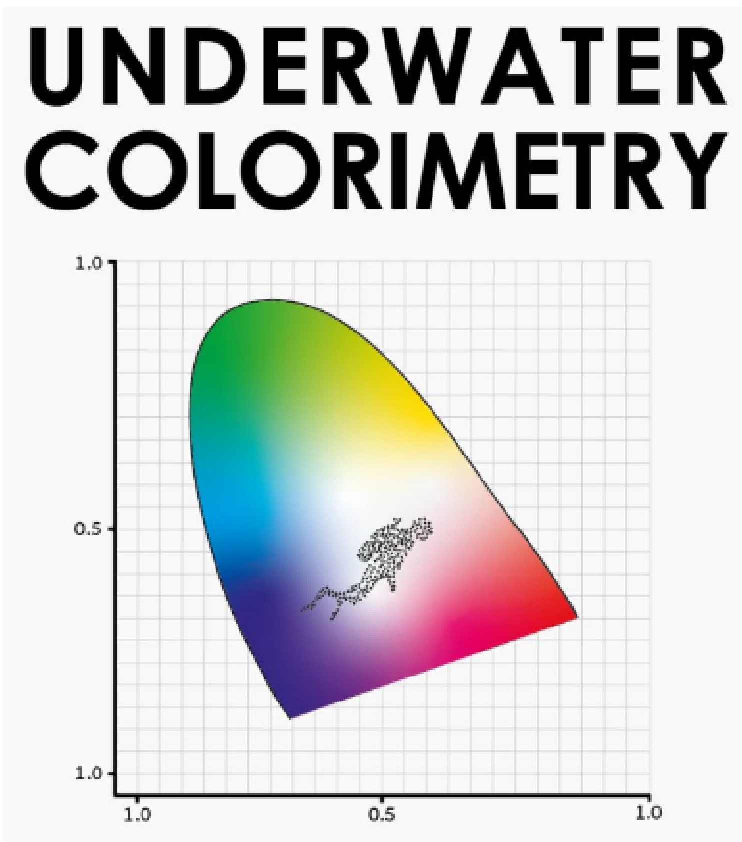
Underwater Colorimetry
Lab 4

University of Haifa

January 2025



THE INTERUNIVERSITY INSTITUTE FOR MARINE SCIENCES IN EILAT

Underwater Image Formation

In this lab we will work with the underwater image formation model to gain intuition about the governing concepts.
As we saw in the lecture, the integral form of the underwater image formation model goes as follows:

$$I_c = \overbrace{\int_{\lambda_1}^{\lambda_2} \left[\rho(\lambda)E_0(\lambda)e^{-K_d(\lambda)D} \cdot e^{-c(\lambda)z}\right] \cdot S_c(\lambda)d\lambda}^{\textit{Direct signal } (D_c)} + \underbrace{\int_{\lambda_1}^{\lambda_2} \left[\frac{b(\lambda)}{c(\lambda)}E_0(\lambda)e^{-K_d(\lambda)D}(1 - e^{-c(\lambda)z})\right] \cdot S_c(\lambda)d\lambda}_{\textit{Backscatterd signal } (B_c)}$$

Where:

$S_c(\lambda)$ – *Sensor sensitivity*
$\rho(\lambda)$ – *Target reflectance*
$E_0(\lambda)$ – *Ambient (diffusive) light at the surface*
$b(\lambda)$ – *Scattering coefficient*
$c(\lambda)$ – *Beam attenuation coefficient*
$K_d(\lambda)$ – *Downward Spectral diffusive attenuation coefficient*
z – *The geometric distance along viewin direction*
D – *Depth[m]*

The image formation model can be expressed using linear algebra as a matrix multiplication, as follows:

$$\boxed{I_c = RL_0A_DS_c + \Gamma L_0A_BS_c}$$

Where:

$I_c \in \{n \times 3\}$ – *RGB values of each patch (n patches in total)*
$R \in \{m \times n\}$ – *Reflectances of m patches at n wavelengths*
$L_0 \in \{diag(m \times m)\}$ – *Spectral light at the surface*
$A_D \in \{diag(m \times m)\}$ – *Attenuation of the direct signal*
$A_B \in \{diag(m \times m)\}$ – *Attenuation of the backscattered signal*
$S_c \in \{m \times 3\}$ – *Spectral sensitivities of the camera's channels*
$\Gamma \in \{1 \times m\}$ – *Hadamard product of:* $b(\lambda)$ *and* $\frac{1}{c(\lambda)}$

Lab objectives:

1. Gaining experience working with the underwater image formation model.
2. Gaining intuition about the diffuse downwelling attenuation coefficient $K_d(\lambda)$.
3. Experimenting with optically different, simulated, water types.

Required equipment:

1. Laptop
2. MATLAB or Python

Provided data:

Underwater Colorimetry GitHub Repository

Download the repository as a .zip file. It is very important to place the repository in a folder whose path **does not** contain any spaces or special characters!

Provided File	**Comment**
`Canon_1Ds-Mk-II.csv`	Spectral sensitivities of a Canon camera.
`DGKColorChart.mat`	MATLAB struct containing reflectances and XYZ values of each patch in a DGK color chart.
`DGKcolorchart_reflectances.csv`	Patch reflectances of DGK color chart.
`illuminant-D65.csv`	Lighting conditions.
`Jerlov_b.csv`	Scattering coefficient of Jerlov water types.
`Jerlov_c.csv`	Beam attenuation coefficient of Jerlov water types.
`Jerlov_Kd.csv`	Diffuse downwelling attenuation coefficient of Jerlov water types.

Table 1: Provided files and their descriptions.

Before starting the lab we will first upload all required data to MATLAB (or Python)

Lab Report Due

Sunday 26.1.25 at 9:00 am, by email to Amir

amirhadadad@gmail.com

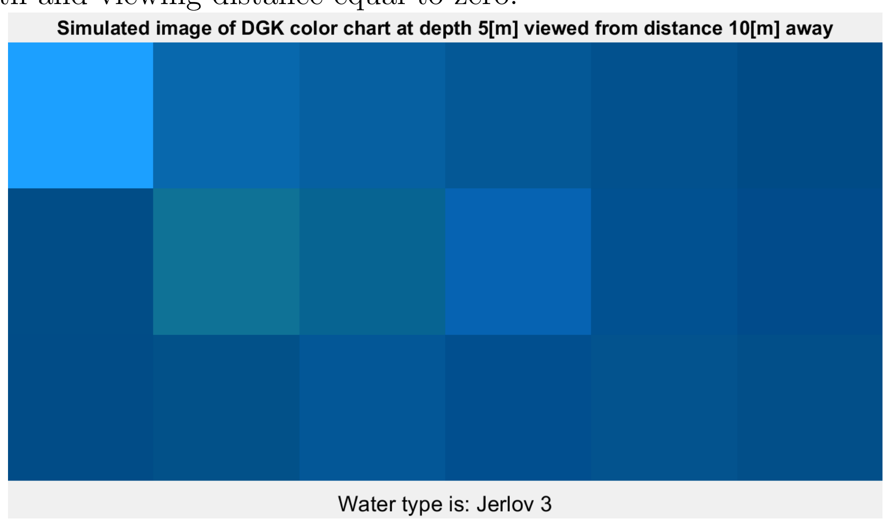
Exercise 1

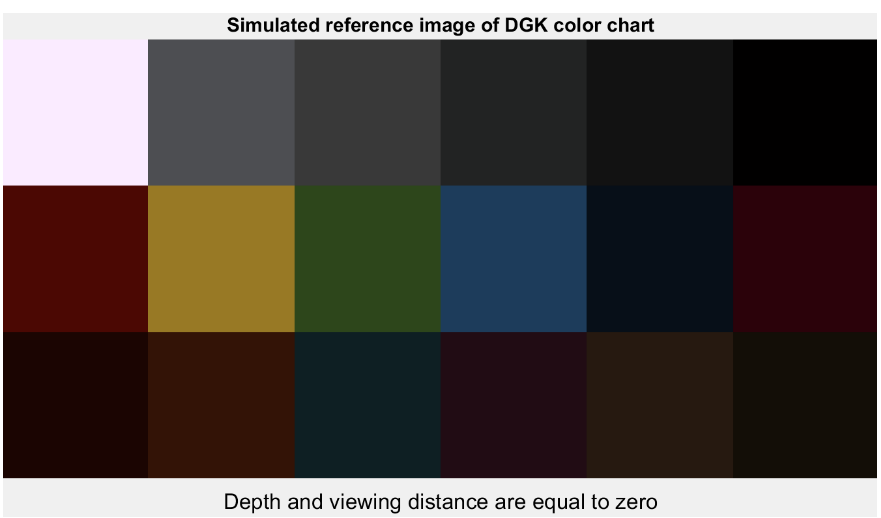
Simulating DGK color chart underwater

In this first exercise, we will simulate our DGK color chart as it would have appeared underwater. In order to do so, we will use illuminant D-65 as ambient light field and the Canon_1Ds-Mk-II camera sensitivities.
Next step that we need to do is to optically define the water body, for that we will use the optical properties of 8 different water types from Jerlove's data-set.
Lastly, we need to define the viewing geometry, i.e. how deep is the color chart and how far it is from our camera.

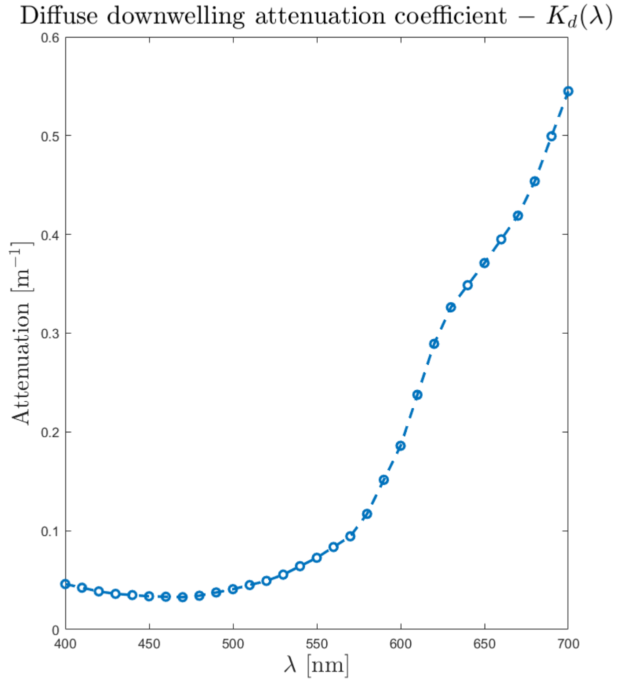
Include in your report - Exercise 1

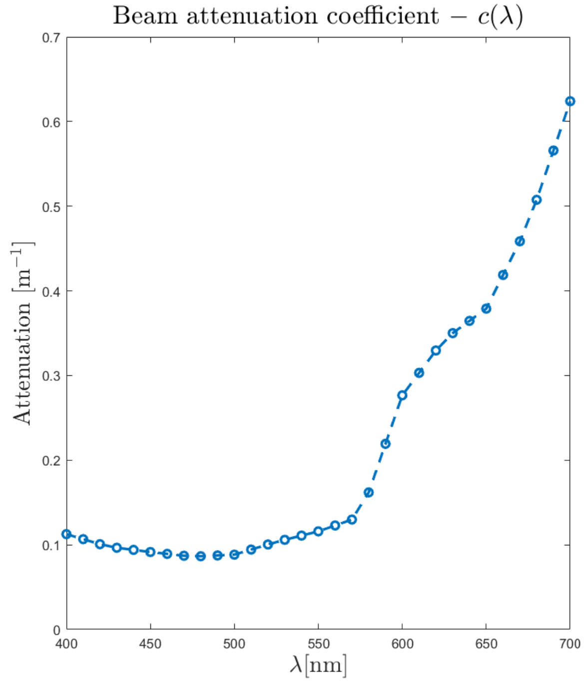
Visualize our DGK color chart under several conditions, experiment with **AT LEAST** 3 different [water type - depth - viewing distance] combinations. Also include a reference image at depth and viewing distance equal to zero.





Additionally, include a plot of the optical properties $K_d(\lambda)$ and $c(\lambda)$ associated with each simulated combination.





Overall you should have:

- 1 reference image at depth and viewing distance equal zero.
- 3 images simulated under 3 different combination of optical conditions and viewing geometry.
- 3 plots of $K_d(\lambda)$ and $c(\lambda)$ for each simulated image.

Discuss (in one paragraph!):

1. How do the attenuation coefficients, especially $K_d(\lambda)$, explain the resulted patch colors in the images?
2. How do depth and viewing distance affect the color of the patches? Can you tell which affects the most?

Exercise 2

Direct signal (D_c) and Backscatter (B_c)

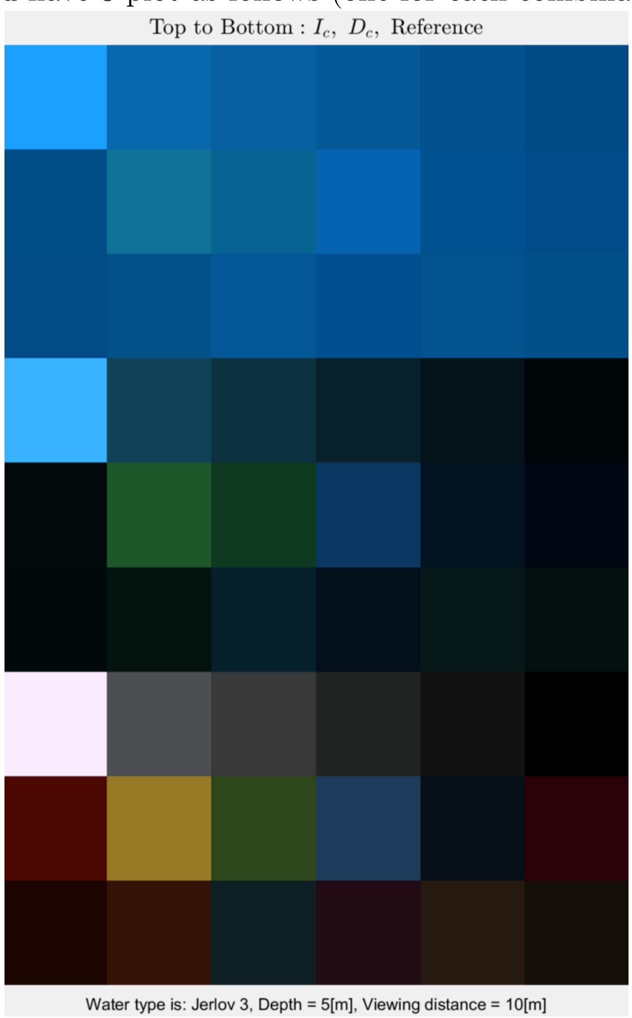
After obtaining simulated underwater images, lets explore the effects of light interacting with water. As we saw in the lectures, the underwater water image (I_c) generally has 2 components:

- The direct signal D_c
- The backscattered signal B_c

In this exercise, we will see how the direct signal attenuates underwater and how the backscattered signal is added to the image when the viewing distance increases.

Include in your report - Exercise 2

Use the same 3 combinations from exercise 1 and display for each image (I_c) only the direct signal (D_c). You should have 3 plot as follows (one for each combination):



Discuss your results, 1 paragraph max!

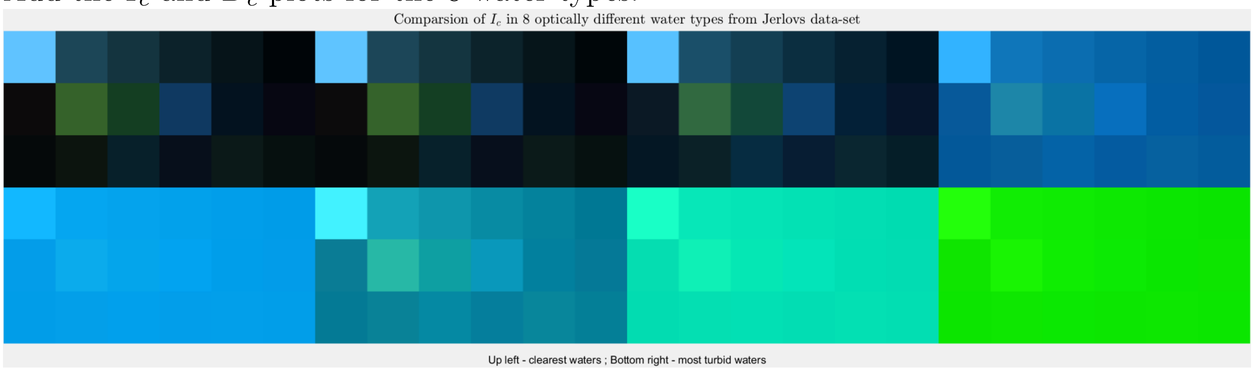
Exercise 3

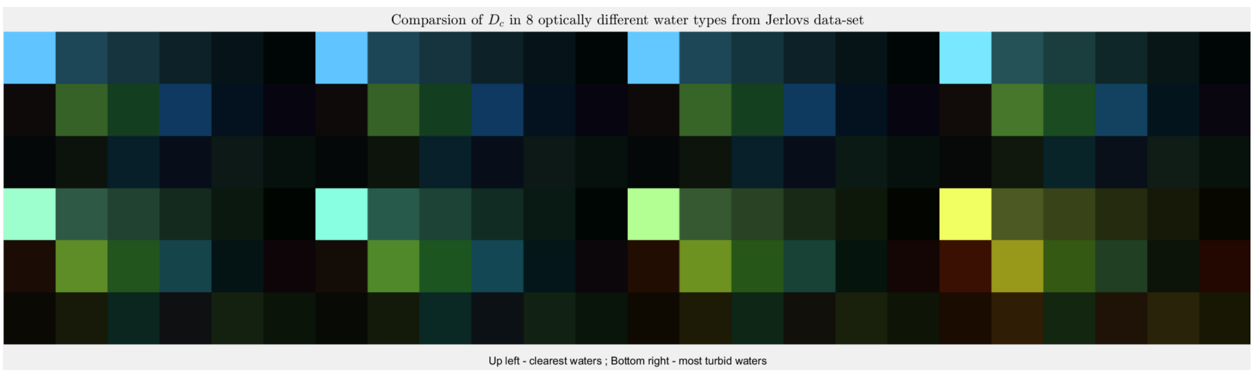
Optical comparison of different water types (Jerlov)

Now lets do overall comparison between all of the water types we have available to use (8 in total). In order to do so, we will plot 2 figures with 8 simulated DGK images in each, one for each water type.
Experiment with water type, depth and viewing distance to capture a set-up at which all, or most, patches are visible.

Include in your report - Exercise 3

Add the I_c and D_c plots for the 8 water types:





In one paragraph per question, discuss:

1. Why does the direct signal (D_c) attenuate differently in each water type? Why same patches under the same illuminant and viewing geometry appears so differently?
2. Why the backscattered signal (B_c) under the same illuminant and viewing geometry appears so differently?

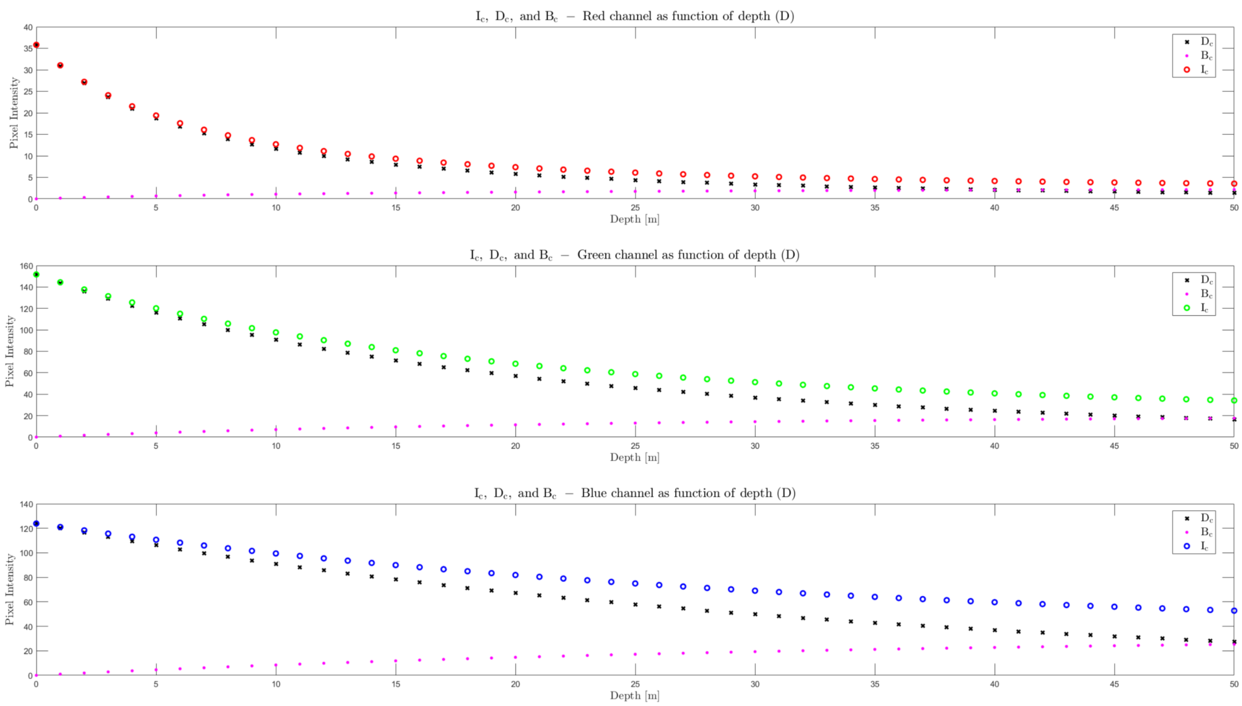
Exercise 4

RGB's (I_c) as function of viewing distance (z)

In this exercise we will dive deeper to examine the simulated RGB values rather then the full image in water types 1,2,3 and 8. We will plot the RGB values as function of distance for each one of the specified water types and try to understand the results.
Initially we will plot the RGB values of the white patch, then experiment with different patches and write about your results!

Include in your report - Exercise 4

1. You should have 4 plots RGB(white patch) vs. distance, choose 1 of them and show it on the report.



   Don't forget to specify the viewing distance you used!

2. Try different patches other then white and include at least another figure from different patch but **keep the viewing distance the same**.

Discuss:

1. What would you expect to see in the interception point between D_c and B_c? Why?

2. Why the graphs of the red, green and blue channels appear different vs. distance?

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