Passively Recorded Acoustic Data as a Component of Marine GIS

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Abstract

Animals in the sea use sound for sensing their surroundings. Therefore, passively recorded acoustic data, incorporated into a marine GIS, provides critical information for understanding ocean habitat characteristics and for describing the acoustic interactions between marine organisms and their environment. This information is particularly important for evaluating the potential impacts of man-made sound sources in the marine environment. Specialized acoustic arrays and AUVs, in concert with advanced signal and array processing techniques, allow researchers and managers to passively record sound in the ocean and to determine the locations of specific sound sources as a function of time and recording position. Acoustic data layers can be used for habitat classification, monitoring, behavioral studies, and for identifying areas of potential impacts to the marine environment from anthropogenic sources of ocean noise. An example utilizing acoustic data as a component of a marine geodatabase for a Southern California rockfish habitat will be presented.

Background Information

Sound in the ocean originates from man-made sources and from natural sources. Man-made noise sources can be unintentional, such as ships and boats, or intentional such as military sonars, fish finders, seismic survey arrays, and bottom sounders. Recordings of sound in shallow water very near to shore (Figure 1) also indicate that noise from aircraft, land detonations, and vehicles on the beach can enter the near shore marine environment. Man-made sounds in the ocean can have negative impacts on marine animals, for example, the generation of certain military sonars have been associated with a few mass strandings of beaked whales (Cox, et, al., 2004).

Naturally occurring sounds in the ocean can be broken into two categories: physical noise sources (Figure 2) and biological noise sources. Physical sources of natural sound originating above or at the water's surface include bolides, precipitation, wind, ocean surface waves, and ice cracking/glacier calving. Physical sources of natural sound originating below the water's surface include sediment transport, underwater landslides and turbidity currents, earthquakes, and volcanic and venting activity (D'Spain and Wartzok, 2005).

Biological sources of sound include marine mammals, fishes, and invertebrates. Hundreds of marine animal species are known to be somniferous. A variety of the fishes have been determined to be sound producers (Tavolga, 1964). Invertebrates such as sea urchins and snapping shrimp are also known to create sound (NRC 2003, Cato, 1978). Additionally, a large number of marine mammals, including odontocetes, mysticetes, and pinnipeds, produce sounds of varying types.

Biological sound sources in the ocean can be a significant component of the undersea noise field. Research has been performed on the impact of biological sounds to sonar operations, and has recently been done on the impact of man-made sounds on biological communities. Additionally, sound in the oceans has been used to understand fish ecology, monitor locations of animals, and monitor biological populations and essential fish habitat (Rounntree, et. al., 2002). A potentially significant portion of ambient ocean noise comes from biological choruses. Fish choruses have been recorded in Australian waters (McCauley and Cato, 1998) as well as offshore California (D'Spain et.,al., 1997, Johnson, 1948, Fish, 1964). Notably, low frequency biological choruses were recorded using acoustic arrays in two sets of experiments performed by MPL(D'Spain, Berger, Kuperman, and Hodgkiss, 1997).

Animals use the sounds in the ocean environment for a variety of purposes:

a) sensing properties of the ocean environment
b) mating and courtship
c) locating prey and predator avoidance
d) aggression, defense
e) navigation
f) communication

One way sound is used by fish is for mating and courtship. An example is the plainfin midshipman fish (west coast, North America). Male fish "hum" to attract a mate, and "grunt" to deter others from eggs (Bass and Bodnar, 1998). Another use of sound is for place identification. Ambient noise of underwater habitats differs, and the noise field of a specific place can be important. In one study (Nature News, April 7, 2005), researchers constructed several artificial reefs. Some had sounds from a healthy reef playing underwater, some did not. The reefs with sound recordings attracted a far greater amount of fish than that of the silent reefs.

Sound may be the primary way that many marine species sense the properties of the ocean environment. Therefore, ocean noise is an important component when describing a marine habitat. This importance is evident by the above examples of how sound plays a significant role in the life histories of marine species and species interaction with the marine environment.

Experiment description

Passive acoustic data can be collected from several instrument platforms using hydrophone (underwater sound recording devices) arrays. Often, hydrophones are strung together to form a line array which is placed on the ocean bottom, hung from a buoy, or deployed from a vessel such as a ship or platform. Also, hydrophone arrays have been incorporated into Autonomous Underwater Vehicles (AUVs) for acoustic data collection (Zimmerman, et. al., 2005). Figure 3 shows an example of hydrophones in an AUV.

Data discussed in this paper were collected as part of the Mid-Frequency Ocean Noise Experiment (MF02b). In July, 2002, the R/P FLIP (Figure 4), a 100-m manned spar buoy operated by the Marine Physical Laboratory (MPL), was placed in a 3-point moor in 175-m-deep water on a bathymetry ridge called the "40-Mile Bank". This was about 60 km west of San Diego near San Clemente Island. FLIP was located 2 km away from the "43-Fathom Spot", a popular fishing area in the Southern California Bight and rockfish habitat, and was used as a platform to deploy an acoustic recording array. This 2D billboard array (Figure 5a and 5b) was composed of 4 vertical staves, each with 32 elements. The 4X32 elements consisted of hydrophones – underwater sound recording devices. At the top and bottom of the array were instruments to measure heading, pitch, and roll of the array, as well as water temperature and depth. Data was recorded continuously from 23-30 July, 2002.

When the data was examined, a biological chorus was evident on at least two consecutive nights. The chorus (Figure 6) is composed of sounds centered around 1.5 kHz and between 4 and 5 kHz (D'Spain and Batchelor, accepted for publication, 2005). Individual calls were not discernable, just a cloud of sound. The two separate frequency clouds exhibit the same variability over time; therefore they most likely come from the same source. The chorus begins around sunset, and drops off at sunrise, which is a common aspect of other biological choruses in the Southern California Bight.

Data processing

The first step in the data processing is to choose appropriate time periods and frequencies. Four time periods were chosen for this study. The first was a portion of the night time biological chorus data. Next, for comparison, a time period dominated by wind generated noise was processed. For added interest, two control time periods with an acoustic source were chosen. One has the source 10 m below the water's surface; the other had the source at a depth of 52 m. This acoustic source broadcast specific tones underwater from a small research vessel near FLIP.

The next step was selecting an appropriate frequency of interest. 3500 Hz was chosen, it is a tone transmitted by the acoustic source and is within the frequency band of the biological chorus. As the MF02 experiment was not intended to study biologics, other oceanographic instruments were operating during data collection and their signals were removed from the data prior to processing.

The main goal of the data processing for this application is to identify *where* specific sounds are coming from with respect to the array. This is accomplished using a technique called beamforming. The MF billboard array has greater spatial resolution in the vertical than in the horizontal, therefore different types of beamforming were used in the two different directions. Data were processed both in the vertical direction and in the horizontal direction. This approach results in a sound pressure level for each of 32 vertical slices and a sound pressure level for each of 9 horizontal slices. By examining the different levels, it is possible to identify where a sound is from in depth and azimuth, with respect to the array.

Sound levels are reported in dB (decibels) re 1 $\mu Pa^2/Hz$. Note that a decibel is a ratio of squared pressure amplitude, and that a level of 30 dB in water is quite different than 30 dB in air because of a difference in reference value. Also, beamforming with an array of this geometry results in a left/right ambiguity i.e., sound coming from a given horizontal slice on the left-hand side of this billboard array cannot be distinguished from that coming from the corresponding horizontal slice on the right-hand side (D'Spain and Batchelor, 2005).

Incorporating this acoustic information, the output of the beamforming, into ArcInfo is fairly straightforward. For each time period, the resulting sound levels and azimuths are first separated into 32 text files (by depth bins with respect to the array). Each of these is then read into Excel and assigned the transformed azimuths (real world azimuths with respect to true north as opposed to azimuths with respect to the array). As the direction in which the array was facing was measured throughout data collection, the rotation is straightforward and specific to each time period.

A file of empty polygons was created in 20 degree-in-azimuth wedges centered at the location of the array (Figure 7). The polygons were assigned the sound pressure level associated with the corresponding azimuth. For example, for an azimuth of 10 degrees, the sound pressure level is 32 dB re 1 μPa^2/Hz. The wedge centered on 10 degrees with respect to the array location is assigned a value of 32 dB re 1 μPa^2/Hz.

These polygon files can be added to a marine geodatabase. In the following example, layers include FLIP location (the array was deployed from FLIP), bathymetry, and the controlled acoustic source location/ship track.

Example

The results of data processing include polygon layers of ocean noise with respect to a recording array. The polygons are able to depict noise levels at the array and which direction in azimuth the noise arrives from. In this example, separate files are used for different noise arrival (at the array) depths.

The nighttime biological chorus data is presented first (Figure 8). For clarity, the colorbar scheme used for figures 9-11 will be identical, but different than the scheme used for figure 8. Figure 8 shows that the sound levels arriving at the array vary as a function of azimuth. A difference of 3 dB is significant in ocean noise. The chorusing sounds are coming from either the deep waters off the shelf to the west, or the shallow flats to the east (left/right ambiguity) and not the bathymetry high as expected.

Figure 9 is an illustration of the ambient ocean noise during a wind-dominated time period. (Wind-generated ocean surface wave activity is a main component of ambient ocean noise re Figure 2.) Note that a comparable level of sound is arriving from all directions with respect to the array.

The control data set, that of known acoustic sources, are presented in figures 10a, 10b, 11a, and 11b. The data show that the highest levels of sound are coming from the direction of the source (refer to Figure 10a – the yellow area depicts the azimuth of the source, and the azimuth from which the highest levels of sound are arriving from). The source-generated sound levels are about 20 dB higher than the ambient noise (Figure 10a). Two source time periods are shown. In the first, the acoustic source was 10 m below the ocean surface. The MF billboard array allows for beamforming in both azimuth and elevation with respect to the array. Two elevation angles of sound arrival are presented. Figure 10a is sound coming from elevation angles upward from the horizontal direction; figure 10b is sound arriving at the array in the horizontal direction. The sound levels in the source direction upward looking from the array are higher than sound levels from the source direction coming from the horizontal. Figure 11a and 11b are of data from an acoustic source lowered to 52 m below the ocean surface. The sound levels from the source direction upward looking from the array are lower than sound levels from the source direction coming from the horizontal.

The example data demonstrate the potential of utilizing passive ocean acoustic data in GIS. It is possible to discern differences in sound levels in azimuth and elevation (water depth) with respect to the recording array. As sound is potentially the most important way that marine organisms sense their environment, interact with their environment, and interact with each other, ocean noise should be considered a significant component of marine habitats. Therefore, passive acoustic data should be included in a marine GIS involving marine animals, both for scientific studies and for management purposes.

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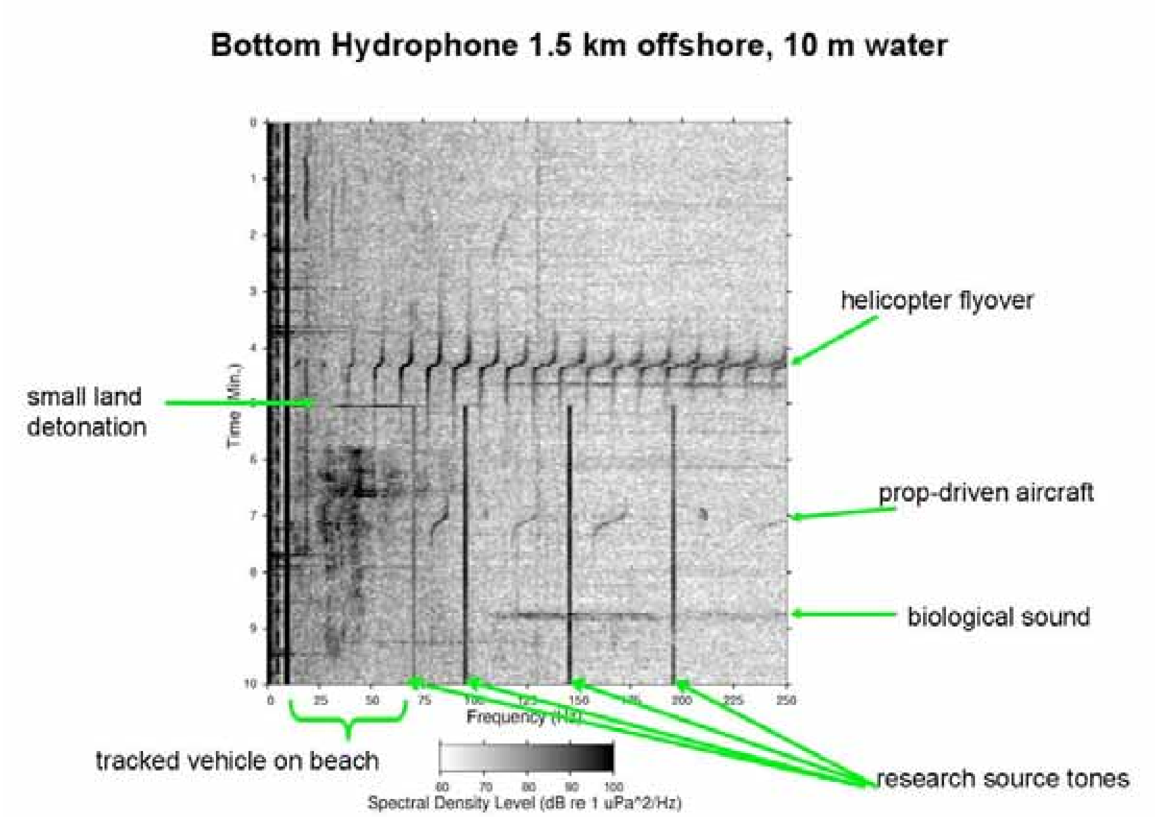

Bottom Hydrophone 1.5 km offshore, 10 m water
helicopter flyover
small land detonation
prop-driven aircraft
biological sound
tracked vehicle on beach
research source tones
Time (Min.)
0
1
2
3
4
5
6
7
8
9
10
Frequency (Hz)
0
25
50
75
100
125
150
175
200
225
250
60
70
80
90
100
Spectral Density Level (dB re 1 uPa^2/Hz)

Figure 1

Natural Physical Sources

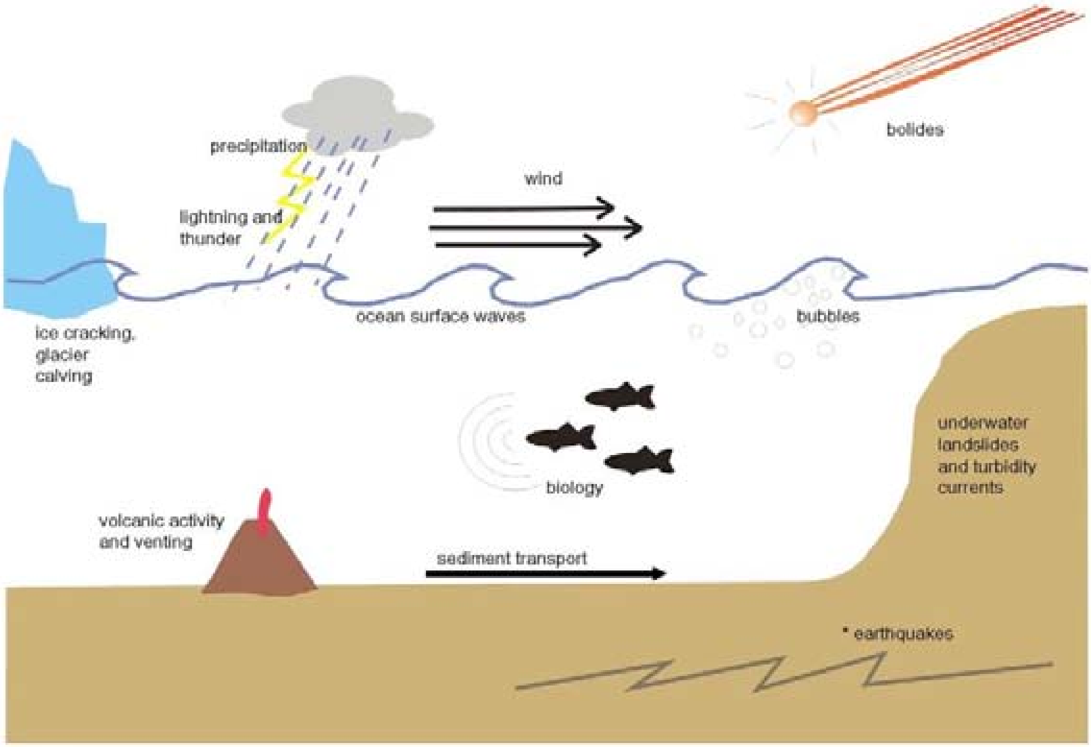


Figure 2

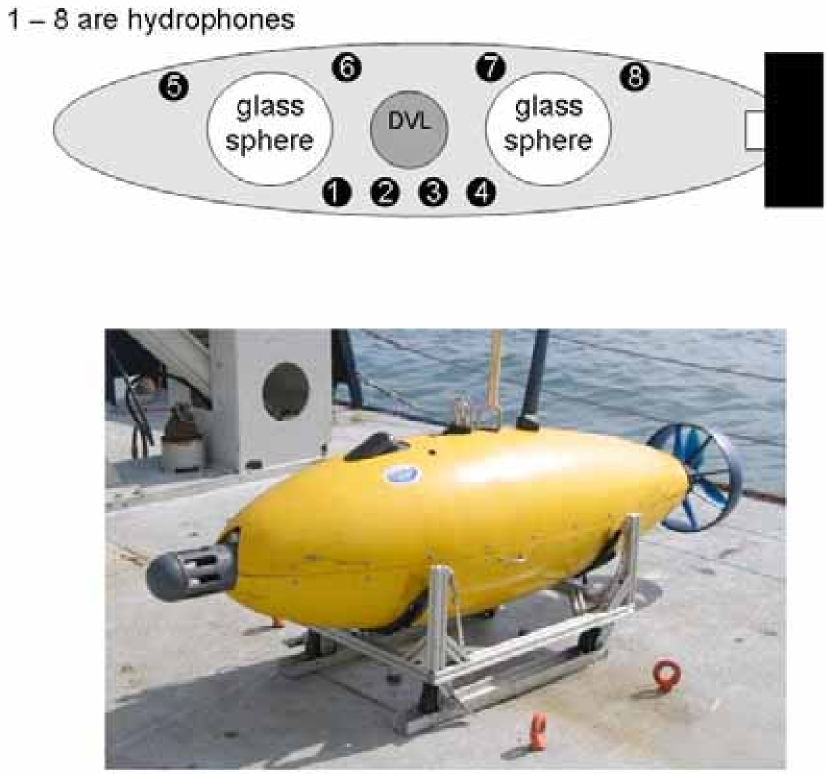


Figure 3

Figure 4

Figure 5a

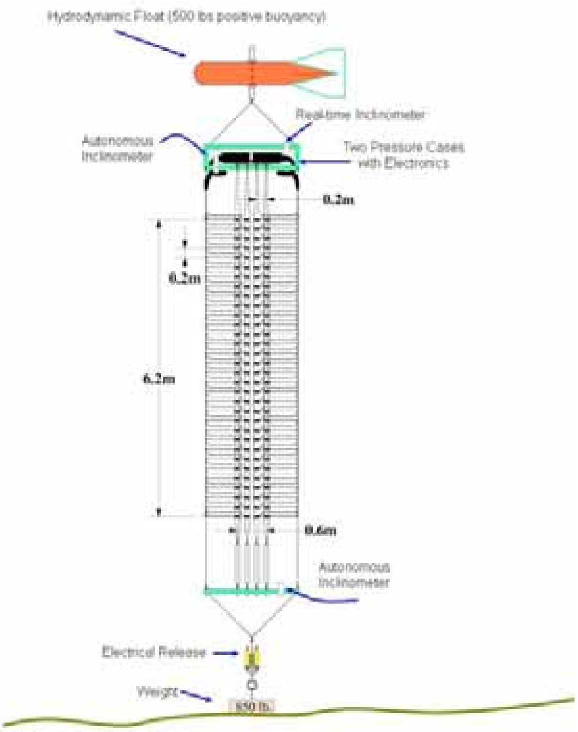
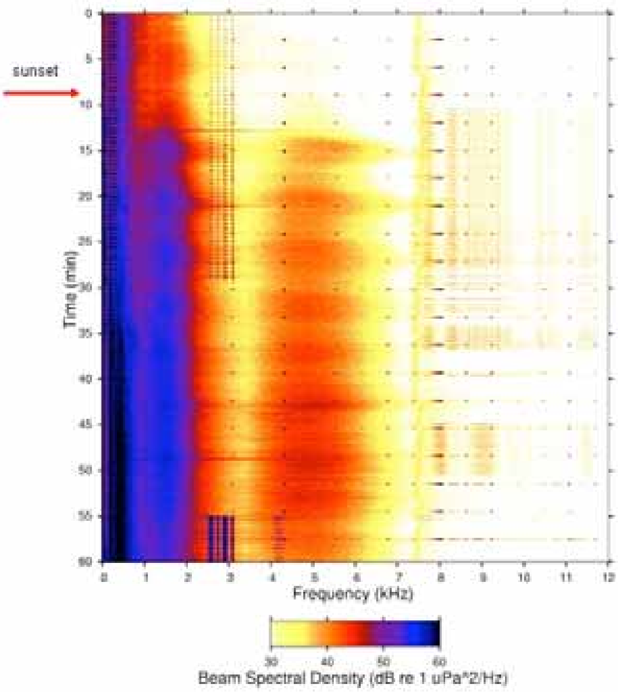


Figure 5b



sunset
Time (min)
0
5
10
15
20
25
30
35
40
45
50
55
60
Frequency (kHz)
0
1
2
3
4
5
6
7
8
9
10
11
12
30
40
50
60
Beam Spectral Density (dB re 1 uPa^2/Hz)

Figure 6

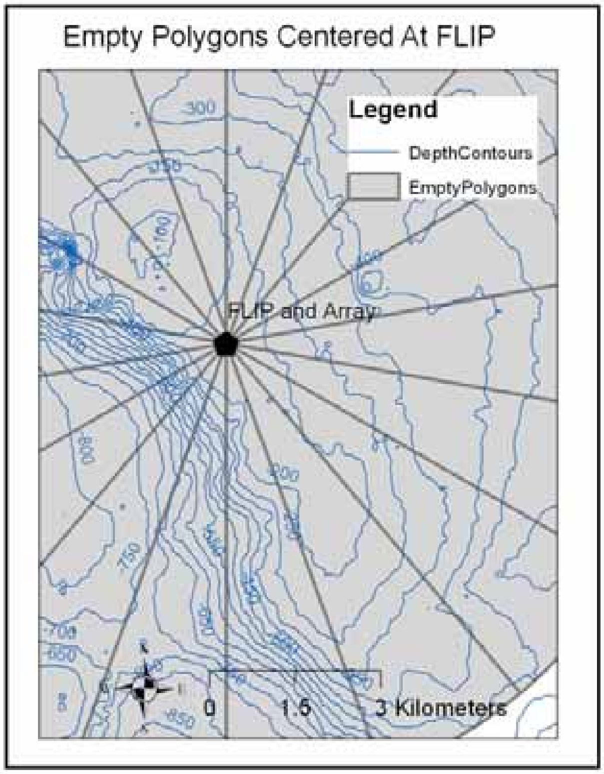

Empty Polygons Centered At FLIP
Legend
DepthContours
EmptyPolygons
FLIP and Array
-300
-350
-400
-800
-750
-700
-850
0
1.5
3 Kilometers

Figure 7

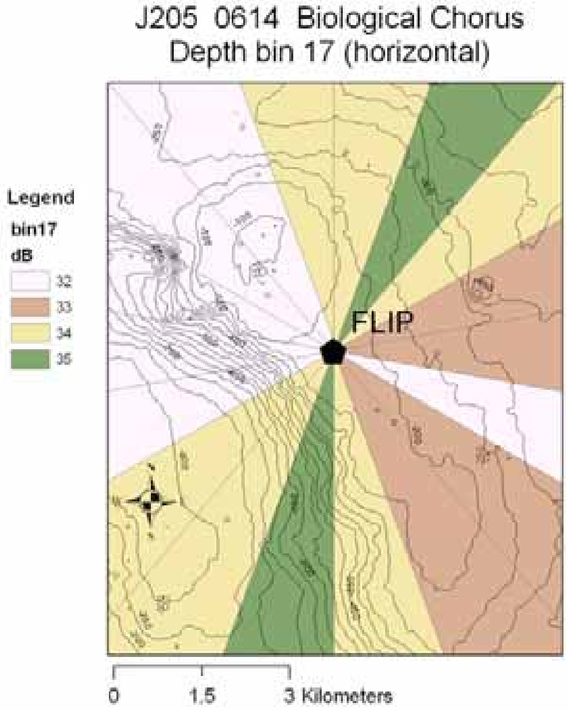
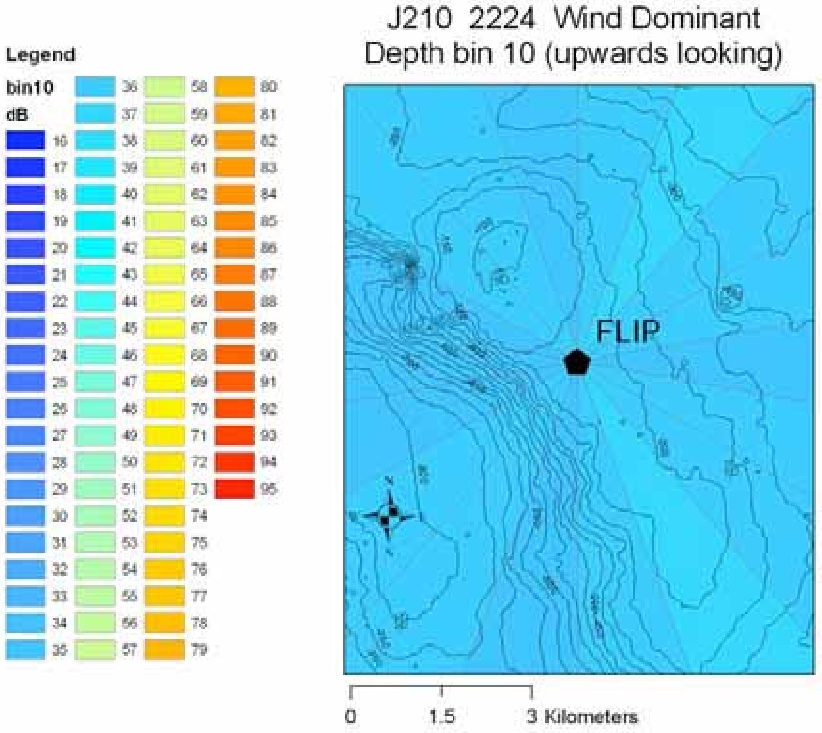

J205 0614 Biological Chorus
Depth bin 17 (horizontal)
Legend
bin17
dB
32
33
34
35
FLIP
0
1.5
3 Kilometers

Figure 8


J210 2224 Wind Dominant
Depth bin 10 (upwards looking)
Legend
bin10
dB
16
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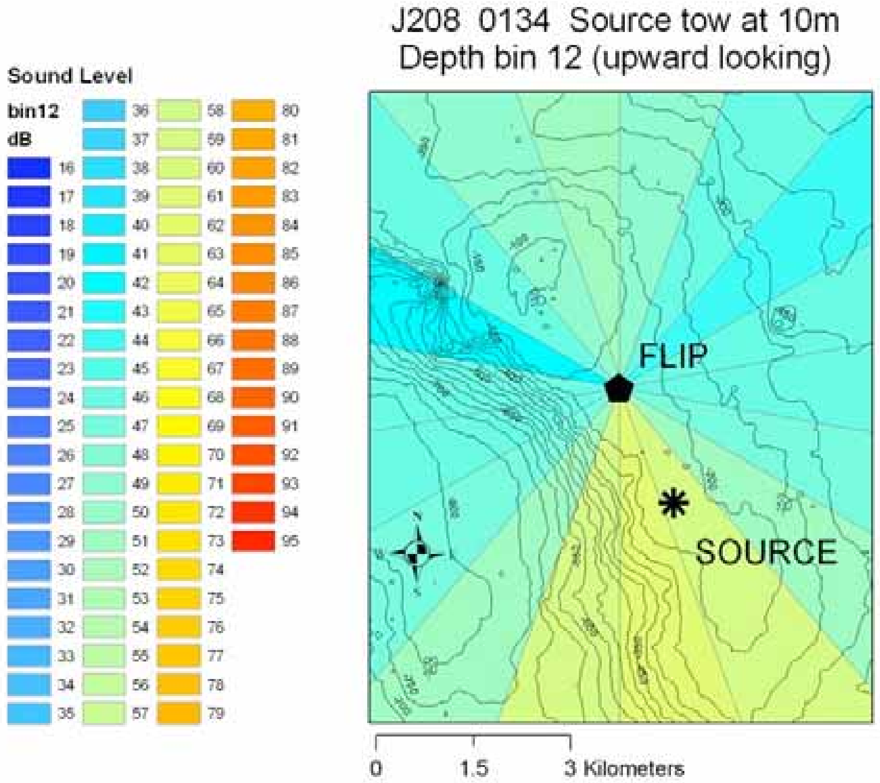
92
93
94
95
FLIP
N
0
1.5
3 Kilometers

Figure 9


J208 0134 Source tow at 10m
Depth bin 12 (upward looking)
Sound Level
bin12
dB
16
17
18
19
20
21
22
23
24
25
26
27
28
29
30
31
32
33
34
35
36
37
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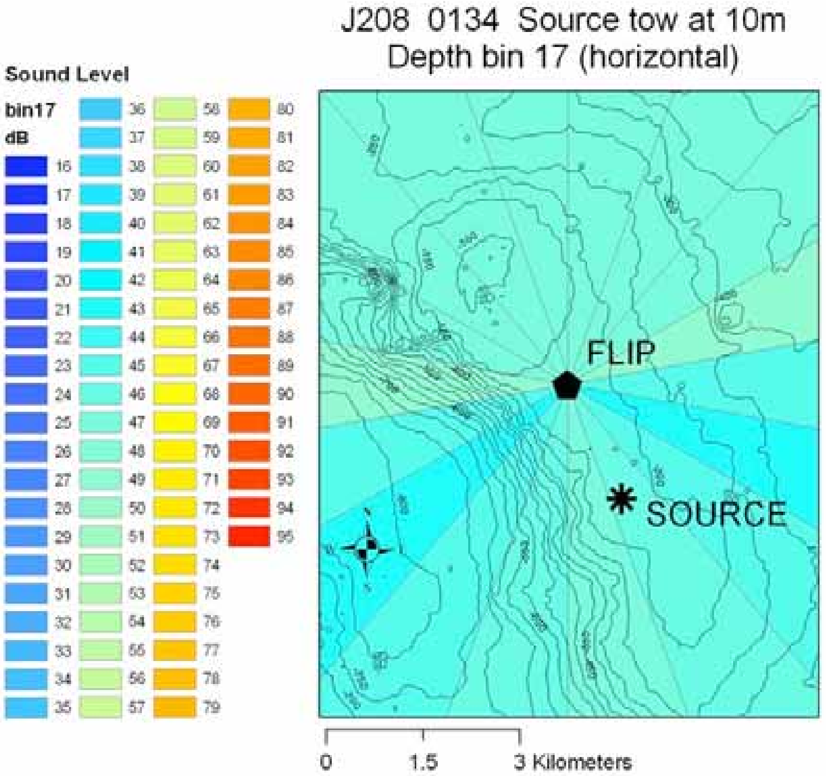
95
FLIP
SOURCE
N
0
1.5
3 Kilometers

Figure 10a



J208 0134 Source tow at 10m
Depth bin 17 (horizontal)

Figure 10b

J208 0304 Source tow at 52m
Depth bin 12 (upward looking)

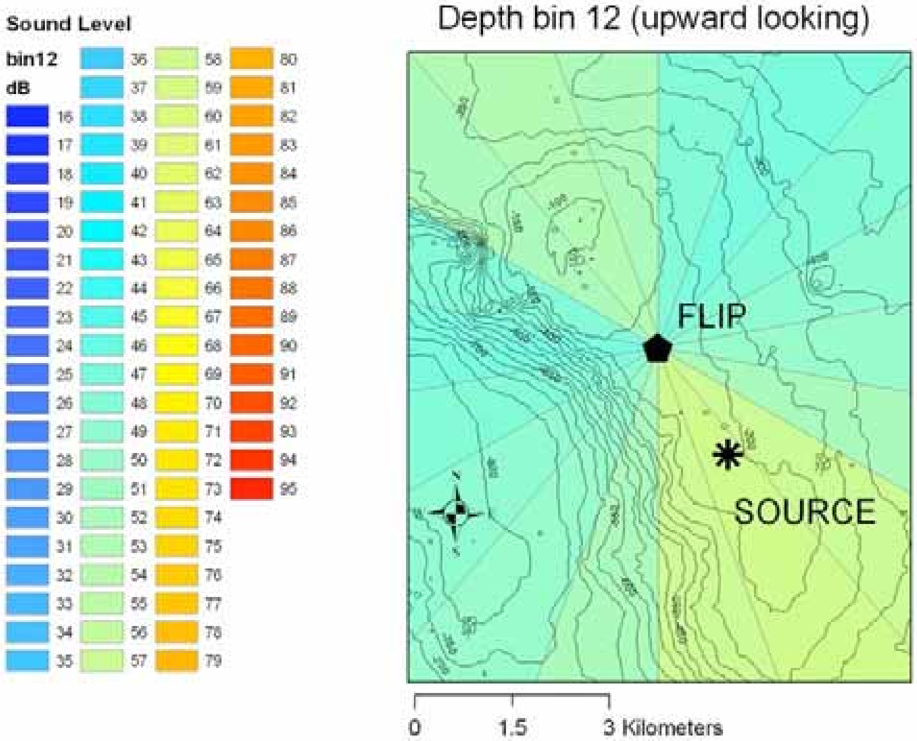


Figure 11a

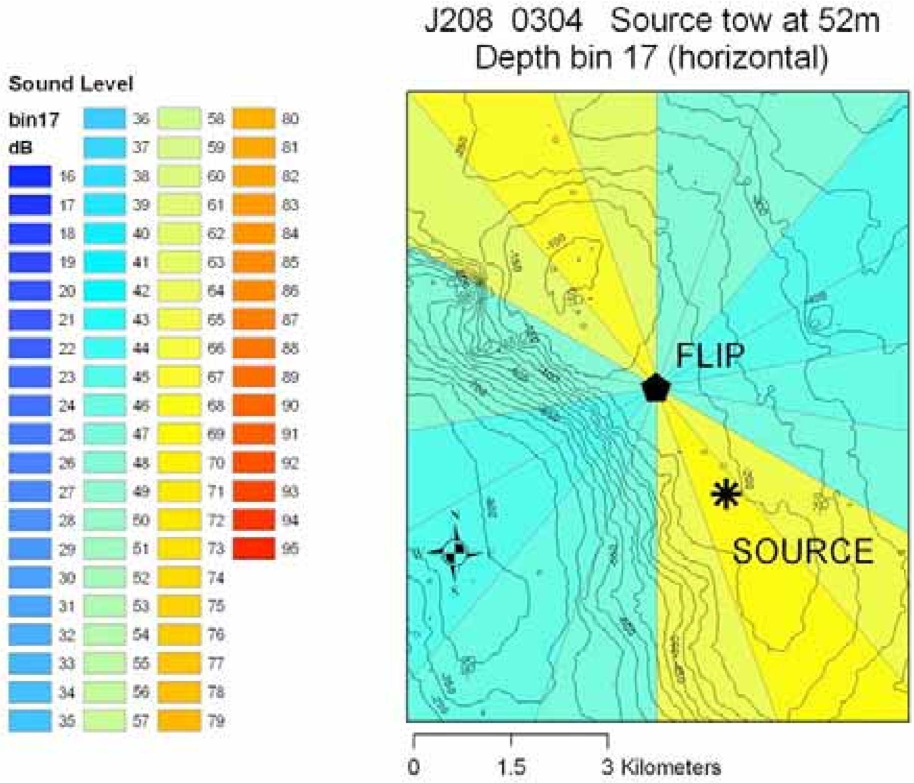

J208 0304 Source tow at 52m
Depth bin 17 (horizontal)
Sound Level
bin17
dB
16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34 35
36 37 38 39 40 41 42 43 44 45 46 47 48 49 50 51 52 53 54 55 56 57
58 59 60 61 62 63 64 65 66 67 68 69 70 71 72 73 74 75 76 77 78 79
80 81 82 83 84 85 86 87 88 89 90 91 92 93 94 95
FLIP
SOURCE
0
1.5
3 Kilometers

Figure 11b