Source Levels of the Washington State Ferry in Haro Strait

Erin E. Bauer
Colorado College Physics Department, Colorado Springs, Colorado
Should have a date, I would think
~~Abstract:~~ bold this

Using an underwater hydrophone array located off the coast of San Juan Island, Washington and a calibrated mobile hydrophone system, source levels of the Washington State Ferry on its path through Haro Strait were calculated. Initial observation of sound levels seemed unusually intense and raised questions of atypical sound propagation patterns in the area. Further analysis of more extensive measurements of the Washington State Ferry confirmed an average source level of 205 dB re 1 μPa@1m. need some error limits here Such a high source level calculation fully accounted for any seemingly anomalous sound intensities and dismissed the need for any further exploration of atypical sound propagation. This seems too strong to me. You imply that the bathymetry etc have no role. Do you have evidence of this? For example, does spherical spreading from OrcaSound to the ferry seem to explain the propagation? Does the sound seem to spread even more that spherical?

I. Introduction

The path of the Washington State Ferry through Haro Strait, as observed from a point six nautical miles south of the ferry on the west side of San Juan Island, Washington, produces unexpectedly intense sound patterns. Observing the sound of the ferry through the OrcaSound hydrophone array, located 200 meters off the shore of San Juan Island (latitude 48° 33.5', longitude 123° 10.4'), received sound levels from the ferry are significantly just how much? higher than those from closer vessels. This paper will explore these seemingly anomalous sound intensities of the Washington State Ferry, looking at any unexpected underwater source levels or sound propagation to attempt to explain discrepancies between expectation and observation.

Figure 1 shows a map with the path of the ferry, with visual observation as seen from OrcaSound marked in red.

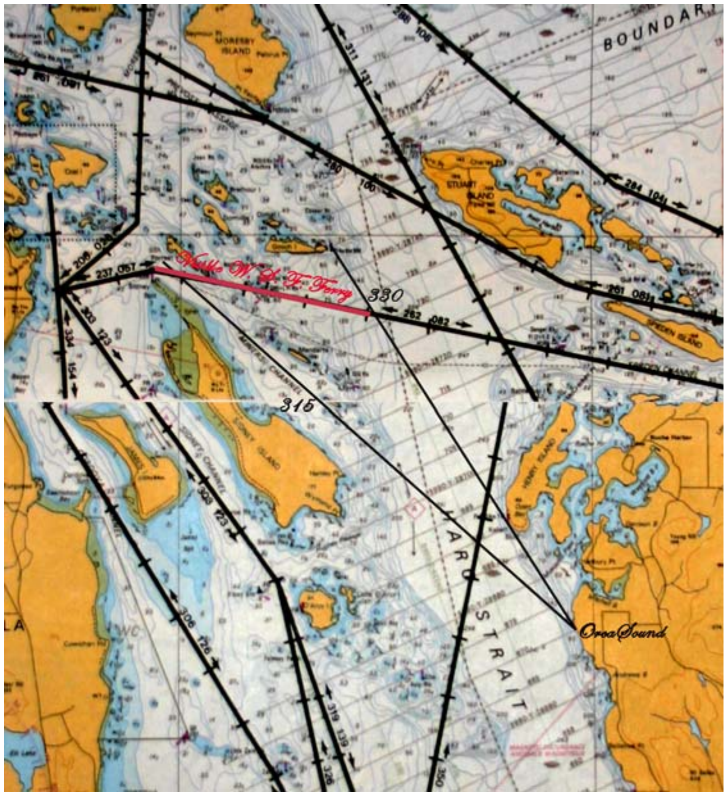

Fig. 1. Path of the Washington State Ferry and surrounding area

Can you confirm this sketch using the online reporting that the Washington State Ferry does?

II. Procedure

Sound from the ferry was recorded with both the OrcaSound hydrophone array and a mobile hydrophone located varying distances from the ferry.

A. System Calibration

Sound levels from the mobile hydrophone were recorded and saved with a laptop computer. Later analysis of these data files produced an R.M.S. voltage for each file. This recorded voltage corresponded with a decibel level on the computer on a relative scale of –50 to zero units. Calibration of this mobile system with the previously calibrated OrcaSound hydrophone system (Veirs 2004) produced an actual received decibel level. The laptop computer was set with a gain of 1100 throughout the calibration and data collection processes.

To correlate recorded voltage levels to a relative decibel level on the mobile computer, sounds were inputted to the computer using a function generator, then recorded while noting the corresponding decibel level. Logarithms of recorded voltage levels were plotted against observed decibel levels to determine the corresponding linear relationship, shown in Figure 2.

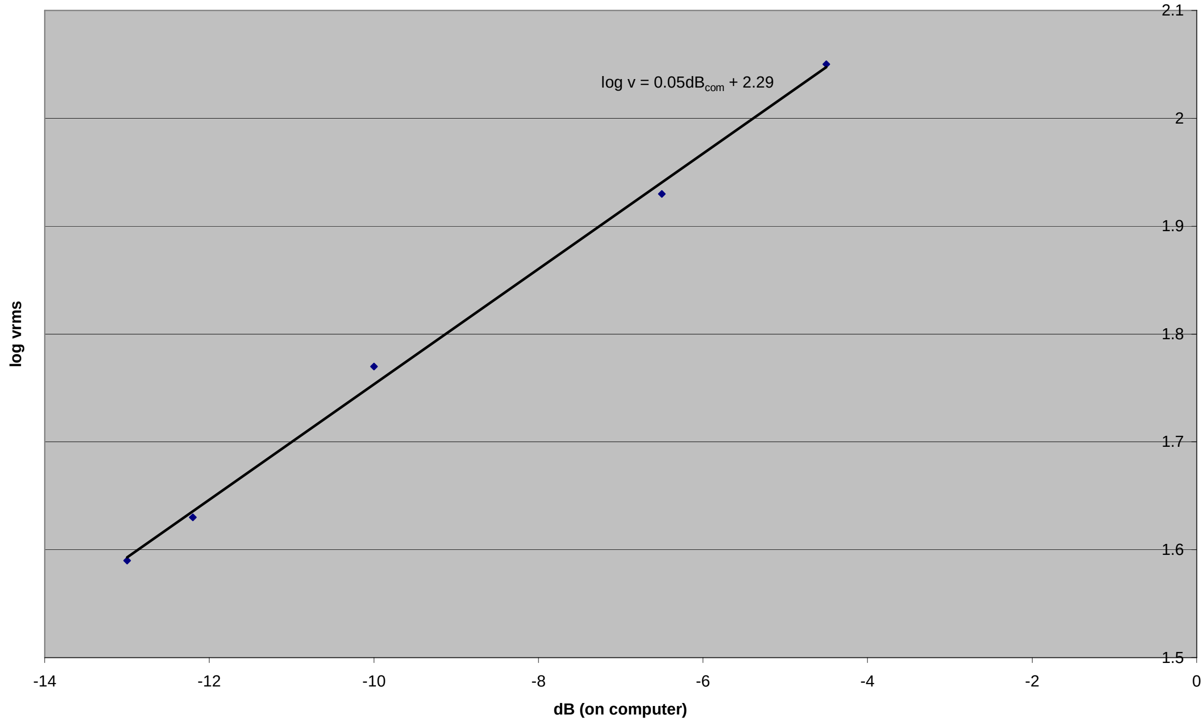

Fig. 2. Logarithm of voltage level vs. computer decibel level
what is bgv above? Should it be log v? Capital V is more common for voltage.
Why not stop the x axis at –4? Is the font above readable?

Fitting a line to the data produced an equation of $\log v = 0.05dB_{com} + 2.29$, where v = the R.M.S. voltage level of each file and dB_{com} = the corresponding decibel level on the laptop computer.

To convert relative decibel levels on the laptop computer to actual received decibel levels, the computer was connected to one hydrophone in the OrcaSound array, while the other three hydrophones remained in the usual configuration. Sound levels of the two systems were then recorded and plotted to determine the corresponding relationship, shown in Figure 3.

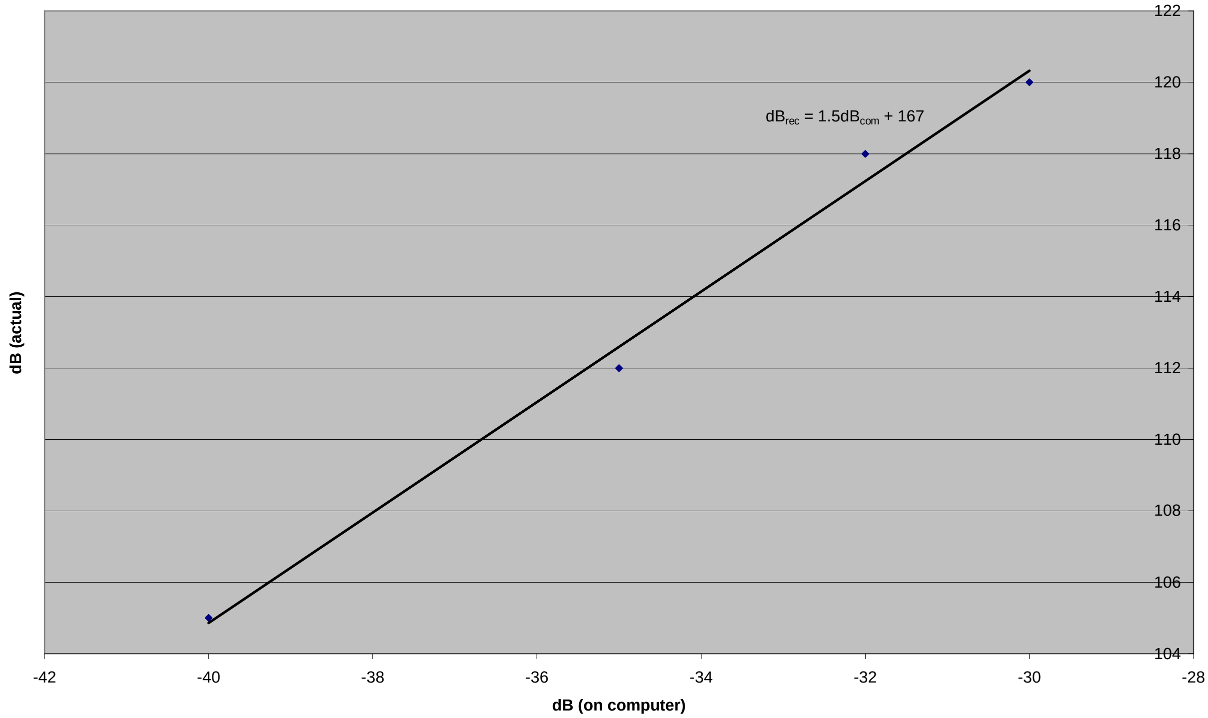

Fig. 3. Actual received decibel level vs. computer decibel level

Fitting a line to the data produced an equation of $dB_{rec} = 1.5dB_{com} + 167$, where dB_{com} = the decibel level on the laptop computer and dB_{rec} = the actual received decibel level as related to the OrcaSound array.

~~Putting~~ – are you solving for something? Putting doesn't sound like algebra both equations together produces a final calibration equation of $dB_{rec} = 30\log v + 98.3$, where v = the R.M.S voltage level of each recorded computer file, and dB_{rec} = the actual received decibel level.

B. Data Collection

Sound from the ferry was recorded by the OrcaSound hydrophone array from a distance of six nautical miles (11 kilometers). This distance was measured using a map with the ~~known~~ expected? ferry path.

Sound was also recorded by the mobile hydrophone system at distances of 300 to 1800 meters from the ferry. The hydrophone was deployed at a depth of approximately two meters off a ~~stationary~~ drifting? catamaran and sound levels were recorded as the ferry passed. Distances from the hydrophone to the ferry were measured using a range finder.

Background voltage levels were measured throughout the data collection process at times without ferry or other significant additional noise.

III. Results

A. OrcaSound array data

Table 1 shows a sequence of recordings made by the OrcaSound hydrophone array as the ferry passed through Haro Strait, with received decibel levels, signal decibel levels after removing background noise, and calculated source levels of the ferry. The OrcaSound system has been calibrated to produce actual decibel levels, so no further calibration is needed. Background decibel levels have been removed using the equation, $dB_{sig} = 10\log(10^{dB_{rec}/10} - 10^{dB_{bk}/10})$ (Richardson et al. 1995), using an average background decibel level of 104 dB re 1 μ Pa. Source levels have been calculated using a spherical spreading model of sound propagation with the equation, $dB_{source} = dB_{sig} + 20\log R$ (Richardson et al. 1995), where R=11,112 meters. Explain why you are using spherical spreading here? What kinds of physical arguments about spreading can you make and what other source levels might result? Include alternate spreading calculations in the table below. Here is where you need to include and discuss the vertical sound speed profile that we measured?

Test	dB_{rec}	dB_{sig}	dB_{source}
1	111.00	110.03	190.95
2	112.41	111.73	192.65
3	115.53	115.21	196.13
4	116.80	116.57	197.49
5	116.38	116.12	197.04
6	112.01	111.26	192.18

Table 1. Sound data taken with the OrcaSound hydrophone array

Using this data, the average underwater source level of the ferry, as measured from the OrcaSound hydrophone array, is 194 dB re 1 μ Pa@1m. (assuming spherical spreading)

B. Mobile hydrophone data

Table 2 shows a sequence of tests made as the ferry passed the mobile hydrophone, with R.M.S. voltages from the computer recordings, signal voltages after removing background noise, actual received decibel levels calculated through the previously discussed calibration equation, distances in meters from the hydrophone to the ferry, and calculated source levels of the ferry. Voltage background noise has been removed through the equation, $v_{source(rms)} = (v_{rec(rms)}^2 - v_{bk(rms)}^2)^{1/2}$ (Galli et al. 2003), using an average background voltage level of 5.56. Source levels have again been calculated using the equation, $dB_{source} = dB_{rec} + 20\log R$. Again, discuss why you are using this model alone. Does it make more or less sense to do this 'near' the ferry than it does at OrcaSound?

Test	$v_{rec(rms)}$	$v_{sig(rms)}$	dB_{rec}	R (m)	dB_{source}
1	93.31	93.14	157.37	1800	222.48
2	84.19	84.01	156.03	1500	219.55
3	72.56	72.35	154.08	1250	216.02
4	79.48	79.29	155.28	1100	216.12
5	95.67	95.51	157.70	1000	217.70
6	81.07	80.88	155.54	1000	215.54
7	82.40	82.21	155.75	1200	217.33
8	91.11	90.94	157.06	900	216.04
9	80.56	80.37	155.45	1000	215.45
10	103.34	103.19	158.71	1400	221.63
11	84.18	84.00	156.03	1500	219.55
12	144.67	144.56	163.10	388	214.88
13	55.84	55.56	150.64	391	202.48
14	101.56	101.41	158.48	400	210.52

Table 2. Sound data taken with the mobile hydrophone system

Using this data, the average underwater source level of the ferry, as measured from the mobile hydrophone array, is 216 dB re 1 μ Pa@1m.

Combining the OrcaSound and mobile hydrophone results, the average underwater source level of the Washington State Ferry is 205 dB re 1 μ Pa@1m. think about how you should average two sound intensity measurements. Then think about what a dB is and figure out how to "combine" two dB's to get the average sound level in dB.

The ferry produces a wide range of frequencies (70 to 4140 Hz), with an average dominant frequency of 1420 Hz.

IV. Discussion

Sound levels of the Washington State Ferry as it crosses Haro Strait seem unusually intense when observed by the OrcaSound hydrophone array. Anticipated explanations for such observation include unexpected source levels or atypical sound propagation. ~~Measured source levels~~an average source level of 194 dB re 1 μ Pa@1m ~~from~~ computed from measurements at OrcaSound seem anomalously intense when compared with other large vessels (give this comparison), but data from closer to the ferry confirms such intense source levels. High source level rather than unusual sound propagation accounts for seemingly anomalous sound patterns. Simply put, the Washington State Ferry sounds unusually loud because it is unusually loud.

As a comparison of the 205 dB re 1 μ Pa@1m source level of the ferry, large tankers generate an average broadband source level of 186 dB re 1 μ Pa@1m, while air gun arrays, at 216 dB re 1 μ Pa@1m, produce more similar source levels to those of the ferry. This statement needs a reference and it would be nice if some refs outside of our textbook could be included.

I think your conclusion is oversimplified. In addition to the ferry sounding 'loud' we also notice that container ships in that northern region are readily audible as well. And, the sound of the ferry comes and goes as the ferry passes along and this must have something to do with the bathymetry.

Please review the structural requirements for this paper and make sure that you have met all of the requirements. I don't see error analysis, discussion of models, photos …

References It would be good to have something from the primary 'research' literature in your references (and in your paper).

Galli, Luke, Hurlbutt, Brian, Morton, Bill, Schuster, Sarah, Jewett, Winn, & Van Hilsen, Zach (2003). Boat Source-Level Noise in Haro Strait: Relevance to Orca Whales.

Richardson, John W., Greene, Charles, Malme, Charles, & Thomson, Denis. *Marine Mammals and Noise.* Academic Press: San Diego, 1995.

Veirs, Val (2004). Source Levels of Orca (*Orcinus Orca*) Social Vocalizations Measured with a Shore-Based Hydrophone Array.