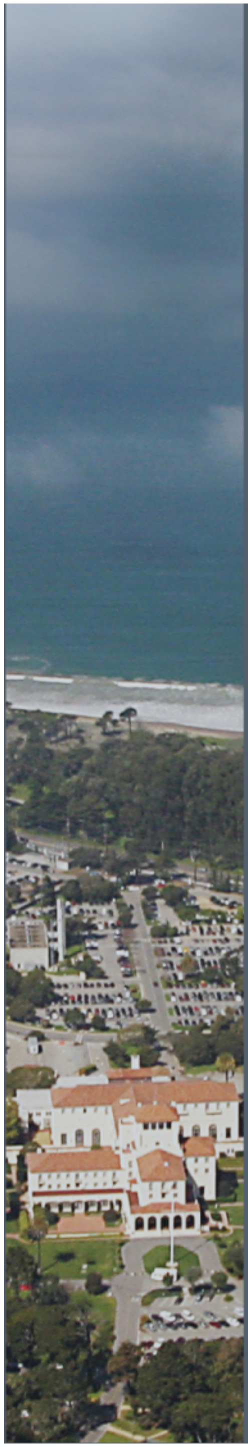

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ENVIRONMETAL EFFECT ON UNDERWATER OPTICAL TRANSMISSION

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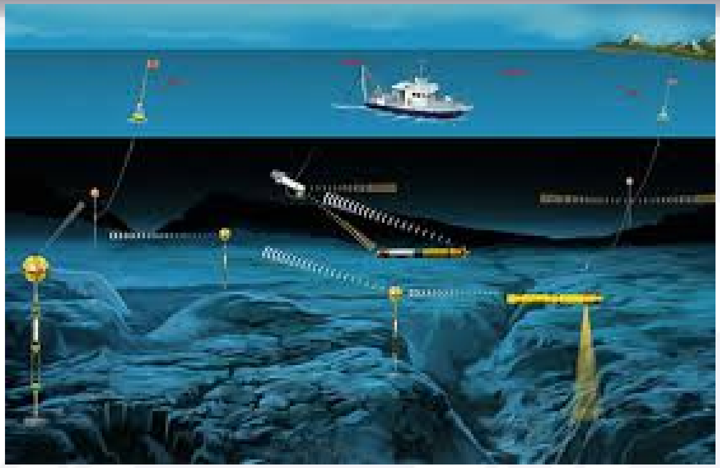
Effect of Ocean Environment on Underwater Communication and Detection

- Optical communication/detection systems are an alternative to acoustics
- The ocean optical properties are highly variable and depend on ocean environment
- Absorption and scattering by seawater and particles including chlorophyll-a causes light attenuation.

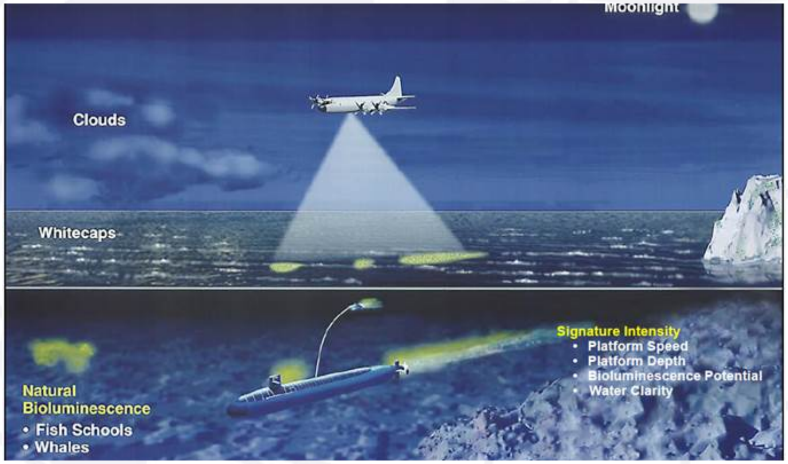
Radiative Transfer Equation

$$\left[\frac{1}{v}\frac{\partial}{\partial t}+\mathbf{s}\cdot\nabla+c(z)\right]L(t,r,\mathbf{s})=b(z)\int_{2\pi}\beta(\mathbf{s},\mathbf{s}')L(t,r,\mathbf{s}')d\Omega'$$

$$+\ E(t,\mathbf{r},\mathbf{s})$$



http://www.whoi.edu/page.do?pid=119416&tid=3622&cid=163149



http://www.aticourses.com

OPNAV-N97 Interest

Development of transfer and correlation functions that relate measurements of one type to another (e.g., mixed layer depth and Lidar optical penetration depth) that could be used to infer profiling data using hull-mounted sensors without having the submarine make a vertical excursion.

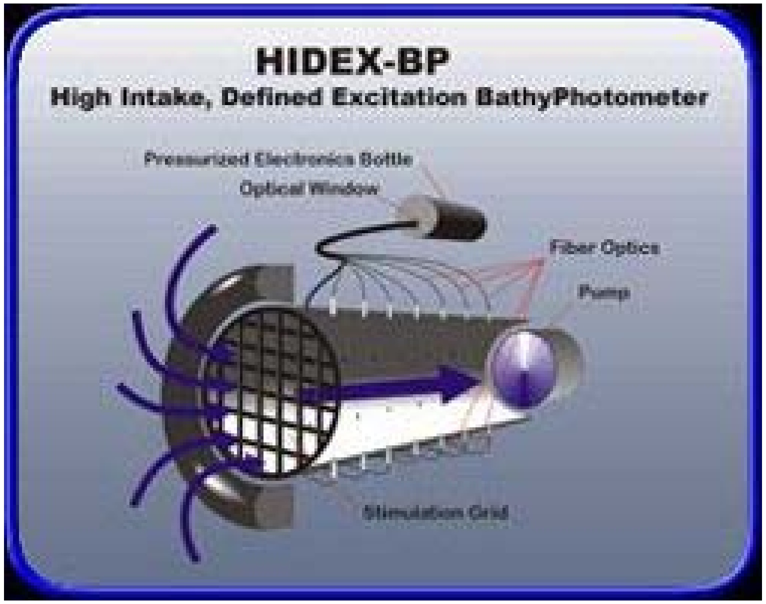
Outlines

- (1) Data Analysis: establishment of relationship between optical parameters (absorption, scattering, and attenuation coefficients) and ocean environment (T, S, Chl-a, …) from glider and shipboard observations in the Arabian Gulf, Gulf of Oman, Adriatic Sea, and East Asian Marginal Seas

- (2) Modeling: identify underwater optical path loss through solving the underwater radiative transfer equation (RTE)

(1) Data Analysis

Ship Board Observation -HIDEX-BP

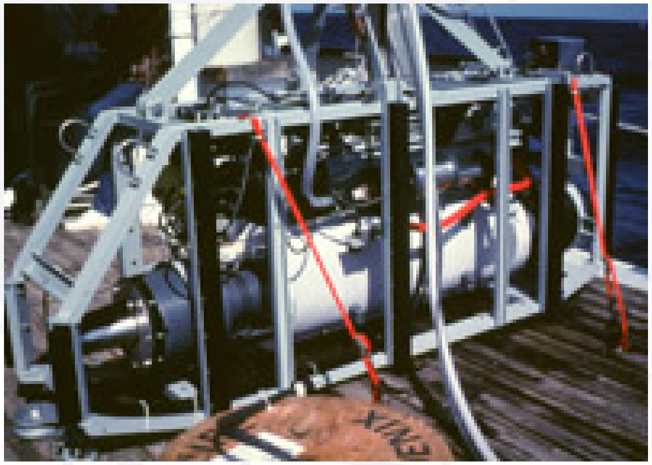


From http://www.teamorca.org/cfiles/biolum_study.cfm

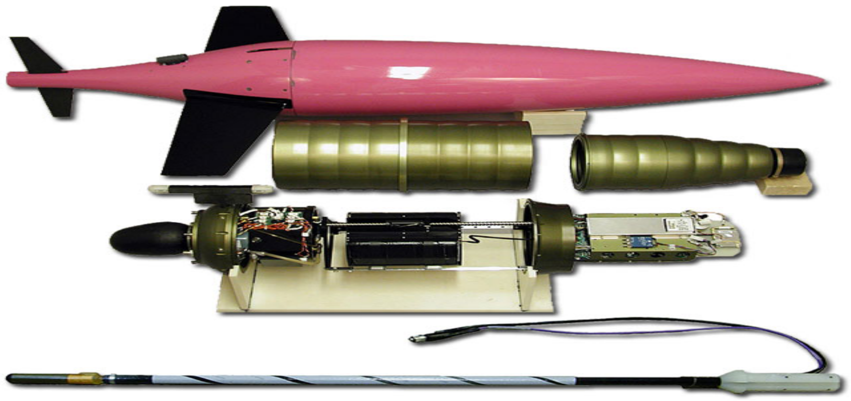
- A vertical profiler
- High intake flow (up to 35L/s)
- Long residence time
- Faster profile rate, 200-meter HIDEX profiles takes 20 minutes to complete.

- Environmental instrumentation includes:

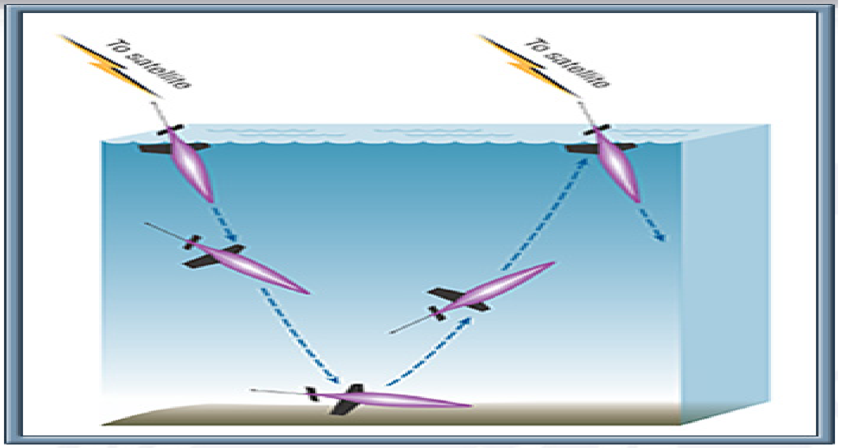
1. A Sea Bird model SBE CTD
   Measure temperature (ºC), salinity (PSU), and depth (m).
2. A Chelsea Mk II Aquatracka fluorometer
   Measure chlorophyll-a fluorescence (μg/L) at wavelength 676 nanometers (nm).
3. A Sea Tech 25 cm pathlength transmissometer
   Measure red light (670 nm) transmission (%).
4. APL (Applied Physics Laboratory) 1 m pathlength transmissometer
   Measure blue light (490 nm) transmission (%).



Instrumentation on Glider



From SEAGLIDER Fabrication Center. seaglider.washington.edu



From Applied Physics Laboratory www.apl.washington.edu

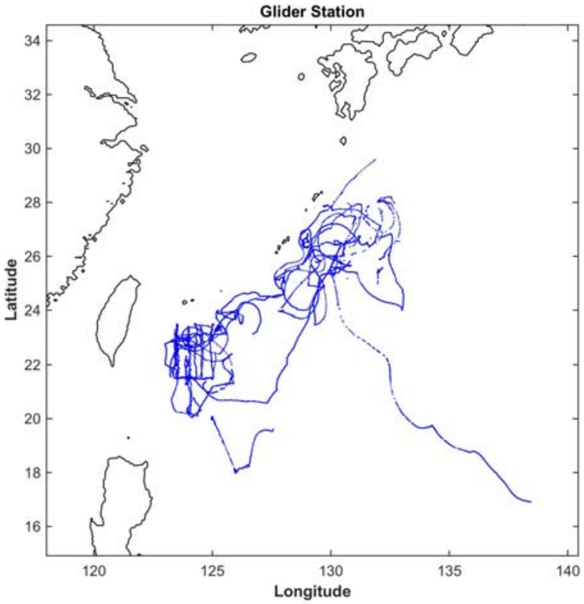
- Profiles from surface to 1500m
- Buoyancy engine produces slight buoyancy changes to induce pitched upward or downward gliding. Internal battery pack is shifted side to side to facilitate turning.
- Uses Iridium LEO system to obtain GPS fixes, upload data, and receive command and control instructions from NAVO Glider Operations Center (GOC).

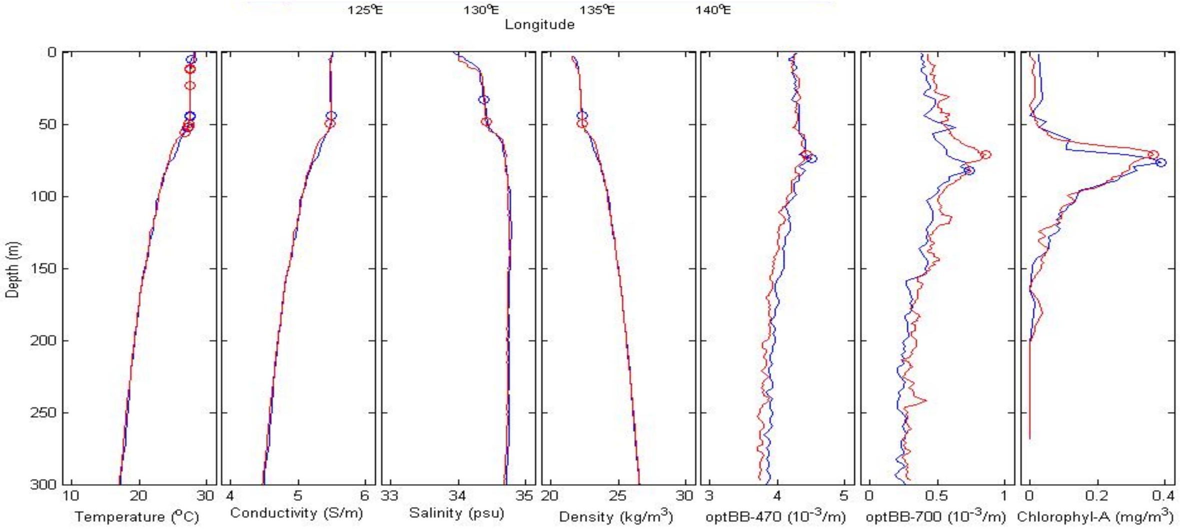
<u>Instrumentation</u>

1) Seabird Electronics' SBE 41 CTD sensor
- 1 Hz sample rate
- T accurate to .001 degrees C
- Salinity accurate to .005 PSU*
- Pressure accurate to 2 dbar*

2) WET Labs, Inc ECO bb2fl optical sensor
- Optical Backscatter @ 470nm and 650nm*
- Fluorimeter: Chlorophyll-A @ 470 nm*
- Samples in top 300m to preserve battery life

Example – One Cycle Downward/Upward Profiles



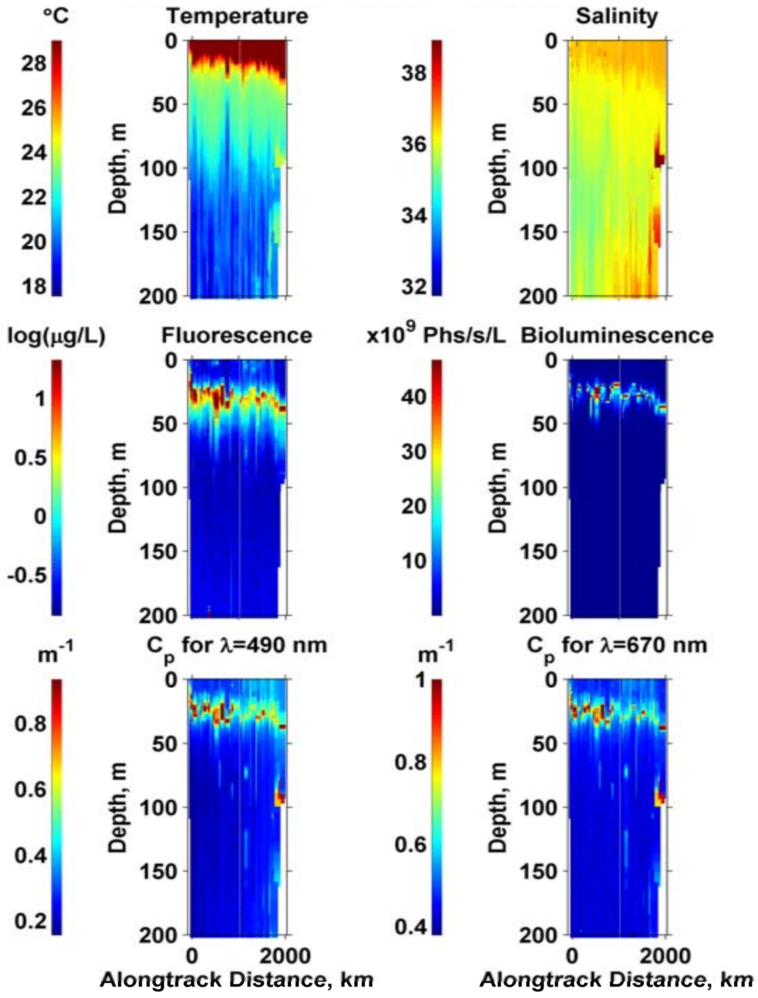


Example -Along the Ship Track in the Arabian Gulf

- (T, S) ←→ Optical Parameters

Fluorescent Chlorophyll →

Cp → Beam Attenuation Coefficient



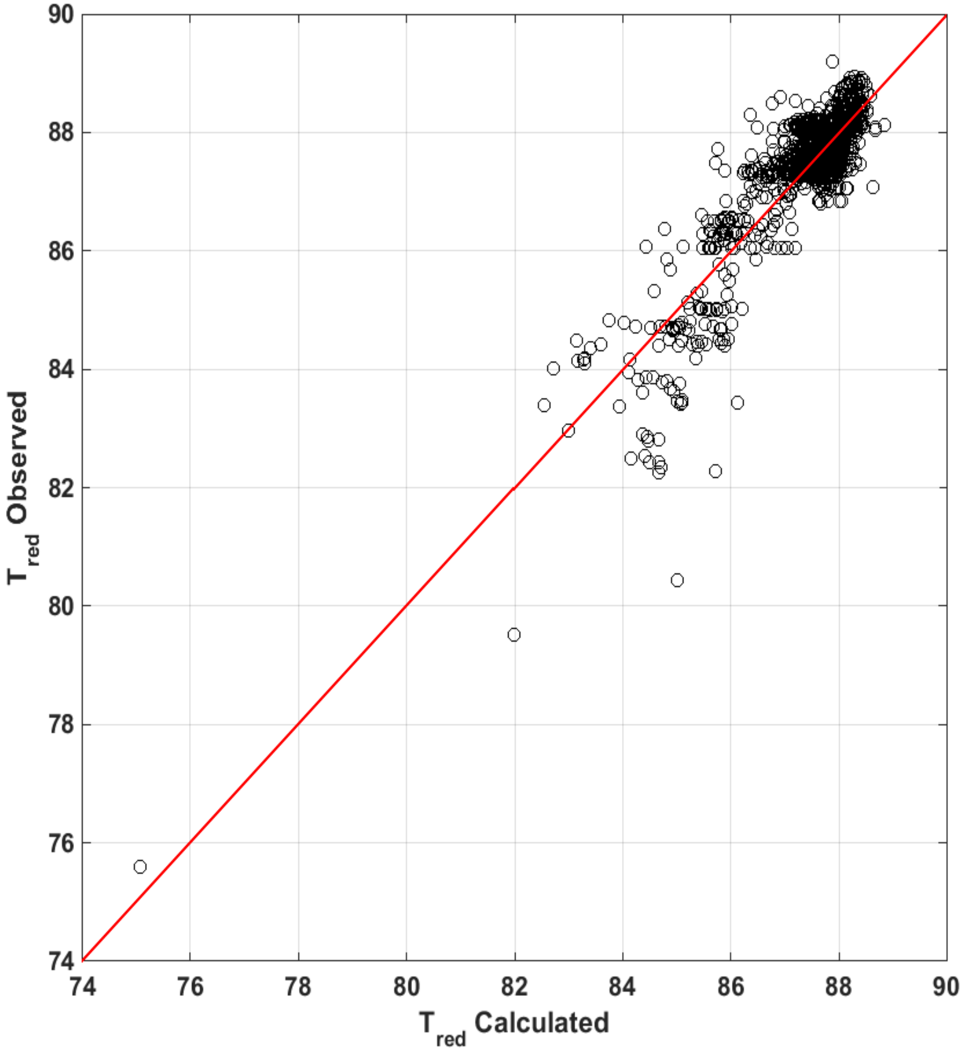
Optical Parameters ←→ Ocean Environment

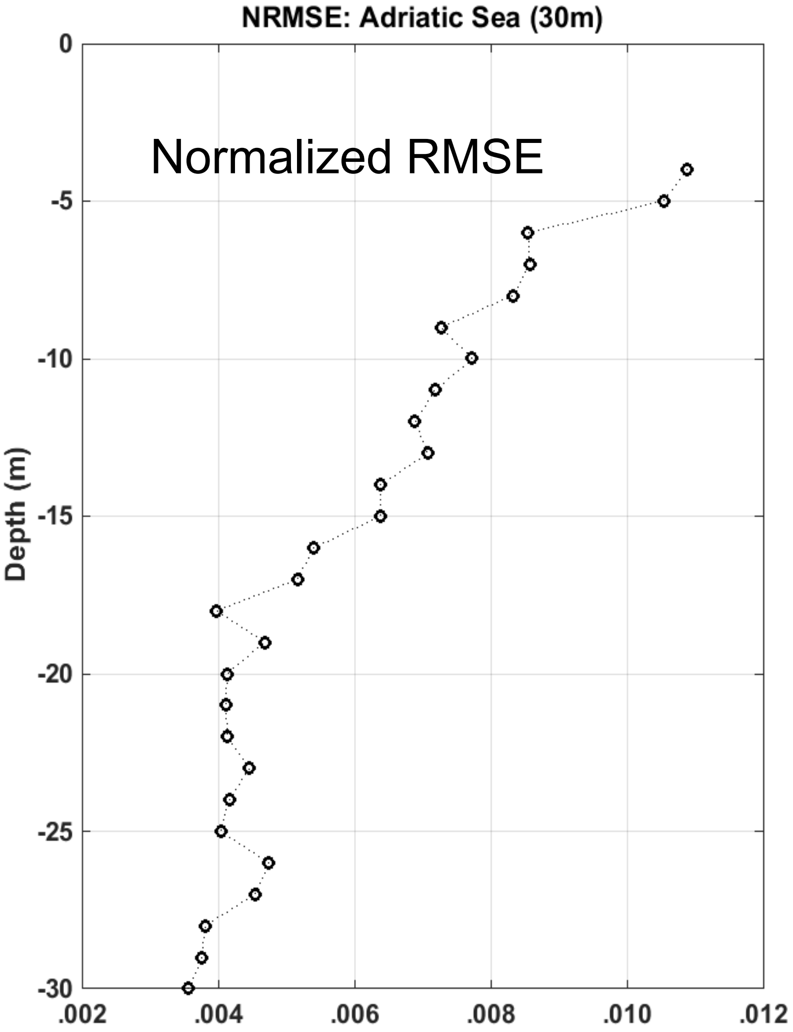
$$\text{Transmittance}(z) = a_0 + a_1 T(z) + a_2 S(z) + a_3 B(z) + a_4 \text{Chl}_F(z)$$

$$\text{Transmittance}(z) = \begin{cases} T_{670} \rightarrow T_{red} \\ T_{490} \rightarrow T_{blue} \end{cases}$$

Mean NRMSE: 0.0059

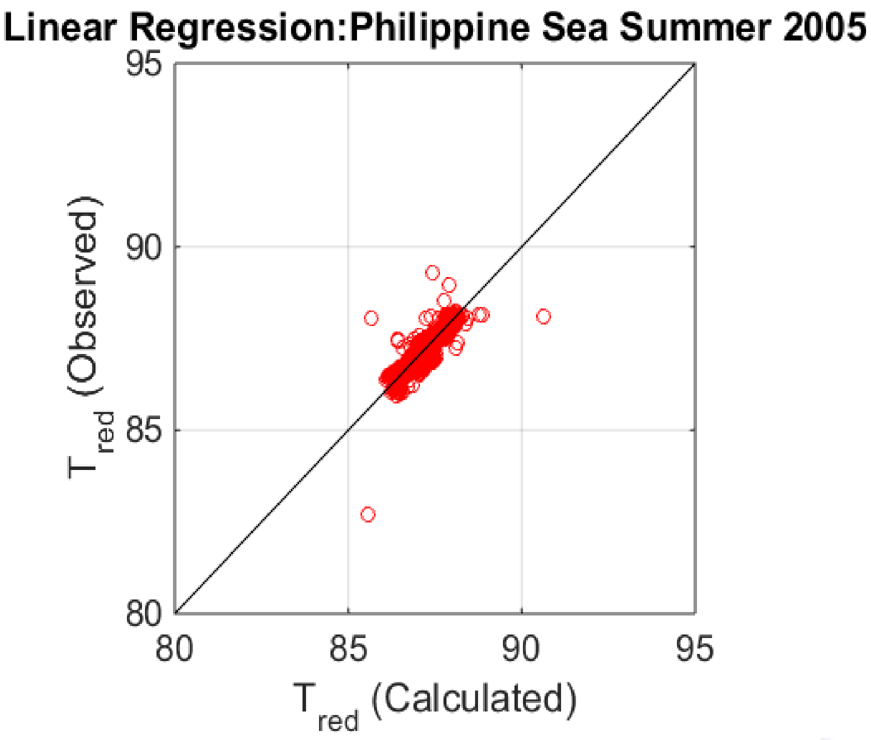
Transmittance (T_{670}) Adriatic Sea

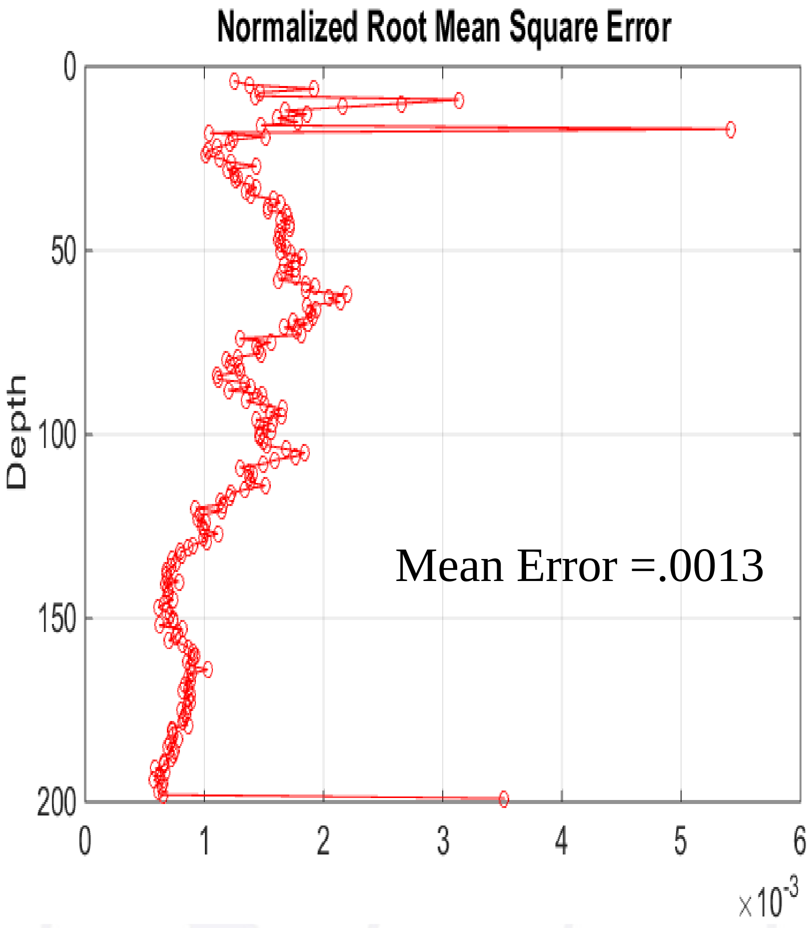




Mean NRMSE: 0.0059

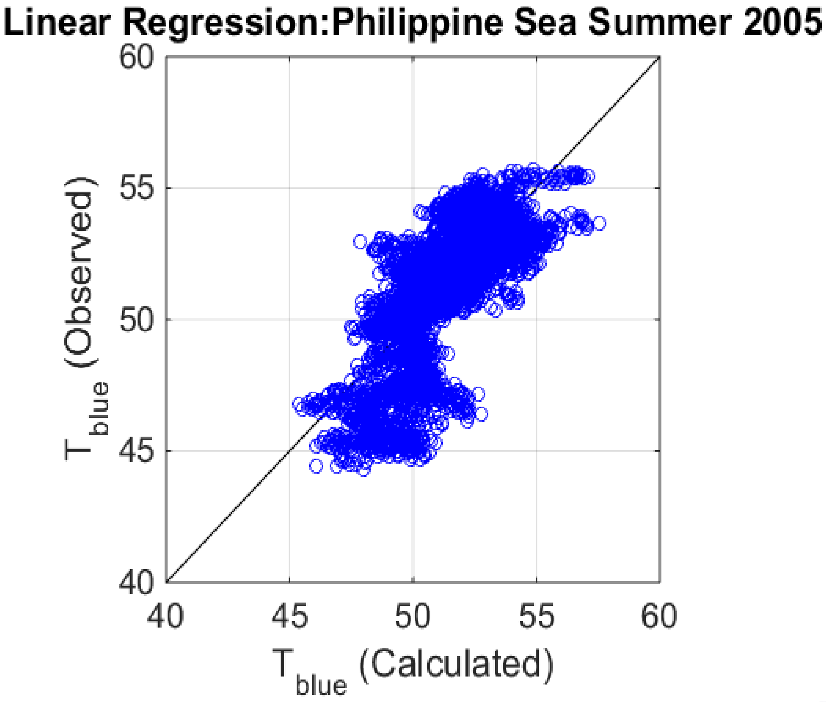
T_{670}
Philippine Sea-Summer 2005

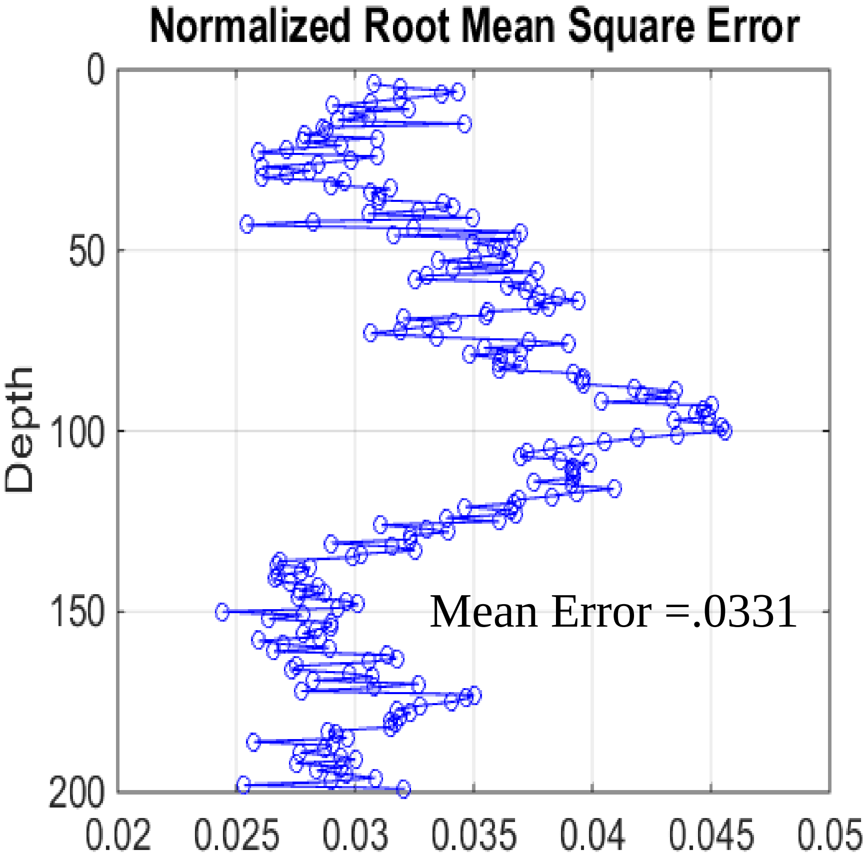




Mean Error =.0013

T_{490}
Philippine Sea-Summer 2005

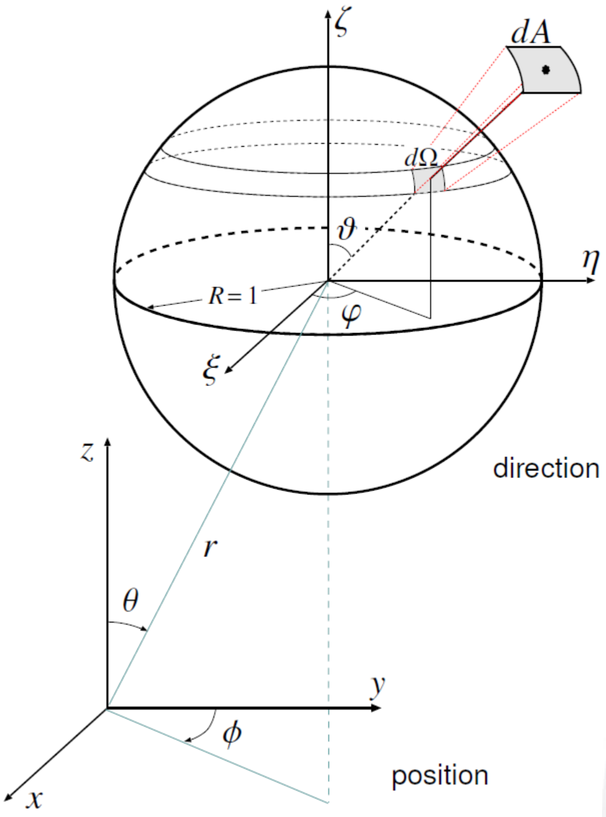


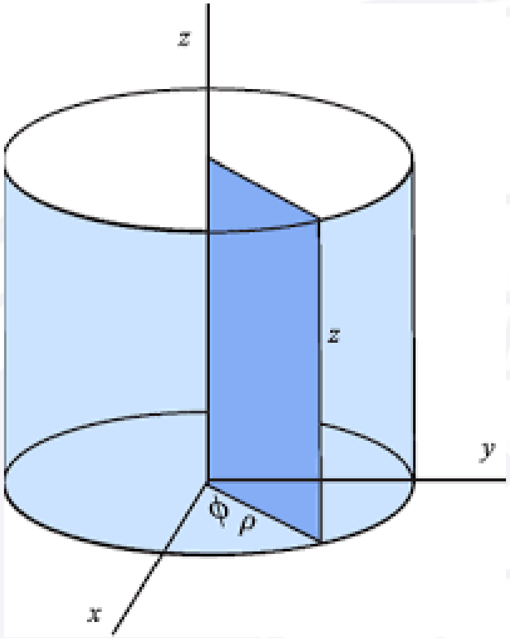


(2) Modeling:

Identify underwater optical path loss

Position and Direction





3D position (x, y, z)

2D position (ρ, z)

Azimuthal symmetry

Steady State 2-Dimensional RTE

$$\mathbf{n}\bullet\nabla L(\rho,z,\mathbf{n}) = -cL(\rho,z,\mathbf{n}) + b\int_{2\pi} \beta(\mathbf{n},\mathbf{n}')L(\rho,z,\mathbf{n}')d\mathbf{n}' + S(\rho,z,\mathbf{n})$$

L(*ρ*, *z*, **n**) is the radiance at position **r** propagating towards the direction **n**

S(*ρ*, *z*, **n**) is the source radiance

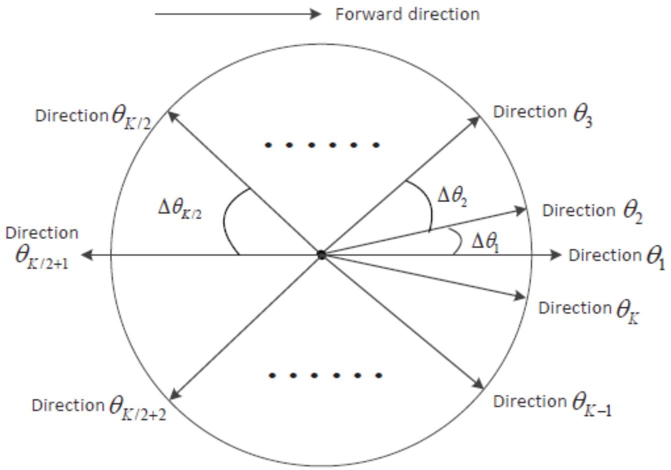
Henyey-Greenstein Phase Function

$$\beta(\mathbf{n},\mathbf{n}') = \frac{1-g^2}{2\pi(1+g^2-2g\mathbf{n}\bullet\mathbf{n}')}$$

$$\mathbf{n}\bullet\mathbf{n}' = \cos\Theta, \quad \Theta \rightarrow \text{ Scattering Angle}$$

2D RTE

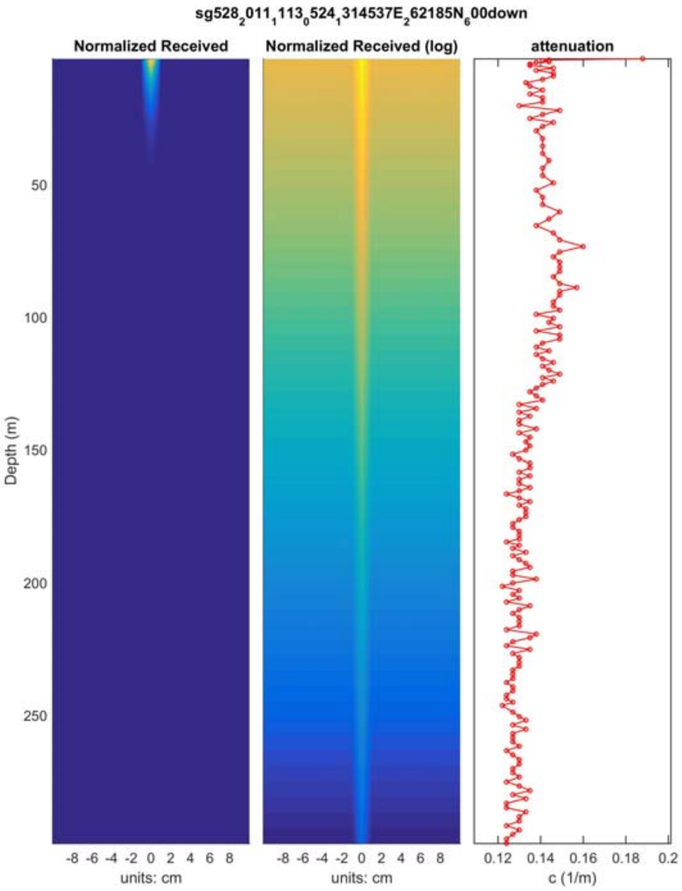
$$\sin\theta_k \frac{\partial L(\rho,z,\theta_k)}{\partial\rho} + \cos\theta_k \frac{\partial L_k(\rho,z,\theta_k)}{\partial z}$$
$$= -cL(\rho,z,\theta_k) + b\int_{2\pi} \beta(\theta_k - \theta')L(\rho,z,\theta')d\theta' + E(\rho,z,\theta_k)$$

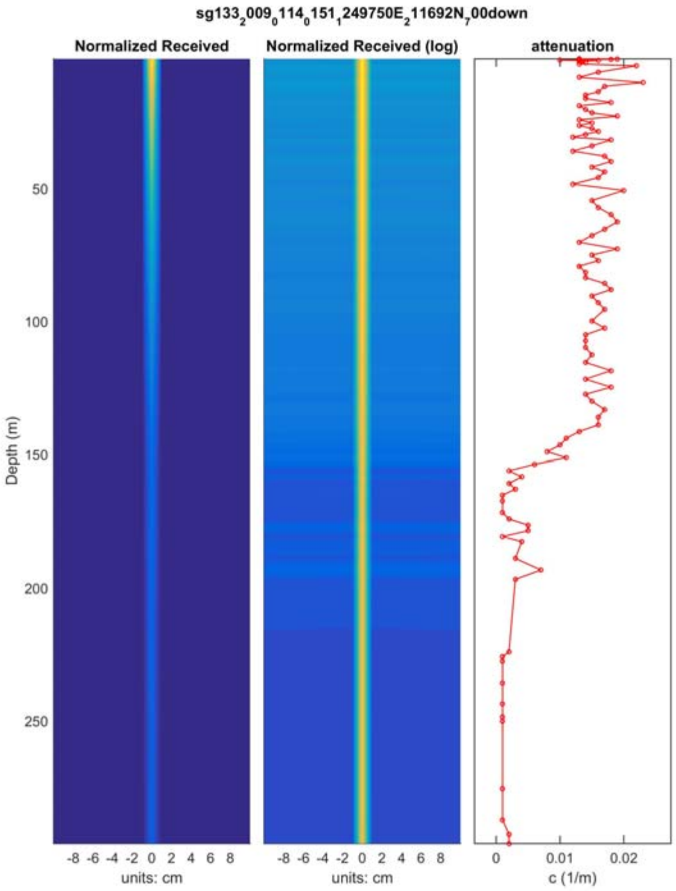


Li et al. 2015
(IEEE Wireless Communication Letters)

Integration of L over scattering angle

Light source at the Surface in the Western North Pacific





L(**r**) log [**L**(**r**)]

High *c*

L(**r**) log [**L**(**r**)]

Low *c*

Conclusions

- Relationships between (T, S, Chl,…) to the optical parameters such as absorption, scattering, and attenuation coefficients → connection between ocean environmental model and optical RTE.

- Simple 2D RTE solver is useful for identifying underwater optical transmission.

Acknowledgement

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  Oceanography Technical Director

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