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Hochschule Bremen
City University of Applied Sciences

UNDERWATER ACOUSTICS AND SONAR
SIGNAL PROCESSING

SS 2018

ASSIGNMENT 2

SOUND ATTENUATION IN THE OCEAN

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by

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Contents

Chapter 1

Introduction

Salt water as a medium is dissipative. Due to viscosity of salt water (above 100 kHz), relaxation (i.e. the conversion of acoustic energy into heat) of magnesium sulphate (above 100 kHz or 10 kHz to 100 kHz) and boric acid (above 1 kHz or $\leq$10 kHz) sound waves are attenuated. There are numerous empirical models available for the prediction of attenuation of underwater sound, e.g. Thorp, Schulkin-Marsh and Francois-Garrison. The absorption of low frequency sound is comparably small. However, the magnitude of absorption increases with increasing frequency. In contrast to the sea surface, sound waves can penetrate into soft sea floors and consequently be absorbed significantly. Since the sea bed is a solid, also shear waves can develop. At long distances, losses in acoustic sound intensity result from attenuation and scattering losses. Sound attenuation in underwater environments is dependent on temperature, salinity, pressure and pH. If sound is propagating into the sea bed, it also is attenuated as a function of sediment type.

This assignment consists of three parts: In the first part we develop a MATLAB program that calculates the sound attenuation in seawater by means of Thorp, Schulkin & Marsh and Francois &

Garrison formula. The results of the three approaches are then compared. The next two parts are done for Francois & Garrison formula. The dependency on the frequency, salinity and temperature for a depth of 50m is investigated and finally a graph for attenuation versus frequency is plotted and frequency regions where the different attenuation processes dominate are specified.

Chapter 2

Theory

2.1 Sound attenuation in water

An acoustic signal underwater experiences attenuation due to spreading and absorption. The acoustic energy of a sound wave propagating in the ocean is partly absorbed, i.e. the energy is transformed into heat and partly lost due to sound scattering by in homogeneities. On the basis of extensive laboratory and field experiments the following empirical formulae for attenuation coefficient in sea water have been derived. Sound absorption in sea water is a function of frequency, temperature, salinity, pH, and pressure. When the acoustic wave propagates in sea water, absorption loss occurs, which is caused by a part of the energy changing into the heat owing to the viscous friction of the water molecule, aside from the spreading loss. The absorption loss is represented as α r, where α is the coefficient in dB/Km and r is the transmission distance.

2.1.1 Thorp formula

The absorption coefficient for frequency range 100 Hz to 3 kHz can be expressed empirically using Thorps formula which defines α_w [dB/m] as a function of f [kHz].

$$\alpha_w = \frac{0.11f^2}{1+f^2} + \frac{44f^2}{4100+f^2}$$

2.1.2 Schulkin and Marsh formula

The absorption coefficient for frequency range 3 kHz to 500 kHz can be expressed empirically using Schulkin and Marsh model which defines α_w [dB/m] as a function of f [kHz].

$$\alpha_w = 8.686.10^3(\frac{SAf_tf^2}{f_t^2+f^2} + \frac{Bf^2}{f_t})(1 - 6.54.10^{-4}P)$$

where $A = 2.34.10^{-6}, B = 3.38.10^{-6}$, S in [ppt], f in [kHz], relaxation frequency $f_t = 21.9.10^{\frac{6-1520}{T+273}}$ with T in [°C] for $0 \leq T \leq 30$ and the hydrostatic pressure is determined by $P = 1.01(1 + z0.1)$ in $[kg/cm^3 = at]$

2.1.3 Francois and Garrison Formula

The absorption coefficient for frequency range 100 Hz to 1 MHz can be expressed empirically using Francois and Garrison model which defines α_w [dB/m] as a function of f [kHz].

$$\alpha_w = \frac{A_1 P_1 f_1 f^2}{f_t 1^2 + f^2} + \frac{A_2 P_2 f_2 f^2}{f_t 2^2 + f^2} + A_3 P_3 f^2$$

The first term gives the sound absorption due to the Boric Acid and second term gives the sound absorption due to the magnesium sulphate. The contribution of sound absorption due to these chemical ingredients has been found to be small. The third term represents the sound absorption due to pure water. The pressure dependency of above equation is shown by P1, P2 and P3 constants .Frequency dependency is given by f1 and f2 which are the relaxation frequencies of Boric Acid and Magnesium sulphate. f is the frequency of sound. The constants A1, A2 and A3 shown are not purely constants but it has been experimentally proved that their values vary with the water properties, like temperature, salinity and pH of water. The total coefficient of absorption of sea water is calculated by considering separately the absorption due to boric acid, magnesium sulphate and pure water.

$A_1 = \frac{8.686}{c} 10^{0.78ph-5}, f_1 = 2.8\sqrt{\frac{S}{35}} 10^{4-\frac{1245}{T+273}}$

$P_1 = 1, c = 1412 + 3.21T + 1.19S + 0.0167Z_m$

$A_2 = 21.44\frac{S}{c}(1 + 0.0025T), f_2 = \frac{8.17.10^{\frac{8-1990}{T+273}}}{1+0.0018(S-35)}$

$P_2 = 1 - 1.37.10^{-4} z_m + 6.2.10^{-9} z_m^2$

$$A_3 = \begin{cases} 4.937.10^{-4} - 2.59.10^{-5}T + 9.11.10^{-7}T^2 - 1.5.10^{-8}T^3 & \text{for } T \leq 20 \\ 3.964.10^{-4} - 1.146.10^{-5}T + 1.145.10^{-7}T^2 - 6.5.10^{-8}T^3 & \text{for } T \geq 20 \end{cases}$$

$P_3 = 1 - 3.83.10^{-5} z_m + 4.9.10^{-10} z_m^2$

with S in [ppt], f in [kHz], T in [°C]. Furthermore z_m, ph and c denote the water depth in [m], the ph-value and the sound speed in [m/s] respectively.

Chapter 3

Experimental research

3.1 Comparision of the results of different empirical formulae

By using the empirical formulae of Thorp, Schulkin and Marsh, Francois and Garrison's models to calculate the attenuation coefficient , the graph of attenuation coefficient versus frequency is plotted and compared.

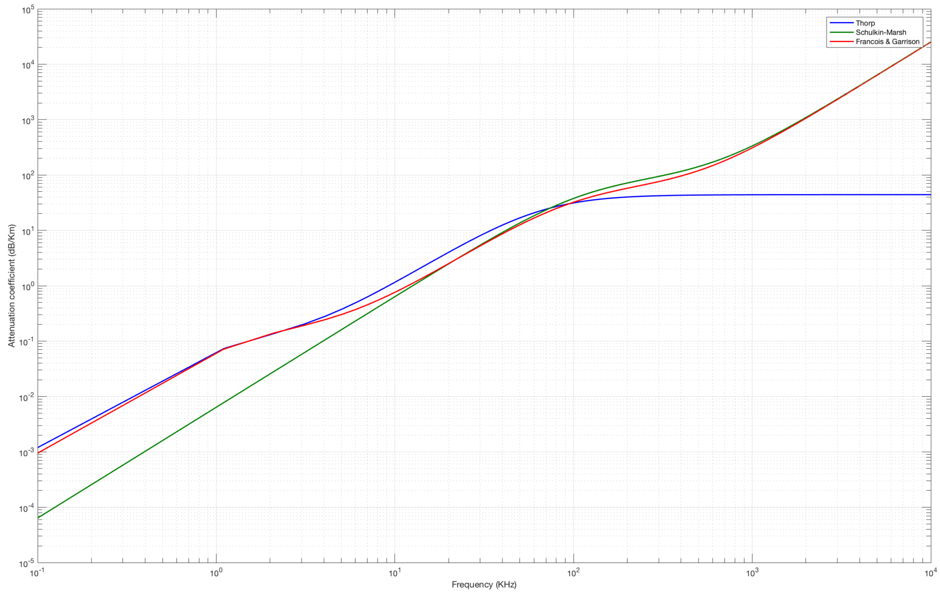

Figure 3.1: Comparision of different empirical formulae

3.2 Dependence of attenuation coefficient on different parameters for Francois and Garrison's model

3.2.1 Dependence on frequency

A graph of frequency versus attenuation coefficient is plotted for a depth of 50m by keeping temperature and salinity constant and varying frequency. This graph is done in-order to check how each factor contributes to the attenuation coefficient.

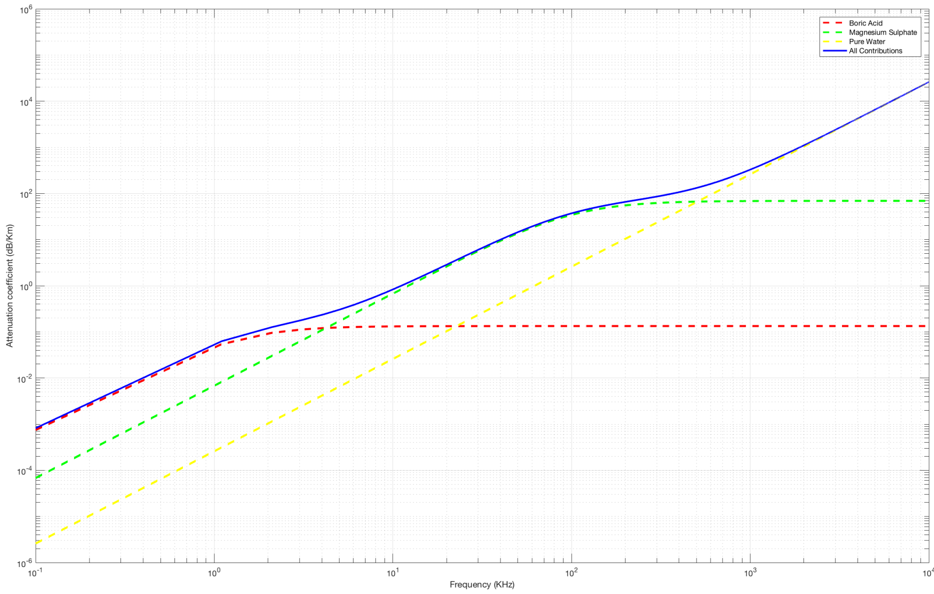

Figure 3.2: Dependency on frequency

3.2.2 Dependence on salinity

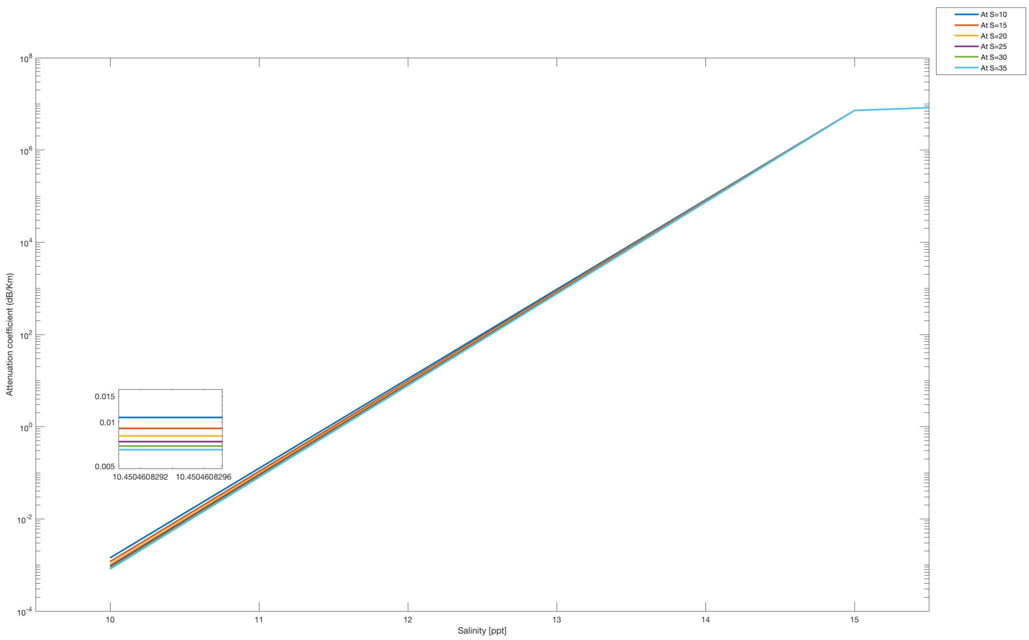

Figure 3.3: Dependency on salinity

A graph of salinity versus attenuation coefficient is plotted for a depth of 50m by keeping temperature and frequency constant and varying salinity. In-order to differentiate the lines for various salinities, we zoomed the graph with the help of 'magnify' function which was taken from the internet.

3.2.3 Dependence on temperature

A graph of temperature versus attenuation coefficient is plotted for a depth of 50m by keeping salinity and frequency constant and varying temperature.

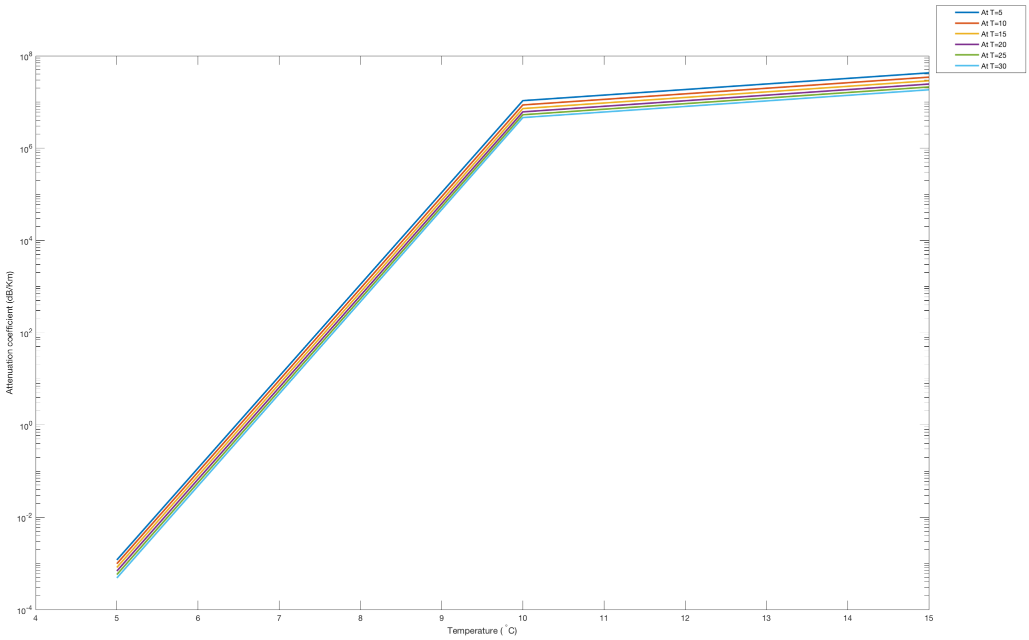

Figure 3.4: Dependency on temperature

3.3 Attenuation versus frequency graphs for Francois and Garrison's model

Set of attenuation versus frequency graphs are obtained for a depth of 50m and various values of temperature and salinity. This graph shows how temperature and salinity affect the attenuation coefficient.

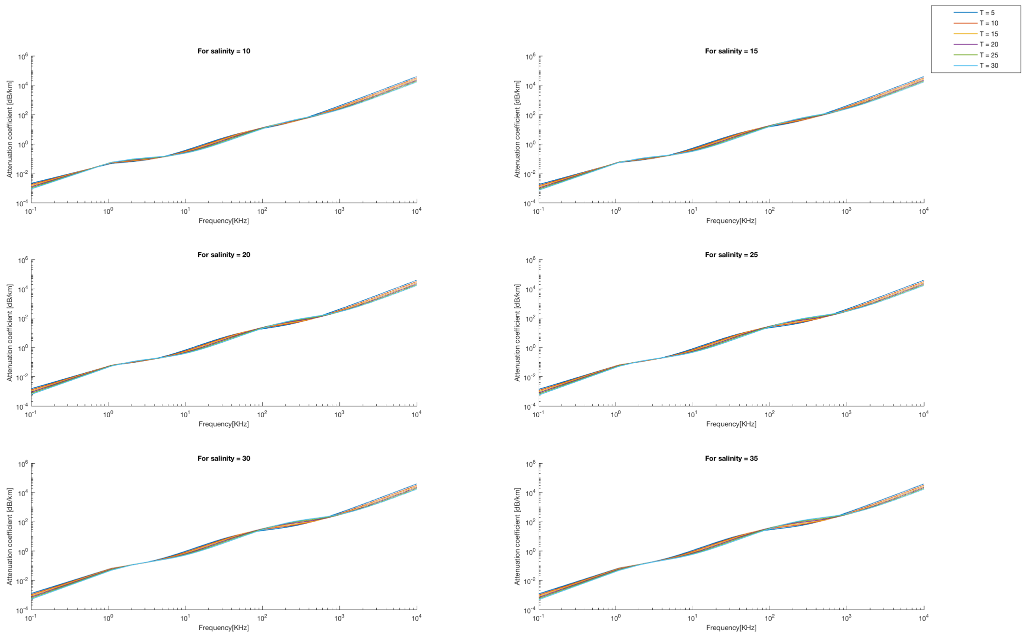

Figure 3.5: Attenuation versus frequency

Chapter 4

Conclusion

From the first part, it can be concluded that according to Thorp formula the attenuation of sound is increasing up to a certain range of frequency and then it remains unchanged. From Schulkin and Marsh formula we can state that attenuation of sound increases with increase in frequency. Francois and Garrison formula is almost similar to Schulkin and Marsh at higher frequencies and similar to Throp at low frequencies.

The contribution of boric acid, magnesium sulphate and pure water in the Francois-Garrison model was studied and it concludes that boric acid contributes to the overall contribution only at very low frequencies while pure water contributes at very high frequencies and magnesium sulphate in between the two.

Absorption decreases with temperature and it increases with frequency, salinity, and pH. At high frequencies, the dependence of attenuation coefficient on temperature is much stronger than that on the remaining frequencies. At low frequencies where the effect of boric acid is significant, absorption coefficient shows considerable variation with the pH of sea water.

From the final set of graphs it can be proved that as the temperature increases there is increase in attenuation of sound, but after reaching a certain range of frequency there is slight change in attenuation which occurred due to the variations in salinity.

Chapter 5

Appendix

5.1 MATLAB code to compare the results of different empirical formulae

```
%file saved as USP2_1.m
frequency = 0.1:10000;
depth = 10;
depth_max = 1000;
temperature = 15;
salinity = 35;
A = 2.34*10^-6;
B = 3.38*10^-6;
relaxation_Frequency = 21.9 * 10^(6-1520/(temperature+273));
pressure = 1.01 * (1 + depth * 0.1);
```

```
P1 = 1;
P2 = 1 - (1.37*10^-4)*depth_max + (6.2 * 10^-9 * depth_max^2);
P3 = 1 - (3.83*10^-5)*depth_max + (4.9 * 10^-10 * depth_max^2);
c = 1412 + 3.21*temperature + 1.19*salinity + 0.0167*depth_max;
f1 = 2.8 * sqrt((salinity/35)) * 10^(4 - (1245/(temperature+273)));
f2 = (8.17 * 10^(8-1990/(temperature+273))) / (1 + 0.0018*(salinity-35))
    ;
ph = 8.1;
A1 = ((8.686/c) * 10^(0.78*ph - 5));
A2 = 21.44*(salinity/c)*(1 + 0.025*temperature);
if temperature<=20
A3 = (4.937 * 10^-4) - (2.59 * 10^-5)*temperature ...
    + (9.11 * 10^-7)*(temperature^2) - (1.5 *10^-8)*(temperature^3);
else
A3 = (3.964 * 10^-4) - (1.146 * 10^-5)*temperature ...
    + (1.45 * 10^-7)*(temperature^2) - (6.5.*10^-10)*(temperature^3);
end

thorp = ((0.11.*frequency.^2)./(1+frequency.^2)) ...
    + ((44.*frequency.^2)./(4100+frequency.^2));

shulkin_Marsh = 8.686*10^3*(((salinity.*A.*relaxation_Frequency.*
    frequency.^2) ...
```

```
    ./(relaxation_Frequency.^2 + frequency.^2)) ...
    + (B.*frequency.^2)./relaxation_Frequency) ...
    .*(1 - 6.54*10.^-4.*pressure);

francois_Garrison = ((A1.*P1.*f1.*frequency.^2)./(f1.^2 + frequency.^2)) ...
    + ((A2.*P2.*f2.*frequency.^2)./(f2.^2 + frequency.^2)) ...
    + (A3.*P3.*frequency.^2);

figure();
loglog(frequency,thorp,'b','linewidth',1.5), hold on;
loglog(frequency,shulkin_Marsh,'color',[0 0.5 0],'linewidth',1.5), hold on;
loglog(frequency,francois_Garrison,'r','linewidth',1.5);
grid on;
xlabel('Frequency (KHz)');
ylabel('Attenuation coefficient (dB/Km)');
legend('Thorp','Schulkin-Marsh','Francois & Garrison');
```

5.2 MATLAB code to investigate the dependence of attenuation coefficient on different parameters for Francois & Garrison's model

5.2.1 Dependence on frequency

```
%file saved as USP2_2.m
frequency = 0.1:10000;
temperature = 15;
salinity = 35;
ph = 8;
depth_max = 0.5;
p1 = 1;
p2 = 1 - (1.37 * 10^-4 * depth_max) + (6.2 * 10^-9 * depth_max^2);
p3 = 1 - (3.83 * 10^-5 * depth_max) + (4.9 * 10^-10 * depth_max^2);
c = 1412 + 3.21*temperature + 1.19*salinity + 0.0167*depth_max;
f1 = 2.8 * sqrt((salinity/35)) * 10^(4 - (1245/(temperature+273)));
f2 = (8.17 * 10^(8-1990/(temperature+273))) / (1 + 0.0018*(salinity-35));
a1 = ((8.686/c) * 10^(0.78*ph - 5));
a2 = 21.44*(salinity/c)*(1 + 0.025*temperature);
if temperature <= 20
a3 = (4.937 * 10^-4) - (2.59 * 10^-5)*temperature ...
```

```
    + (9.11 * 10^-7)*(temperature^2) - (1.5 *10^-8)*(temperature^3);
else
a3 = (3.964 * 10^-4) - (1.146 * 10^-5)*temperature ...
    + (1.45 * 10^-7)*(temperature^2) - (6.5.*10^-10)*(temperature^3);
end
boric_Acid = ((a1.*p1.*f1.*frequency.^2)./((f1.^2)+(frequency.^2)));
magnesium_Sulphate = ((a2.*p2.*f2.*frequency.^2)./((f2.^2)+(frequency.^2)));
pure_Water = (a3.*p3.*frequency.^2);
all_Contributions = boric_Acid + magnesium_Sulphate + pure_Water;

loglog(frequency,boric_Acid,'--','color','r','linewidth',2), hold on;
loglog(frequency,magnesium_Sulphate,'--','color','green','linewidth',2), hold on;
loglog(frequency,pure_Water,'--','color','yellow','linewidth',2), hold on;
loglog(frequency,all_Contributions,'blue','linewidth',2);
xlabel('Frequency (KHz)'); ylabel('Attenuation coefficient (dB/Km)');
legend('Boric Acid','Magnesium Sulphate','Pure Water','All Contributions');
grid on;
```

5.2.2 Dependence on salinity

```
%file saved as USP2_3.m
frequency=0.1:166667:1000000;
z_max = 0.5;
temperature = 15;
salinity = 10:5:35;
A=[];
for i = 1:6
      u = salinity(i);
c = 1412 + 3.21*temperature + 1.19*salinity(i) + 0.0167*z_max;
ph=8;
A1 = 8.686 ./ c *10^(0.78*ph-5);
p1 = 1;
f1 = 2.8*sqrt(salinity(i)./35).*10.^(4-1245./(temperature+273));
boric_Acid = (A1.*p1.*f1.*frequency.^2)./(f1.^2+frequency.^2);
A2 = 21.44*(salinity(i)/c)*(1+0.025*temperature);
p2 = 1-1.37e-4*z_max+6.2e-9*z_max^2;
f2 = 8.17*10^(8-(1990/(temperature+273)))/(1+0.0018*(salinity(i)-35));
Magnesium_Sulphate = (A2*p2*f2*frequency.^2)./(f2^2+frequency.^2);
if temperature <= 20
A3 = (4.937e-4) - (2.59e-5*temperature)...
      + (9.11e-7*(temperature^2)) - (1.5e-8*(temperature^3));
else
```

```
A3 = (3.964e-4) - (1.146e-5*temperature) ...
    + (1.45e-7*(temperature^2)) - 6.5e-10*(temperature^3);
end
p3 = 1-(3.83e-5*z_max)+(4.9e-10*z_max^2);
pure_Water = A3*p3*frequency.^2;
A = [A;(boric_Acid + Magnesium_Sulphate + pure_Water)];
end
figure ();
plot(salinity,A(1,:),salinity,A(2,:),salinity,A(3,:), ...
    salinity,A(4,:),salinity,A(5,:),salinity,A(6,:),'linewidth',2)
ax = gca; %current axis
ax.XLim = [9.5 15.5];
set(gca, 'YScale', 'log')
xlabel('Salinity [ppt]');
ylabel('Attenuation coefficient (dB/Km)');
hL = legend('At S=10','At S=15','At S=20','At S=25','At S=30','At S=35');
newPosition = [0.85 0.85 0.2 0.2];
newUnits = 'normalized';
set(hL,'Position', newPosition,'Units', newUnits);
magnify;
```

5.2.3 Dependence on temperature

```
%file saved as USP2_3.m
frequency = 0.1:166667:1000000;
z_max = 0.5;
temperature = 5:5:30;
salinity = 35;
A=[];
for i=1:6
    u=temperature(i);
    C = 1412 + 3.21*temperature(i) + 1.19*salinity+0.0167*z_max;
    pH = 8;
    A1 = 8.686 ./ C *10^(0.78*pH-5);
    p1 = 1;
    f1 = 2.8*sqrt(salinity./35).*10.^(4-1245./(temperature(i)+273));
    boric_Acid = (A1.*p1.*f1.*frequency.^2)./(f1.^2+frequency.^2);
    A2 = 21.44*(salinity/C)*(1+0.025*temperature(i));
    p2 = 1 - 1.37e-4*z_max + 6.2e-9*z_max^2;
    f2 = 8.17*10^(8-(1990/(temperature(i)+273)))/(1+0.0018*(salinity-35));
    Mag_sulf = (A2*p2*f2*frequency.^2)./(f2^2+frequency.^2);
    if temperature(i)<=20
    A3 = (4.937e-4) - (2.59e-5*temperature(i)) ...
        + (9.11e-7*(temperature(i)^2)) - (1.5e-8*(temperature(i)^3));
```

```
        else
        A3 = (3.964e-4) - (1.146e-5*temperature(i)) ...
             + (1.45e-7*(temperature(i)^2)) - 6.5e-10*(temperature(i)^3);
        end
p3 = 1 - (3.83e-5*z_max) + (4.9e-10*z_max^2);
pure_Water = A3*p3*frequency.^2;
A = [A ;(boric_Acid + Mag_sulf + pure_Water)];
end
figure ();
plot(temperature,A(1,:),temperature,A(2,:),temperature,A(3,:), ...
     temperature,A(4,:),temperature,A(5,:),temperature,A(6,:),'linewidth',2)
ax = gca; %current axis
ax.XLim = [4 15];
set(gca, 'YScale', 'log')
xlabel('Temperature ( ^{\circ}C)');
ylabel('Attenuation coefficient (dB/Km)');
hL = legend('At T=5','At T=10','At T=15','At T=20','At T=25','At T=30');
newPosition = [0.85 0.85 0.2 0.2];
newUnits = 'normalized';
set(hL,'Position', newPosition,'Units', newUnits);
```

5.3 MATLAB code for attenuation versus frequency using Francois and Garrison's model

```
% file saved as UCP1_5.m
temperature = 5:5:30;
salinity = 10:5:35;
frequency = 0.1:10000;
depth_max = 0.5;
p1 = 1;
p2 = 1 - (1.37 * 10^-4 * depth_max) + (6.2 * 10^-9 * depth_max^2);
p3 = 1 - (3.83 * 10^-5 * depth_max) + (4.9 * 10^-10 * depth_max^2);
for i = 1:6
    u = salinity(i);
    for j = 1:6
        v = temperature(j);
        c = 1412 + 3.21*v + 1.19*u + 0.0167*depth_max;
        f1 = 2.8 * sqrt((u/35)) * 10^(4 - (1245/(v+273)));
        f2 = (8.17 * 10^(8-1990/(v+273))) / (1 + 0.0018*(u-35));
        a1 = ((8.686/c) * 10^(0.78*ph - 5));
        a2 = 21.44*(u/c)*(1 + 0.025*v);
if v <= 20
a3 = (4.937 * 10^-4) - (2.59 * 10^-5)*v ...
    + (9.11 * 10^-7)*(v^2) - (1.5 *10^-8)*(v^3);
else
```

```
a3 = (3.964 * 10^-4) - (1.146 * 10^-5)*v ...
    + (1.45 * 10^-7)*(v^2) - (6.5.*10^-10)*(v^3);
end
boric_Acid = ((a1.*p1.*f1.*frequency.^2)./((f1.^2)+(frequency.^2)));
magnesium_Sulphate = ((a2.*p2.*f2.*frequency.^2)./((f2.^2)+(frequency.^2)));
pure_Water = (a3.*p3.*frequency.^2);
all_Contributions = boric_Acid + magnesium_Sulphate + pure_Water;

        subplot(3,2,i);
        hold on;
        plot(frequency,all_Contributions,'LineWidth',1);
        title(['For salinity = ',num2str(salinity(i))])
        ax = gca; % current axes
        ax.FontSize = 8;
        set(gca, 'YScale', 'log', 'XScale','log')
        %ax.XLim = [1430 1570];
        ylabel('Attenuation coefficient [dB/km]')
        xlabel('Frequency[KHz]')
    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);
```