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ASSIGNMENT 3

SOUND SCATTERING

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by

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Chapter 1

Introduction

When an active sonar pulse is transmitted into the water, some of the sound reflects off of the target. Additionally, there are many other sources where the sound energy may reradiate a portion of the acoustic energy incident upon them. This scattering is caused by the many sources of inhomogeneities in the ocean. These sources may include fish, air bubbles, dust or dirt as well as the ocean bottom, and surface. The above scatterers can be classified into three basically different classes depending on the reverberation they produce. Scatterers occurring in the volume or body of the sea produce volume reverberation. Scatterers on or near the surface cause surface reverberation and scatterers on or near the sea bottom produce bottom reverberation.

In this assignment we first develop a MATLAB program for computing the surface, bottom and volume reverberation coefficient. Then we plot the surface and bottom reverberation coefficients versus the grazing angle for various sets of (frequency, windspeed) and (frequency, bottom type) respectively. Finally the graph for volume reverberation versus frequency for high, moderate and low particle densities is obtained.

Chapter 2

Theory

2.1 Sound Scattering

Scattering results when sound strikes foreign bodies in the water, and the sound energy is reflected. Some reflectors are boundaries (surface, bottom, and shores), bubbles, suspended solid and organic particles, marine life, and minor inhomogeneities in the thermal structure of the ocean. The amount of energy scattered is a function of the size, density, and concentration of foreign bodies present in the sound path, as well as the frequency of the sound wave. The larger the area of the reflector compared to the sound wavelength, the more effective it is as a scatterer. Part of the reflected sound is returned to the source as an echo, i.e, is backscattered, and the remainder is reflected off in another direction and is lost energy. Back-scattered energy is known as reverberation and is divided into three types: surface, bottom and volume.

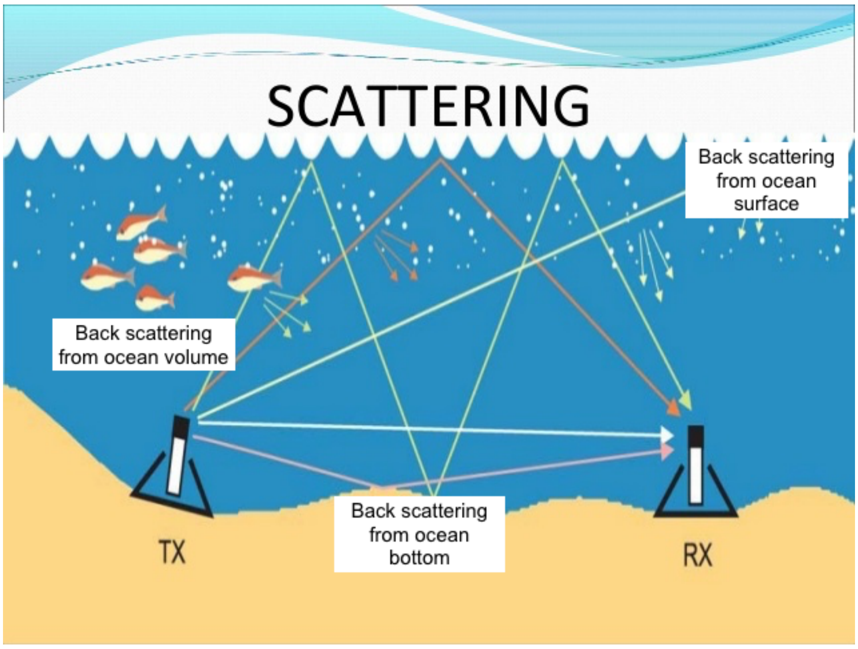
SCATTERING
Back scattering from ocean surface
Back scattering from ocean volume
Back scattering from ocean bottom
TX
RX

Figure 2.1: Different types of reverberations

2.1.1 Surface Backscattering

Surface reverberation is generated when transmitted sound rays strike the surface of the ocean, i.e., the underside of the waves. It is always a factor in active sonar operations, and is directly related to wind speed because it controls wave size and the angle of incidence. The effectiveness of active sonar is severely restricted in shallow waters because in very shallow water, severe reverberation levels may exist due to the presence of so many surfaces for the sound to reflect off. Experiments indicate that the backscattering strength of the sea surface varies with the grazing angle, sound frequency and wind speed induced roughness and that the collected measurements can be fitted by the following empirical expression

$$S_S = 10.log_{10}(10^{-5.05}.(1+v_W)^2.(f+0.1)^{\frac{v_W}{150}}.tan^{\beta}(\theta)) \tag{2.1}$$

with

$$\beta = 4.(\frac{v_W + 2}{v_W + 1}) + (2.5(f + 0.1)^{\frac{-1}{3}} - 4).cos^{\frac{1}{8}}(\theta) \tag{2.2}$$

where S_S represents the surface backscattering coefficient in $[dB/m^2]$. The parameters f, v_W and θ denote the sound frequency in kHz, the wind speed in knots and the grazing angle respectively.

2.1.2 Bottom Backscattering

Bottom reverberation occurs whenever a sound pulse strikes the ocean bottom. In deep water this condition normally does not cause serious problems, but in shallow water, bottom reverberation can dominate the background and completely mask a close target.

Sound reflected from the ocean floor usually suffers a significant loss in intensity. Part of this loss is caused by the scattering effects just described, but most of it results from the fact that a portion of sound energy will enter the bottom and travel within it as a new wave. The net result is that the strength of the reflected wave is greatly reduced. The amount of energy lost into the bottom varies with the bottom composition, sound frequency, and the grazing angle of the sound wave. The total of these losses can vary from as low as 2 dB/bounce to greater than 30 dB/bounce. In general, bottom loss will tend to increase with frequency and with the angle of incidence. Soft bottoms such as mud are usually associated with high bottom losses (10 to 30 dB/bounce); hard bottoms such as smooth rock or sand produce lower losses.

Furthermore, it could be observed that a Lambert?s law relationship between the backscattering strength and the grazing angle fits to many experimental data satisfactorily accurate for angles below 60°. Consequently, the backscattering strength can be described by Lambert's law and an empirically specified scattering coefficient, i.e.

$$S_B = K(f, bt) + 10.log_{10}(sine^2(\theta)) \tag{2.3}$$

This is valid for for $0 \leq \theta \leq 60°$. K(f, bt) denotes the scattering coefficient depending on the frequency of sound f and bottom type bt.

Due to the empirical definition of K(f, bt) it is evident that one will have considerable difficulty in determining an appropriate value for the backscattering strength in practice. Therefore, easier applicable and over the entire grazing angle domain sufficient accurate bottom backscattering models are of interest.

More accurate bottom scattering curves have been derived from measurements taken from SEARAY Model which is applicable for the frequency range of $20kHz \leq f \leq 500kHz$ and APL-UW Model which works for the frequency range of $1kHz \leq f \leq 500kHz$

For the SEARAY Model the reverberation coefficient is defined by

$$S_B = 10.log_{10}(3.03\beta\, f^{\,3.2-0.8bt}10^{2.8bt-12} + 10^{-4.42}) \tag{2.4}$$

with

$$\beta = \gamma(sin(\theta) + 0.19)^{btcos^{16}(\theta)} \tag{2.5}$$

and

$$\gamma = 1 + 125.exp(-2.64.(bt - 1.75)^2 - \frac{50}{bt}.cot^2(\theta)) \tag{2.6}$$

where f, bt and θ denote the sound frequency in kHz, the bottom type and the grazing angle respectively. And bt can be any real number satisfying $1 \leq bt \leq 4$.

2.1.3 Volume Backscattering

Volume reverberation is caused by various reflectors, but fish and other marine organisms are the major contributors. Additional causes are suspended solids, bubbles, and water masses of markedly different temperatures. Volume reverberation is always present during active sonar operations, but is not normally a serious factor in masking target echoes. The one exception involves the deep scattering layer (DSL), which is a relatively dense layer of marine life present in most areas of the ocean. During daylight hours, the layer is generally located at depths of about 600 meters and does not pose a serious problem. At night, however, the layer migrates toward the surface and becomes a major source of reverberation.

The volume reverberation can be modeled by the so-called volume reverberation coefficient.

$$S_V = S_p + 7log_{10}(f) \tag{2.7}$$

where f and $S_p$indicate the frequency in kHz and the particle contribution in $[dB/m^3]$. The particle contribution parameter S_p is $-50dB$ for high particle density, $-70dB$ for moderate particle density and $-90dB$ for low particle density.

Chapter 3

Experimental research

By using the formula for velocity of speed in ocean, the graph of velocity of speed in ocean versus depth is plotted for various values of temperature.

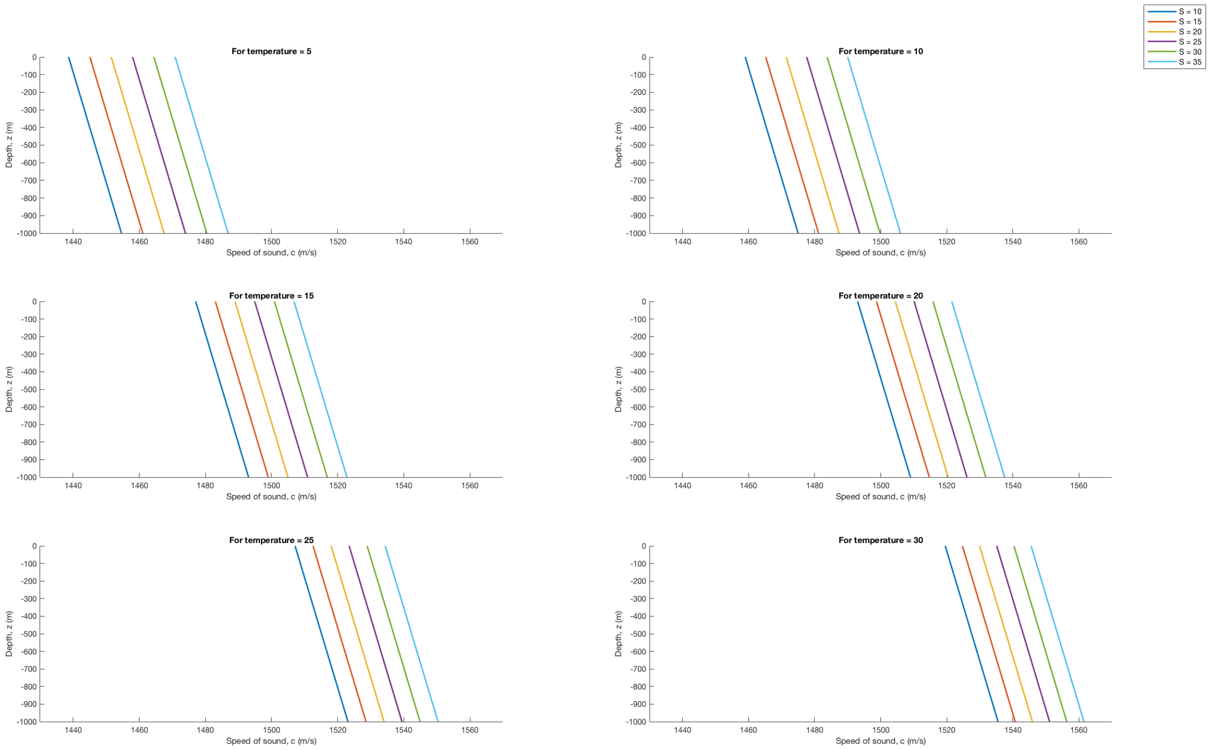

Figure 3.1: c versus z for various sets of T

By using the formula for velocity of speed in ocean, the graph of velocity of speed in ocean versus depth for various values of salinity is obtained.

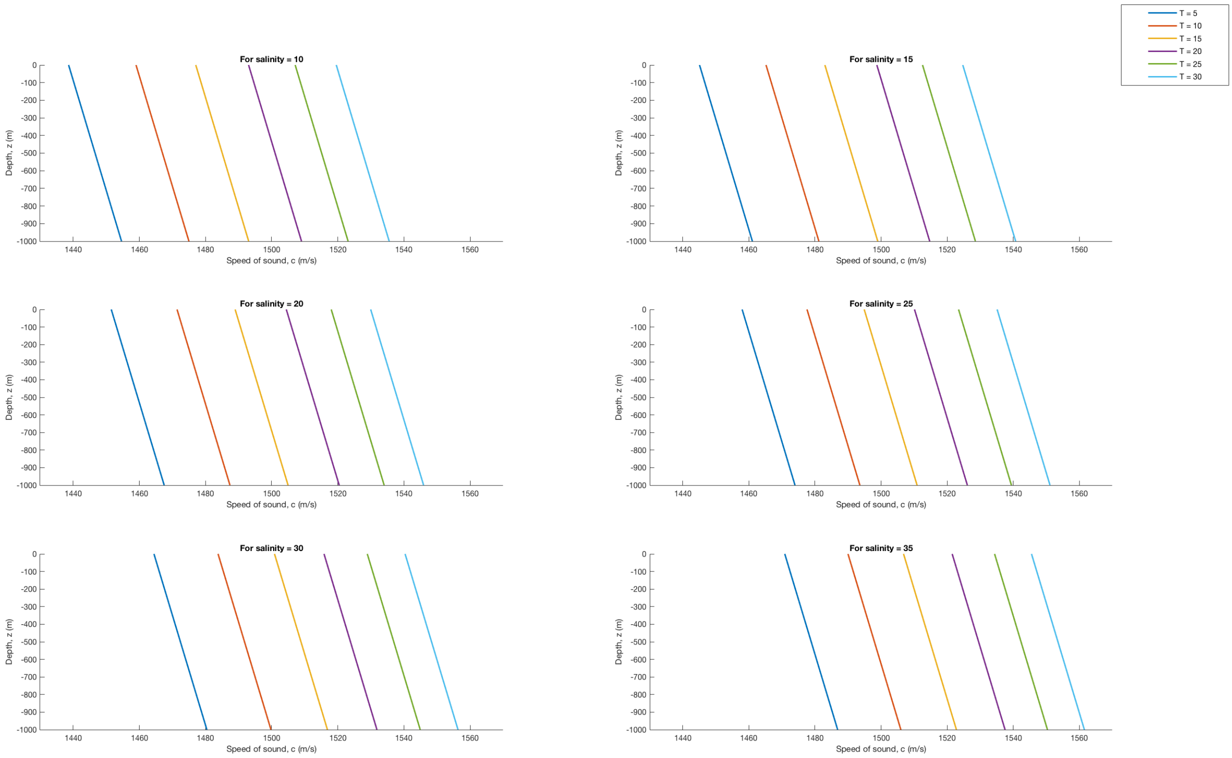

Figure 3.2: c versus z for various sets of S

The dependency of non-linear temperature profile and depth is plotted using an exponential function for temperature. The plot contains of three curves: temperature versus depth, sound velocity (having constant salinity and temperature) versus depth and sound velocity (having expoenential temperature and constant salinity) versus depth.

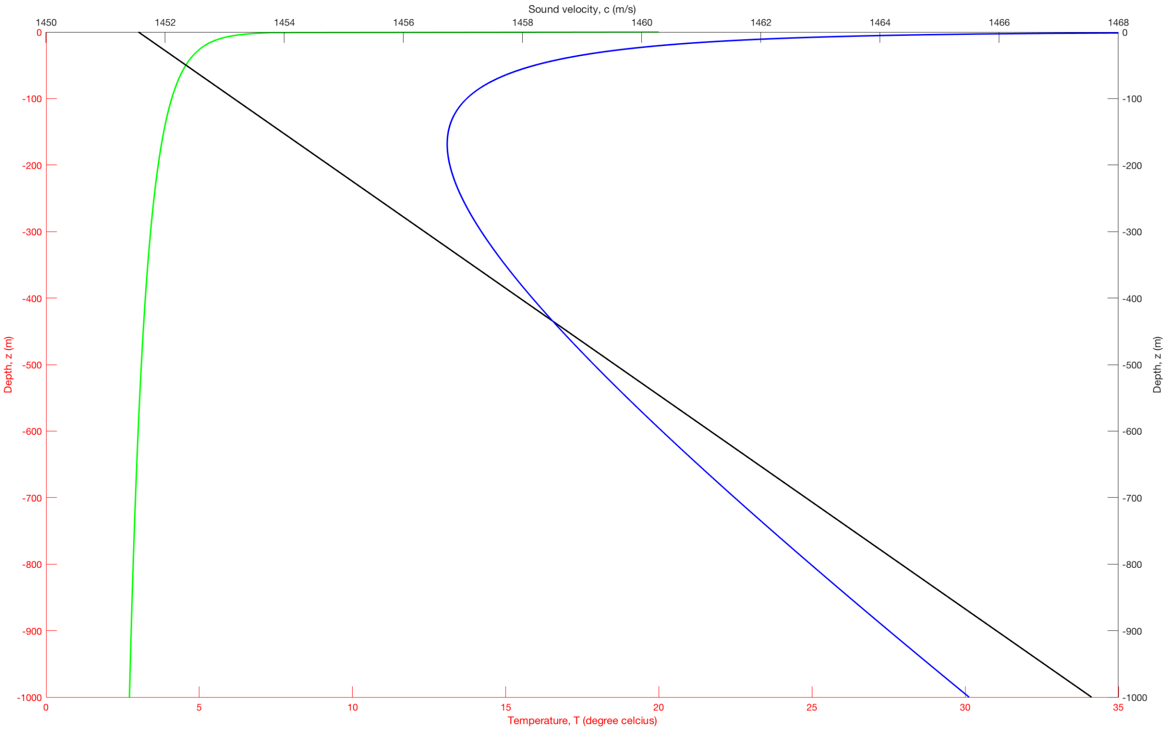

Figure 3.3: Dependency of non-linear temperature profile and depth

Chapter 4

Conclusion

It can be concluded that depth and salinity of the ocean are linearly dependent on sound velocity in the ocean while temperature has non linear dependance on speed of sound in the ocean

Chapter 5

Appendix

5.1 MATLAB code to plot surface reverberation coefficient versus grazing angle

5.1.1 Dependency on frequency

```
frequency = 50;
grazingAngle = 0:0.01:pi/2;
n = length(grazingAngle);
theta = linspace(0,90,n);
for i = 0:1:3
  f = 50*(2^i);
  subplot(2,2,i+1);
for j=0:3
vW = 5*(2^j);
beta = 4*((vW+2)/(vW+1)) + (2.5*((f+0.1)^(-1/3))-4) ...
    .* cos(grazingAngle) .^ (1/8);
sS = 10*log10(((tan(grazingAngle)).^beta) ...
    .*((1+vW)^2)*((f+0.1)^(vW/150))*(10^(-5.05)));
plot(theta,sS,'LineWidth',2)
title(['Frequency = ',num2str(f),' kHz'])
xlabel('Grazing angle [deg]'),
ylabel('Surface reverberation [dB/m^2]')
```

```
ax = gca;
ax.FontSize = 16;
ax.YLim = [-70 10];
hold on
end
end
hL = legend('WS = 5kn','WS = 10kn','WS = 20kn','WS = 40kn');
newPosition = [0.85 0.85 0.2 0.1];
newUnits = 'normalized';
set(hL,'Position', newPosition,'Units', newUnits);
hL.FontSize = 15;
```

5.1.2 Dependency on windspeed

```
frequency = 50;
grazingAngle = 0:0.01:pi/2;
n = length(grazingAngle);
theta = linspace(0,90,n);
for i = 0:1:3
    vW = 5*(2^i);
    subplot(2,2,i+1);
    for j=0:1:3
frequency = 50*(2^j);
beta = 4*((vW+2)/(vW+1)) + (2.5*((frequency+0.1)^(-1/3))-4) ...
    .*cos(grazingAngle).^(1/8);
sS = 10*log10(((tan(grazingAngle)).^beta) ...
    .*((1+vW)^2)*((frequency+0.1)^(vW/150))*(10^(-5.05)));
grid on;
axis([0 100 -70 10])
plot(theta,sS,'LineWidth',2),
title(['Wind speed = ',num2str(vW),'kn']),
xlabel('Grazing angle [deg]'),
ylabel('Surface reverberation [dB/m^2]')
ax = gca;
ax.FontSize = 16;
ax.YLim = [-70 10];
%ax.Xlim = [0 90];
hold on
    end
end
hL = legend('f = 50 kHz','f = 100 kHz','f = 200 kHz','f = 400 kHz');
newPosition = [0.85 0.85 0.2 0.1];
newUnits = 'normalized';
set(hL,'Position', newPosition,'Units', newUnits);
hL.FontSize = 15;
```

5.2 MATLAB code to plot bottom reverberation coefficient versus grazing angle

5.2.1 Dependency on frequency

```
% file saved as UCP1_2.m
temperature = 5:5:30; % temperature varies in steps on 5 from 5 to 30
salinity = 10:5:35; % salinity varies in steps of 5 from 10 to 35
depth = 0:200:1000; % depth varies in steps of 200 from 0 to 1000
for i = 1:6
    u = salinity(i);
    for j = 1:6
        v = temperature(j);
        c = speedOfSound(u, v, depth); % calling the function
        subplot(3,2,i);
        hold on;
        plot(c,-depth,'LineWidth',1.5);
        title(['For salinity = ',num2str(salinity(i))])
        ax = gca; % current axes
        ax.FontSize = 8;
        ax.XLim = [1430 1570];
        ylabel('Depth, z (m)')
        xlabel('Speed of sound, c (m/s)')
    end
end
hL = legend('T = 5', 'T = 10', 'T = 15', 'T = 20','T = 25', 'T = 30');
newPosition = [0.85 0.85 0.2 0.2];
newUnits = 'normalized';
set(hL,'Position', newPosition,'Units', newUnits);
```

5.2.2 Dependency on bottom type

```
% file saved as UCP1_2.m
temperature = 5:5:30; % temperature varies in steps on 5 from 5 to 30
salinity = 10:5:35; % salinity varies in steps of 5 from 10 to 35
depth = 0:200:1000; % depth varies in steps of 200 from 0 to 1000
for i = 1:6
    u = salinity(i);
    for j = 1:6
        v = temperature(j);
        c = speedOfSound(u, v, depth); % calling the function
        subplot(3,2,i);
        hold on;
        plot(c,-depth,'LineWidth',1.5);
        title(['For salinity = ',num2str(salinity(i))])
        ax = gca; % current axes
        ax.FontSize = 8;
        ax.XLim = [1430 1570];
        ylabel('Depth, z (m)')
        xlabel('Speed of sound, c (m/s)')
    end
end
hL = legend('T = 5', 'T = 10', 'T = 15', 'T = 20','T = 25', 'T = 30');
newPosition = [0.85 0.85 0.2 0.2];
newUnits = 'normalized';
set(hL,'Position', newPosition,'Units', newUnits);
```

5.3 MATLAB code to plot volume reverberation coefficient versus frequency

```
temperature = 5:5:30; % temperature varies in steps on 5 from 5 to 30
salinity = 10:5:35; % salinity varies in steps of 5 from 10 to 35
depth = 0:1000; % depth varies in steps of 1 from 0 to 1000
u = 4; % salinity
v = 10; % temperature
expo_temp = 20*exp(-depth.^.1);
line(expo_temp,-depth,'color','g','LineWidth',1.5);
ax1 = gca; %current axis
ax1.XColor = 'r';
ax1.YColor = 'r';
ax1.XLim = [0 35];
ylabel('Depth, z (m)')
xlabel('Temperature, T (degree celcius)')
ax1_pos = ax1.Position; % position of first axes
ax2 = axes('Position',ax1_pos,...
    'XAxisLocation','top',...
    'YAxisLocation','right',...
    'Color','none');
ax2.XLim = [1450 1468];
ax2.YLim = [-1000 0];
ylabel('Depth, z (m)')
xlabel('Sound velocity, c (m/s)')
c = speedOfSound(u, v, depth); % calling the function
line(c,-depth,'Parent',ax2,'Color','k','LineWidth',1.5)
c = speedOfSound(26, expo_temp, depth); % calling the function
line(c,-depth,'Parent',ax2,'Color','b','LineWidth',1.5)
```