Modeling Underwater Light Transmission: Turbidity Effect

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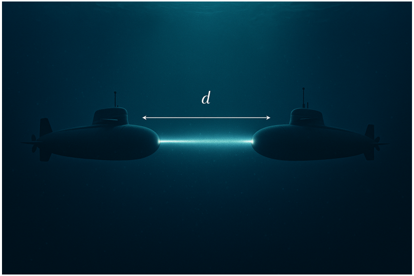
Concept Overview

Why it matters:

- Underwater laser links enable secure, high-speed communication.



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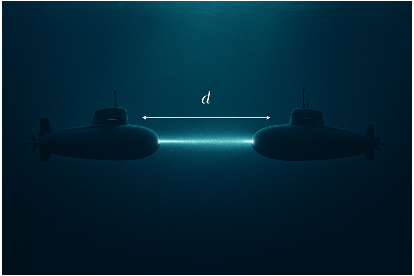

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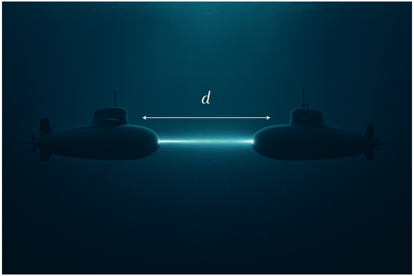
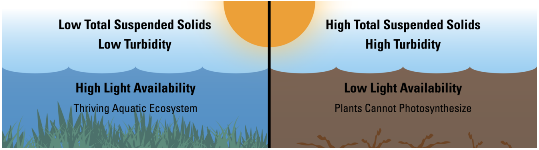


- Performance depends on some factors like water clarity, turbulence.
- Turbidity is the cloudiness or haziness of a fluid caused by large numbers of individual particles that are generally invisible to the naked eye, similar to smoke in air. A number of things contribute to water turbidity- *Absorption and Scattering*.

Jerlov's Classification of Water Turbidity



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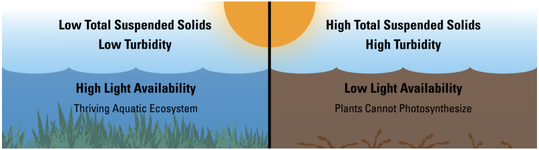

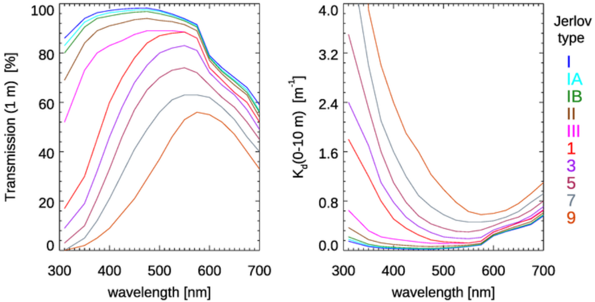

Figure: Jerlov I-9C (Clear to turbid)

Simulation Approach

Beer–Lambert law (same-depth): For a path length d and wavelength λ, $I(d, \lambda) = I_0 \exp\big(-K_d(\lambda)\, d\big)$,
and the deterministic channel transmittance is

$$T_c(d, \lambda) = \frac{P_{\text{received}}}{P_{\text{transmitted}}} = \exp(-K_d(\lambda)\, d).$$

$$T = \frac{I}{I_0} \sim \mathcal{N}(\mu, \sigma^2), \quad \mu = \exp(-K_d d), \quad \sigma = \eta\mu$$

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- Wavelengths: 450–550 nm

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- η: heterogeneity scaling

Transmittance vs distance

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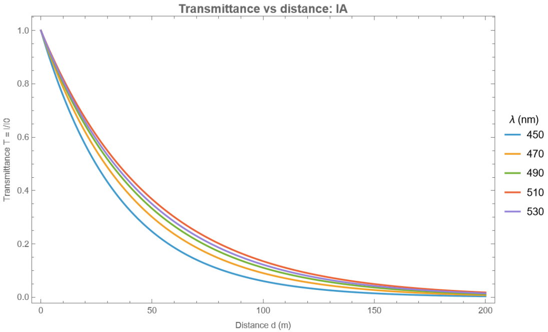
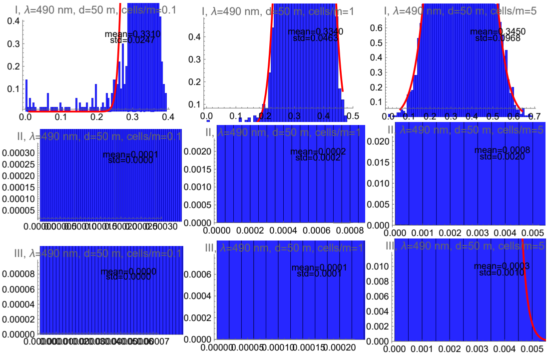
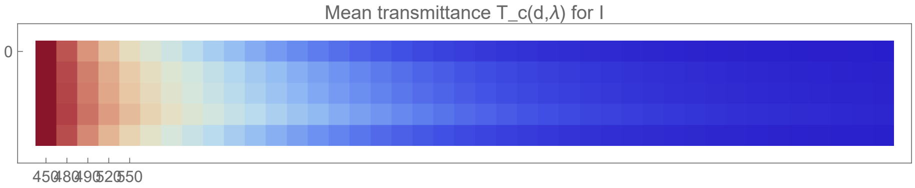


Probability Distribution of I/I_0



Heatmaps across Jerlov types



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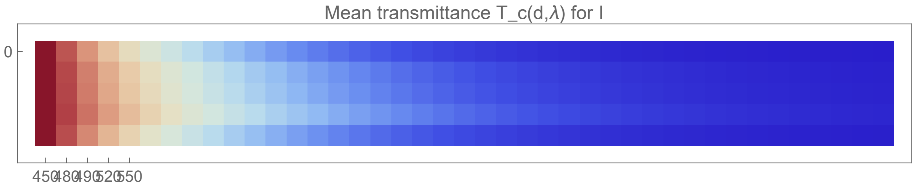

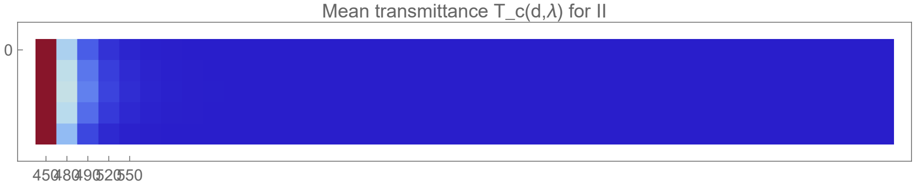

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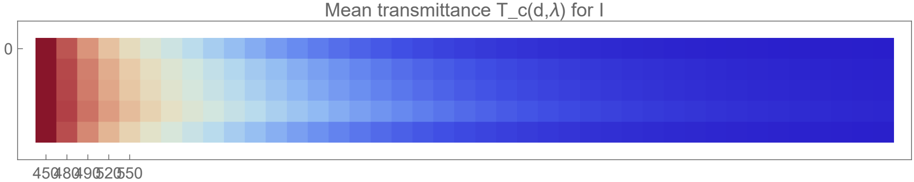

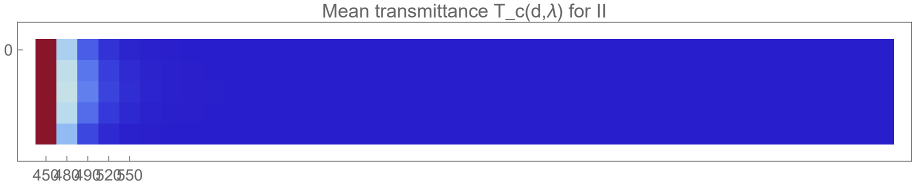

Clear waters retain beam intensity longer; turbid waters attenuate rapidly.

Next Steps

- Separate absorption and scattering effects.

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Acknowledgements

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