HSB
Hochschule Bremen
City University of Applied Sciences

UNDERWATER ACOUSTICS AND SONAR
SIGNAL PROCESSING

SS 2018

ASSIGNMENT 1

SOUND VELOCITY IN THE OCEAN

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by

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Contents

Chapter 1

Introduction

It is proved that while sound moves at a much faster speed in the water than in air, the distance that sound waves travel is primarily dependant upon ocean temperature, salinity and pressure. While pressure continues to increase as ocean depth increases, the temperature of the ocean only decreases up to a certain point, after which it remains relatively stable. These factors have a curious effect on how (and how far) sound waves travel.

This assignment consists of three parts: In the first part we develop a MATLAB program for determining the formula for the velocity of sound in ocean.The second part shows the dependence of velocity of sound in ocean on temperature, salinity and depth. Finally the dependency of the nonlinear temperature profile and the depth of the ocean is plotted.

Chapter 2

Theory

Variations of the sound velocity in the ocean are relatively small due to low absorption compared to speed of light in water. Blue-green light has the lowest attenuation in water upto 20m while sound can travel upto 100km one way and hence sonar is used to navigate, communicate with or detect objects on or under the surface of the water. Sound velocity in ocean lies between about 1450 m/s and 1540 m/s. Even though the changes of sound speed are small, i.e. $\leq \pm 3\%$, the propagation of sound can be significantly affected.

The sound velocity can be directly measured by velocimeters or calculated by empirical formulae if the temperature, salinity and hydrostatic power or depth are known. However, the error of measurements by modern velocimeters is about 0.1 m/s. The accuracy of calculations by the most complete empirical formulae is about the same. Also formulae providing such high accuracy are very cumbersome.

A less accurate but simpler equation is given by:

$$c = 1449.2 + 4.6T - 0.055T^2 + 0.00029T^3 + (1.34 - 0.01T)(S - 35) + 0.016z$$

where temperature, T in ($°C$), salinity, S in (ppt), depth, z in (m) and sound velocity, c in (m/s)

With the following limits:

$0°C \leq$ T $\leq 35°C$

0 ppt $\leq$S $\leq$45 ppt

0 m $\leq$ z $\leq$1000 m

The function for velocity of sound in ocean and the dependency of nonlinear temperature profile and the depth of the ocean is studied. Two sets of waveforms of c versus z for various sets of T and S are plotted in-order to investigate the dependence of c on T, S and z. Also the waveform for the nonlinear temperature profile and the depth of the ocean is obtained and discussed in the following sections.

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.
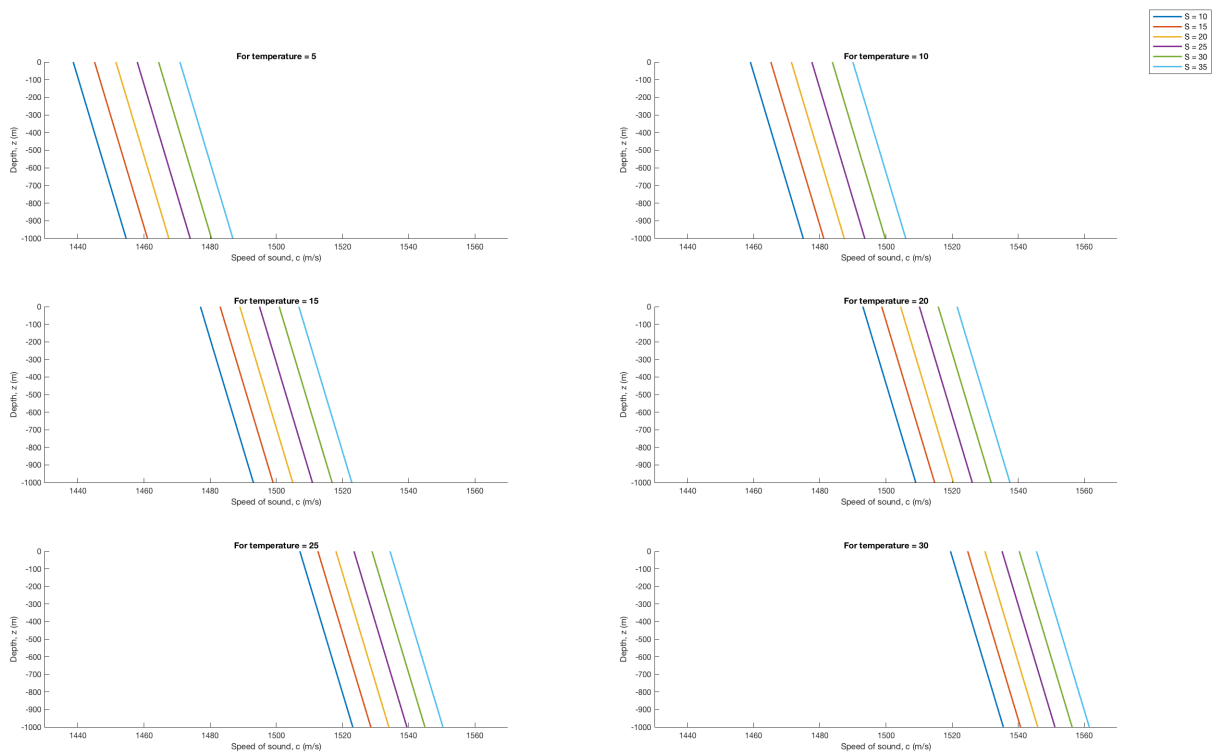

Figure 3.1: c versus z for various sets of T

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.
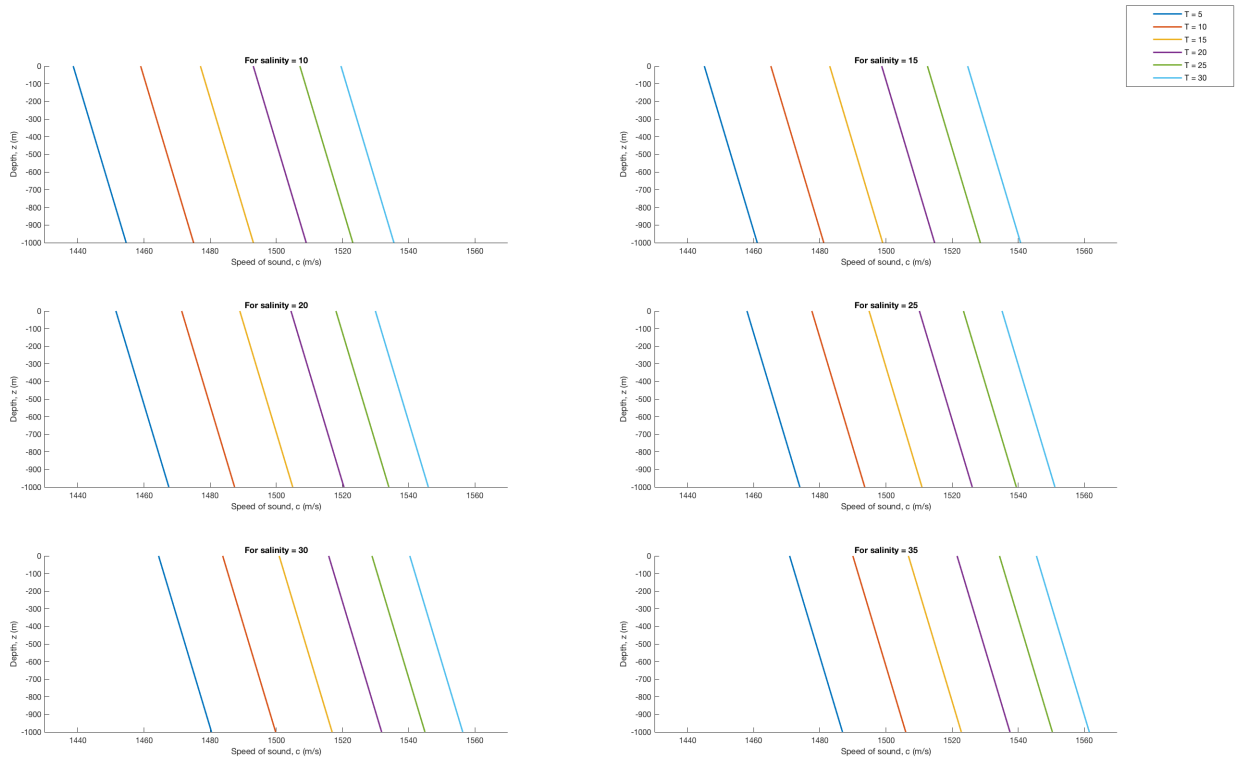

Figure 3.2: c versus z for various sets of S

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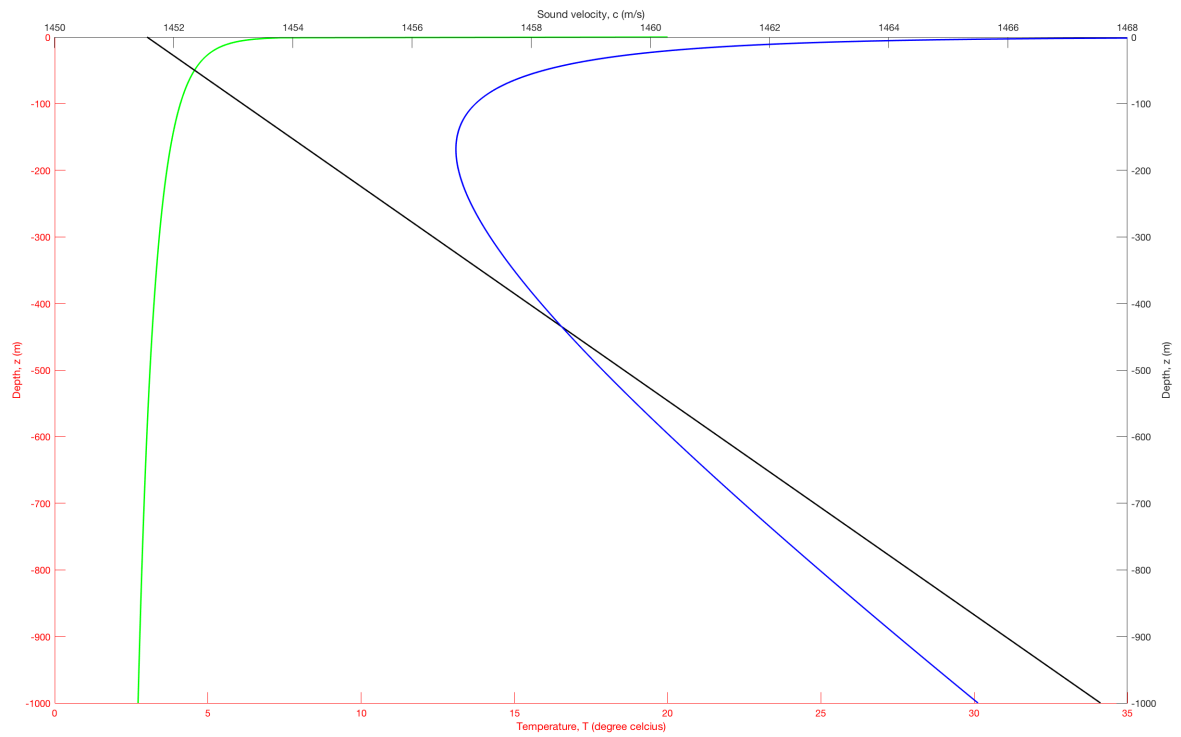
Figure 3.3: Dependency of non-linear temperature profile and depth

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 for dependence of c on T, S and z

5.1.1 Function to compute velocity of sound

```matlab
% Function saved as speedOfSound.m and is called from other MATLAB files
function c = speedOfSound(S, T, Z)
c = 1449.2 + 4.6*T - 0.055*T.^2 + 0.00029*T.^3 ...
            + 1.34*S - 46.9 - 0.01*T.*S + 0.35*T + 0.016*Z;
end
```

5.1.2 For various values of temperature

```matlab
%file saved as UCP1_1.m
temperature = 5:5:30; % temperature varies in steps on 5 from 5 to 30
```

```matlab
3   salinity = 10:5:35; % salinity varies in steps of 5 from 10 to 35

4   depth = 0:200:1000; % depth varies in steps of 200 from 0 to 1000

5   for i = 1:6

6       u = temperature(i);

7       for j = 1:6

8           v = salinity(j);

9           c = speedOfSound(v, u, depth); % calling the function

10          subplot(3,2,i);

11          hold on;

12          plot(c,-depth,'LineWidth',1.5);

13          title(['For temperature = ',num2str(temperature(i))])

14          ax = gca; % current axes

15          ax.FontSize = 8;

16          ax.XLim = [1430 1570];

17

18          % labelling of axes

19          ylabel('Depth, z (m)')

20          xlabel('Speed of sound, c (m/s)')

21      end

22  end

23  % labelling of waveforms

24  hL = legend('S = 10', 'S = 15', 'S = 20', 'S = 25','S = 30', 'S = 35');

25  newPosition = [0.85 0.85 0.2 0.2];
```

```matlab
26  newUnits = 'normalized';

27  set(hL,'Position', newPosition,'Units', newUnits);
```

5.1.3   For various values of salinity

```matlab
1  % file saved as UCP1_2.m

2  temperature = 5:5:30; % temperature varies in steps on 5 from 5 to 30

3  salinity = 10:5:35; % salinity varies in steps of 5 from 10 to 35

4  depth = 0:200:1000; % depth varies in steps of 200 from 0 to 1000

5  for i = 1:6

6      u = salinity(i);

7      for j = 1:6

8          v = temperature(j);

9          c = speedOfSound(u, v, depth); % calling the function

10         subplot(3,2,i);

11         hold on;

12         plot(c,-depth,'LineWidth',1.5);

13         title(['For salinity = ',num2str(salinity(i))])

14         ax = gca; % current axes

15         ax.FontSize = 8;

16         ax.XLim = [1430 1570];

17         ylabel('Depth, z (m)')

18         xlabel('Speed of sound, c (m/s)')

19     end
```

```
20  end

21  hL = legend('T = 5', 'T = 10', 'T = 15', 'T = 20','T = 25', 'T = 30');

22  newPosition = [0.85 0.85 0.2 0.2];

23  newUnits = 'normalized';

24  set(hL,'Position', newPosition,'Units', newUnits);
```

5.2 MATLAB code for dependence of non linear-temperature profile and depth

```
1   temperature = 5:5:30; % temperature varies in steps on 5 from 5 to 30

2   salinity = 10:5:35; % salinity varies in steps of 5 from 10 to 35

3   depth = 0:1000; % depth varies in steps of 1 from 0 to 1000

4   u = 4; % salinity

5   v = 10; % temperature

6   expo_temp = 20*exp(-depth.^.1);

7   line(expo_temp,-depth,'color','g','LineWidth',1.5);

8   ax1 = gca; %current axis

9   ax1.XColor = 'r';

10  ax1.YColor = 'r';

11  ax1.XLim = [0 35];

12  ylabel('Depth, z (m)')

13  xlabel('Temperature, T (degree celcius)')

14  ax1_pos = ax1.Position; % position of first axes
```

```matlab
15  ax2 = axes('Position',ax1_pos,...
16      'XAxisLocation','top',...
17      'YAxisLocation','right',...
18      'Color','none');
19  ax2.XLim = [1450  1468];
20  ax2.YLim = [-1000  0];
21  ylabel('Depth, z (m)')
22  xlabel('Sound velocity, c (m/s)')
23  c = speedOfSound(u, v, depth); % calling the function
24  line(c,-depth,'Parent',ax2,'Color','k','LineWidth',1.5)
25  c = speedOfSound(26, expo_temp, depth); % calling the function
26  line(c,-depth,'Parent',ax2,'Color','b','LineWidth',1.5)
```