Locating Fin Whales with Seafloor Seismometers

OBJECTIVES:

- Locate a fin whale call picked up by a seafloor seismometers using the patterns of echoes that are recorded.
- Discuss how fin whale tracks can be used scientifically.

BACKGROUND

During the winter breeding season male fin whales near the sea surface make 1-second-long calls that they repeat every 20-seconds or so for hours at a time – sometimes even more than a day. The calls are very low in frequency (20 Hz or about the lower limit of human hearing) and very loud (a little louder than a container ship at full speed). Sound can travel great distances underwater – it's even possible to detect a fin whale that is calling tens of miles away!

Seafloor seismometers sit at the bottom of the ocean and measure the shaking from earthquakes. Fin whale calls are so loud and booming that they shake the ground and end up being recorded by the seismometers too.

When a fin whale makes a call, the sound travels through the water at a speed of 1.5 km per second. On its way to the receiver, it can travel along different paths, going directly or bouncing off the surface and seafloor. You can think of the different paths as echoes. Scientists refer to the first path as the "direct" path and to the echoes as "multiples".

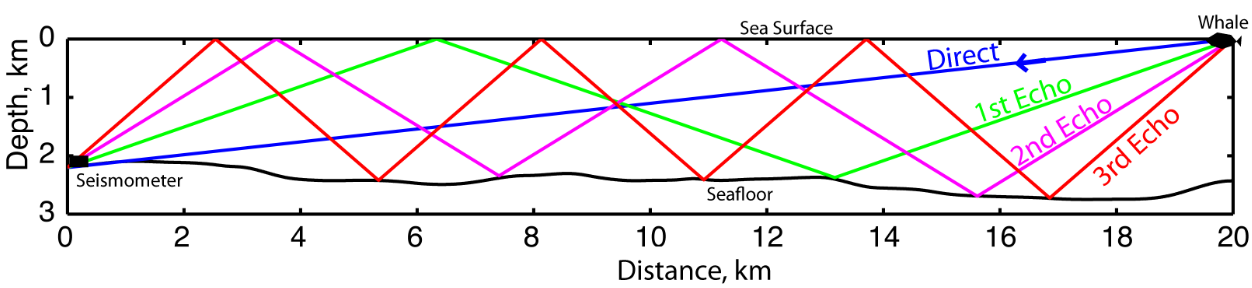


Figure 1. Sound paths for a fin whale call traveling from a whale near the sea surface at a distance of 20 km to a seafloor seismometer.

As the whale gets further away the time gap between the different echoes decreases (a simple result of geometry). Thus, the spacing between recorded signals can tell us the distance to the calling whale (Figure 2)

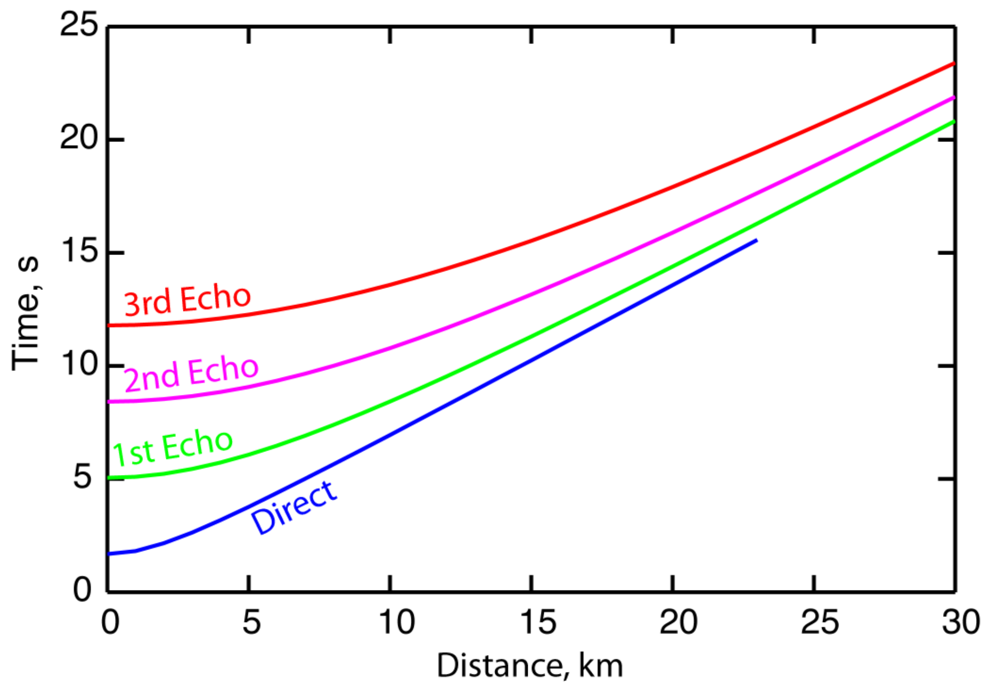


Figure 2. Each line on this figure shows how long the sound takes to travel to a seismometer along a different path. Distance between the whale and the seismometer increases along the x-axis, and the travel time increases as you move up the y-axis. As the whale gets further away, the time between the first arrival and the multiples gets smaller.

In a water depth of 2 km, the signal from the direct path gets weaker as the whale moves further away. Eventually, around 10-15km, it disappears altogether. Only the echoes remain.

INTRODUCTION

For this exercise you are going to work with data from a small seafloor seismic network that was deployed from 2003-6 on the Endeavour segment of the Juan de Fuca ridge which lies about 150 miles off the coast of Vancouver island. It is a seafloor volcano that is famous for its black smoker vent fields and is now one of the sites on the NEPTUNE Canada cabled observatory (http://www.oceannetworks.ca/installations/observatories/northeast-pacific/endeavour). Figure 3 below shows a map of the seafloor along with the locations of the eight seismometers, which are spaced about 3 kilometers apart. Each seismometer has a four-letter name starting with "KE".

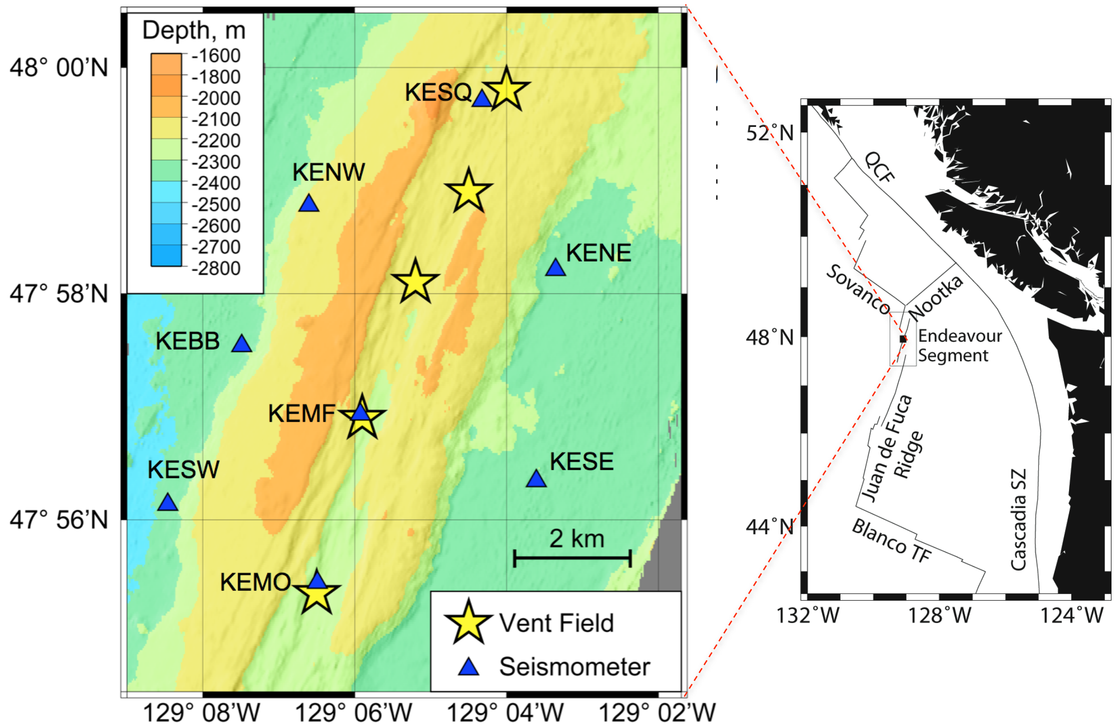


Figure 3 (left) Map of the seafloor showing eight seafloor seismometers that were deployed in ~2 km of water around hydrothermal vent fields along a mid-ocean ridge. (right) the location of the seismometers relative to tectonic plate boundaries off the coast of the Pacific Northwest.

DATA

Figures 4-5 show seismic data for two fin whale calls recorded by the network. These are part of a sequence of over 2500 calls that lasted for nearly a day. Each figure has 8 "seismic traces" which shows how the ground moves over 14 seconds on the eight seismometers. The seismic traces are labeled with the seismometer name. A few of the traces are very noisy (likely from ocean currents or noisy electronics) but fin whale calls are still the loudest signals in most cases. You can see the several signals on many traces – these correspond to the direct path and the echoes.

Figure 6 is a map of the seismic network on which you will plot your locations. You get two copies since it is easiest to locate the two calls on separate plots.

Figure 7 is best printed as a transparency (you can also work with a paper version on a light table or with back-lighting from a tablet or computer screen). It shows the time gap expected between the direct path and the 1st, 2nd and 3rd echoes.

MATERIALS

For the exercise you will need a drawing compass, pencil and an eraser.

LOCATING A CALL

1. Look at the seismic data corresponding to the whale calls. You should be able to see 2 or 3 signals on each seismic trace, the first is the direct arrival and the later signals are echoes. Identify the seismometer that records the whale first – this will be the nearest seismometer to the whale.

2. For each seismic trace mark the PEAK amplitudes of the each signal with a vertical line.
   - You should be able to see 2 or 3 signals per seismometer.
   - Signals will be spaced about 2 to 3 seconds apart.
   - Later signal(s) often have a low amplitudes but you can still see them.
   - Skip noisy seismometers or leave them until last.

3. Use Figure 7 as an overlay. Rotate the overlay 90° clockwise. Work with one seismometer at a time. Align the predicted times shown on Figure 7 with your observations as follows:
   a) First place the "Direct" line of the overlay on top of the 1st vertical line you marked for that seismometer.
   b) Slide the overlay up and down until the 1st echo (and 2nd echo if visible) match the other line(s) you marked for that seismometer.
   c) Read the distance from the "Distance" axis of your rotated overlay.
   d) Write the distance next to the seismometer name on the plot of seismic data.

4. Using the map of Figure 6 draw circles with a drawing compass around each seismometer with a radius equal to the distance to the whale determined above
   - You can adjust the radius of your compass using the scale on the map axes.

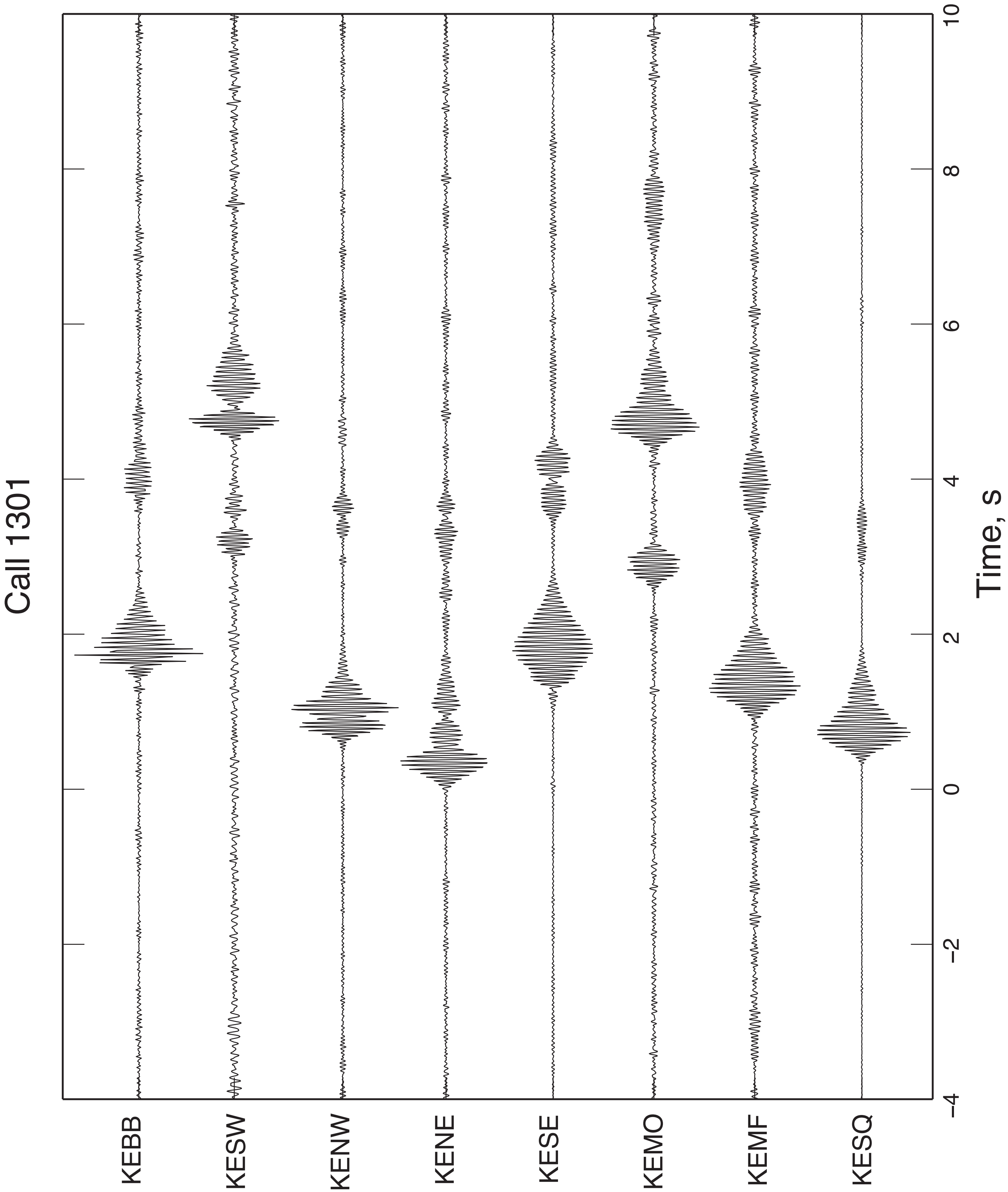
5. The circles should approximately intersect the location of the whale. Mark the best location with an "X".

THINGS TO THINK ABOUT

- Why are the locations not perfect?

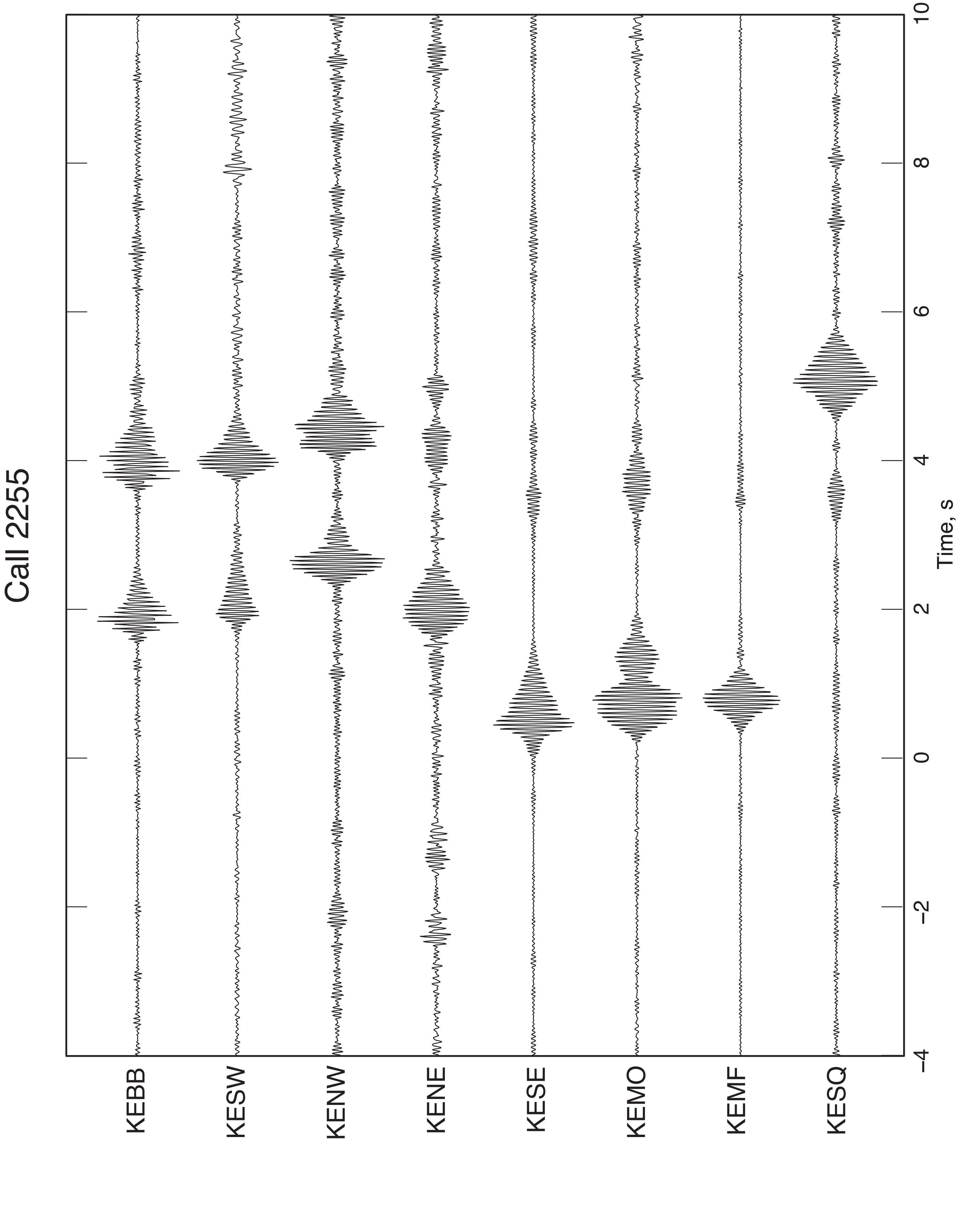
If you located many calls you would obtain a track that would record where the whale swam.

- What might be learned from a fin whale track?
- What other scientific observations would complement fin whale tracks and help us learn more?



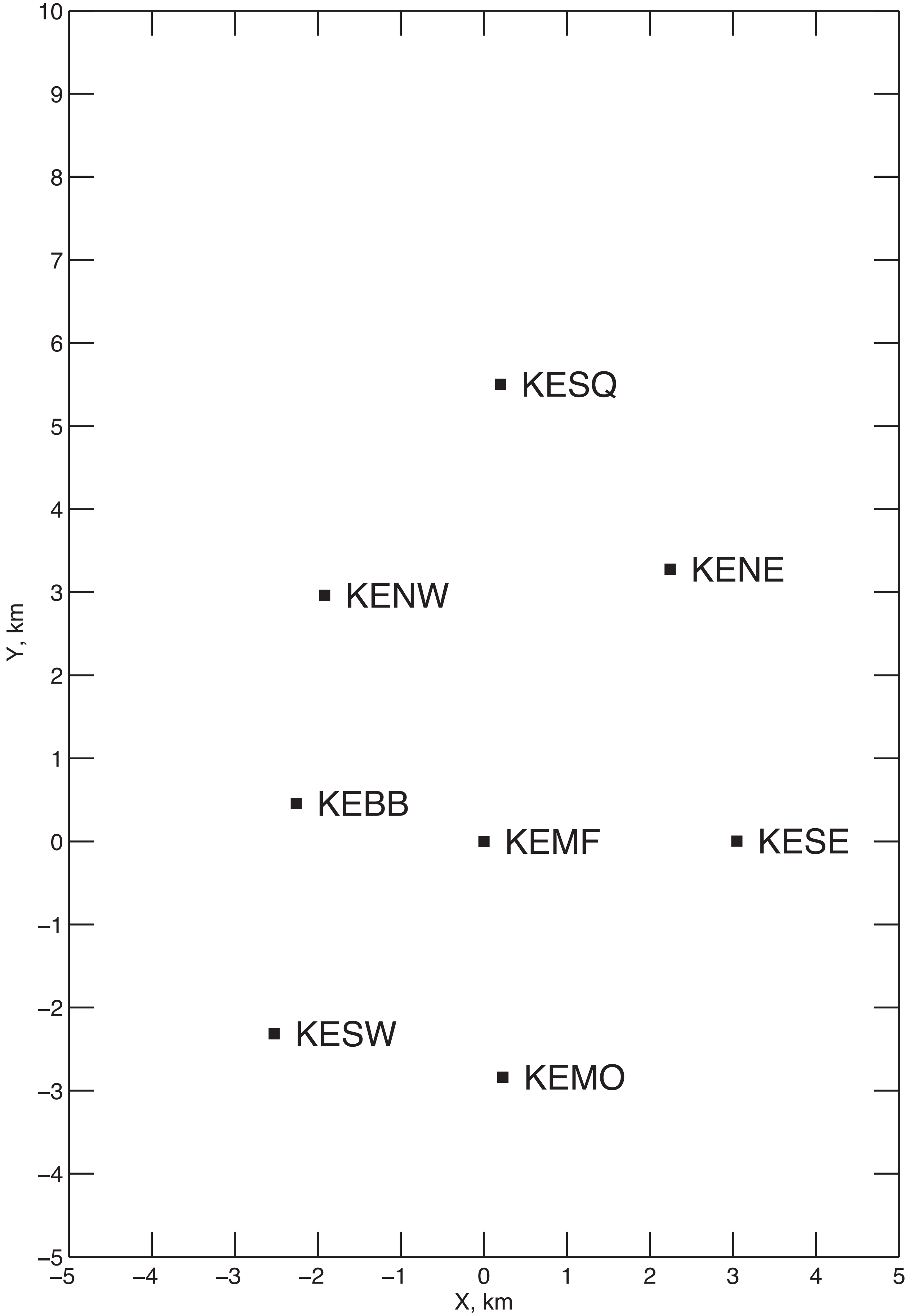
Call 1301
KEBB
KESW
KENW
KENE
KESE
KEMO
KEMF
KESQ
−4
−2
0
2
4
6
8
10
Time, s

Figure 4



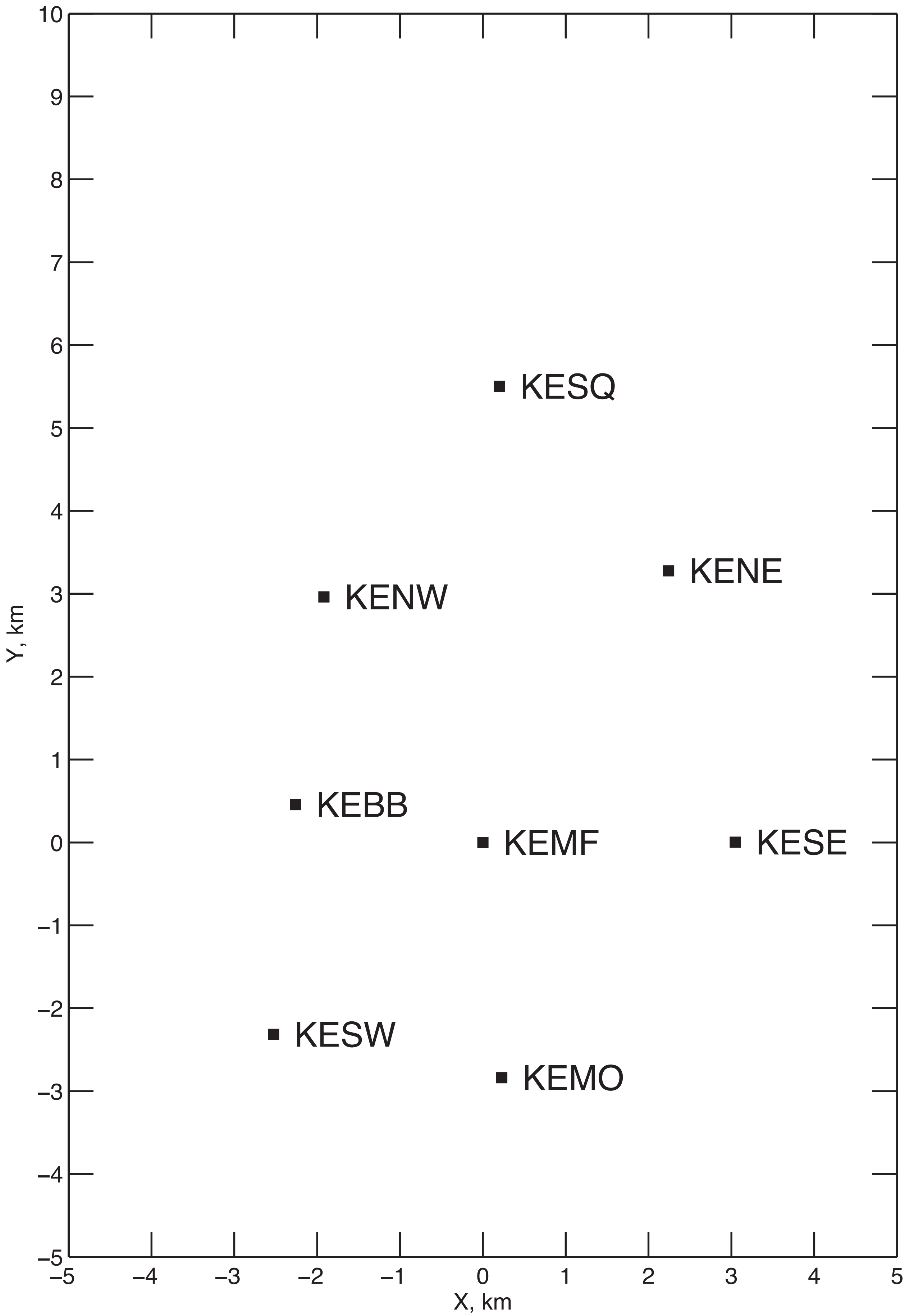
Call 2255
KEBB
KESW
KENW
KENE
KESE
KEMO
KEMF
KESQ
−4
−2
0
2
4
6
8
10
Time, s

Figure 5



KESQ
KENE
KENW
KEBB
KEMF
KESE
KESW
KEMO
Y, km
X, km
10
9
8
7
6
5
4
3
2
1
0
–1
–2
–3
–4
–5
–5
–4
–3
–2
–1
0
1
2
3
4
5

Figure 6



KESQ
KENE
KENW
KEBB
KEMF
KESE
KESW
KEMO
Y, km
X, km
10
9
8
7
6
5
4
3
2
1
0
−1
−2
−3
−4
−5
−5
−4
−3
−2
−1
0
1
2
3
4
5

Figure 6

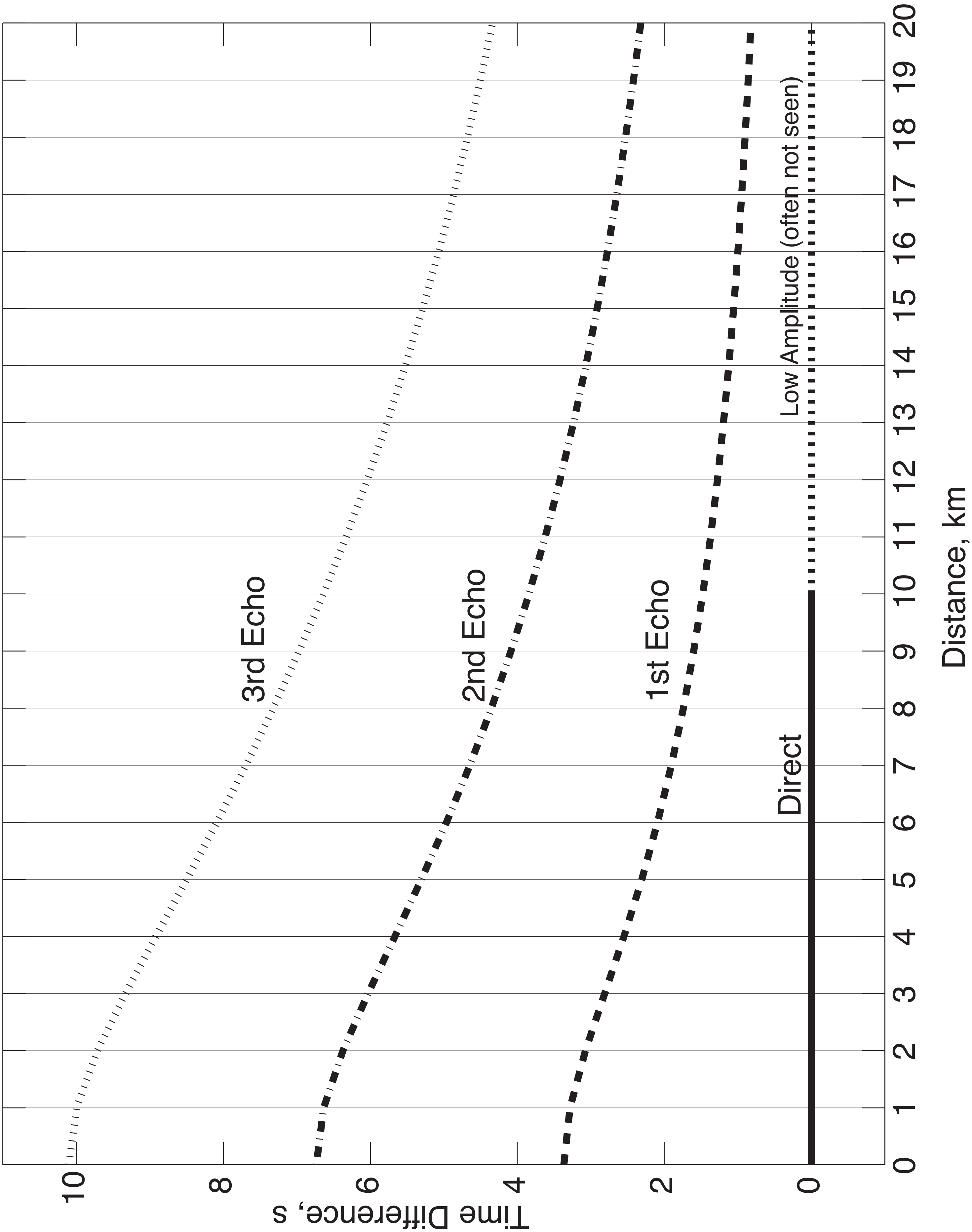

3rd Echo
2nd Echo
1st Echo
Direct
Low Amplitude (often not seen)
Distance, km
Time Difference, s
0
2
4
6
8
10
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20

Figure 7