The Acoustic Signature of High-Temperature Deep-Sea Hydrothermal Vents

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I. Summary

Observations of black smoker fluid properties often contain tidal signals (e.g. Larson & Lilley [2002]), which may be related to the response of the underlying hydrologic system to tidal loading. Recent poroelastic convection models show that fluid flow within black smoker systems may also be sensitive to tidal loading, and that measurements of flow across the seafloor boundary may provide insights into the physics of subseafloor hydrothermal systems [Crone & Wilcock, 2005].

Measurements of flow through high-temperature vents are difficult to obtain, and long time-series measurements do not exist. It has been suggested that sound generated by fluid flow through black smokers may be sensitive to changes in flow rate [Little, 1990]. Thus passive acoustic techniques might provide a non-invasive method for obtaining flow information from these systems.

To assess the possibility of using passive acoustic techniques to study fluid flow through black smokers, we have developed two versions of a deep-sea acoustic recording system, and have deployed the devices at vents in the Main Endeavour field on the Juan de Fuca Ridge. We collected ~48 hours of data from one vent in 2004, and ~6 days of data from another vent in 2005. Our data show that vents radiate acoustic energy at levels well above background, and have distinct and complex acoustic signatures. The acoustic signals vary in time and have tidal periodicity in some frequency bands. We speculate that several acoustic source mechanisms operate within black smokers, possibly including pipe resonance, cavitation, turbulent dissipation, and mixing-induced density perturbations.

II. Motivation

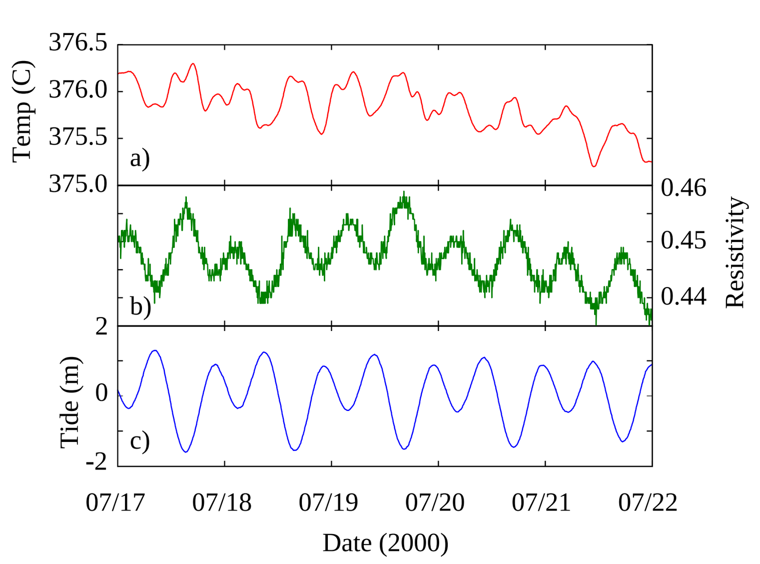

Figure 1. a) Black smoker temperatures, and b) fluid resistivity often correlate with c) tidal height. Measuremennts such as these motivated our desire to better understand the interactions between tidal loading and seafloor hydrothermal systems. (Data provided courtesy of Ben Larson.)

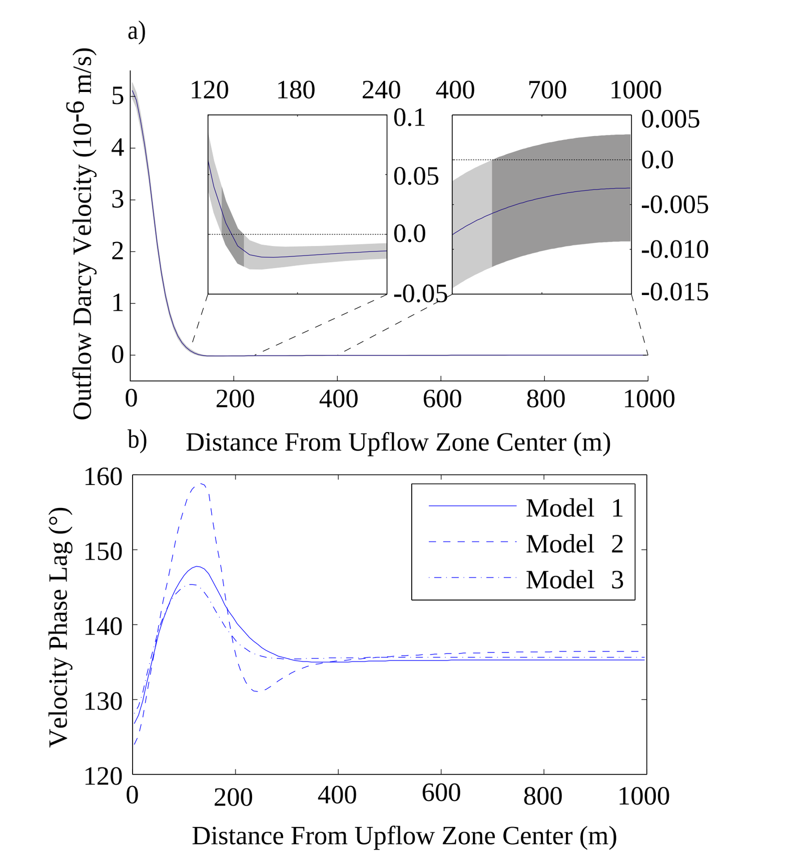

Figure 2. Results from recent poroelastic models of hydrothermal convection [Crone & Wilcock, 2005] predicting a) significant perturbations to flow rates across the seafloor boundary caused by tidal loading, and b) the phase lag of fastest outflow in relation to high tide for different overall permeability models. Flow rate variability is predicted to be large in certain circumstances, and maximal flow rates are predicted to lag high tide by about 125° in the upflow zone. Analytical one-dimensional models predict that maximal flow rates will lag high tide by 135° [Jupp & Schultz, 2004].

III. Recording Systems

	2004 System	2005 System
Controller	16 MHz Persistor	16 MHz Persistor
Memory	4 GB CF	4 GB CF
A/D Converter	12 bit (R212)	16 bit (AD24)
Anti-Aliasing	3-pole Bessel @ 500 Hz	3-pole Butterworth @ 500 Hz
Battery	11.7 V lithium	7.8 V lithium
Sample Rate	1000 Hz	1920 Hz
Programmable Gain	No	Yes
A/D Range	0 – 2.5 V	-2.5 – 2.5 V
Overall Gain (Chan. 0)	-161 dB re 1 V/µ Pa	-181 – -145 dB re 1 V/µPa
Dynamic Range	72 dB re 1 µ Pa	127 dB re 1 µ Pa
Number of Channels	3	2
Recording Capacity	~7 days	~6 days
Pressure Housing	titanium	titanium
Hydrophone Element	Benthos AQ-2000	Benthos AQ-2000

Table 1. Specifications of the first- and second-generation vent sound recording systems. The systems were designed to be low-cost, have low power requirements, and be capable of recording about one week of continuous sound.

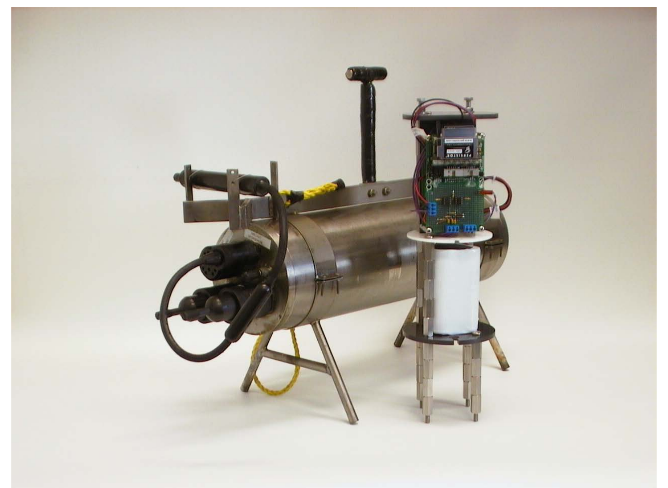

Figure 3. Photograph of the 2004 recording system showing the battery and electronics package, the titanium case, and the attached hydrophone. Not shown is a second hydrophone capable of being positioned very close to the vent orifice with a titanium bracket.

IV. Field Deployments

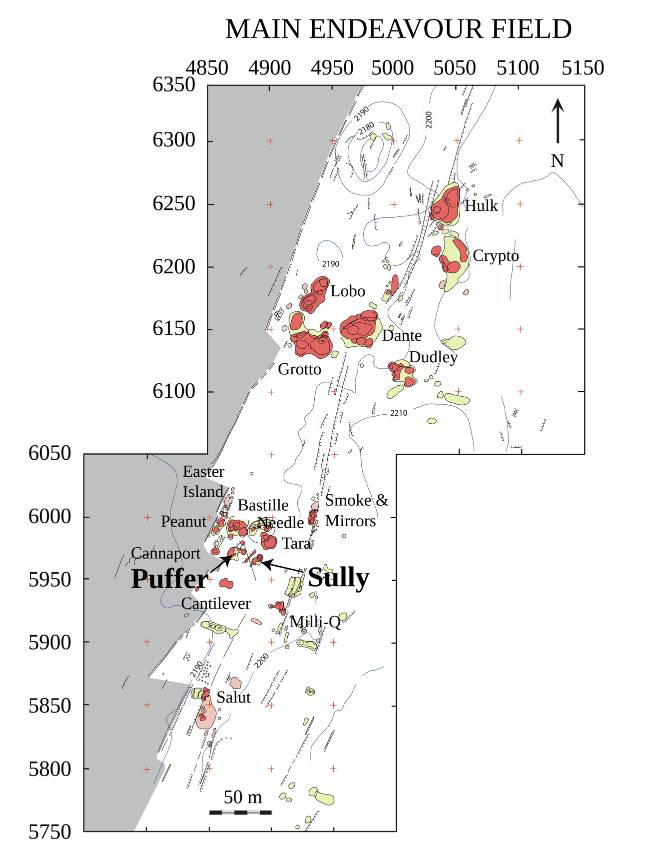

Figure 4. Map showing the deployment locations. In 2004 we deployed an instrument at the Sully vent where it collected ~48 hours of continuous sound. In 2005 we deployed an instrument at the Puffer vent where it collected nearly 6 days of continuous sound. (Base map provided courtesy of Véronique Robigou.)

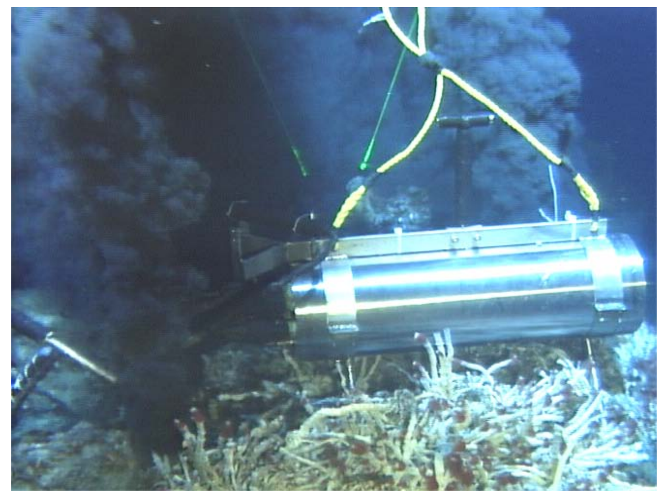

Figure 5. Photograph showing the instrument deployed at Sully in 2004. Data shown in this poster were collected with the hydrophone attached to the pressure case. The second hydrophone, seen at the lower left, failed to collect usable data in 2004 because the gain levels were set too high. The second hydrophone failed in 2005 because it was destroyed by venting fluid.

V. Results

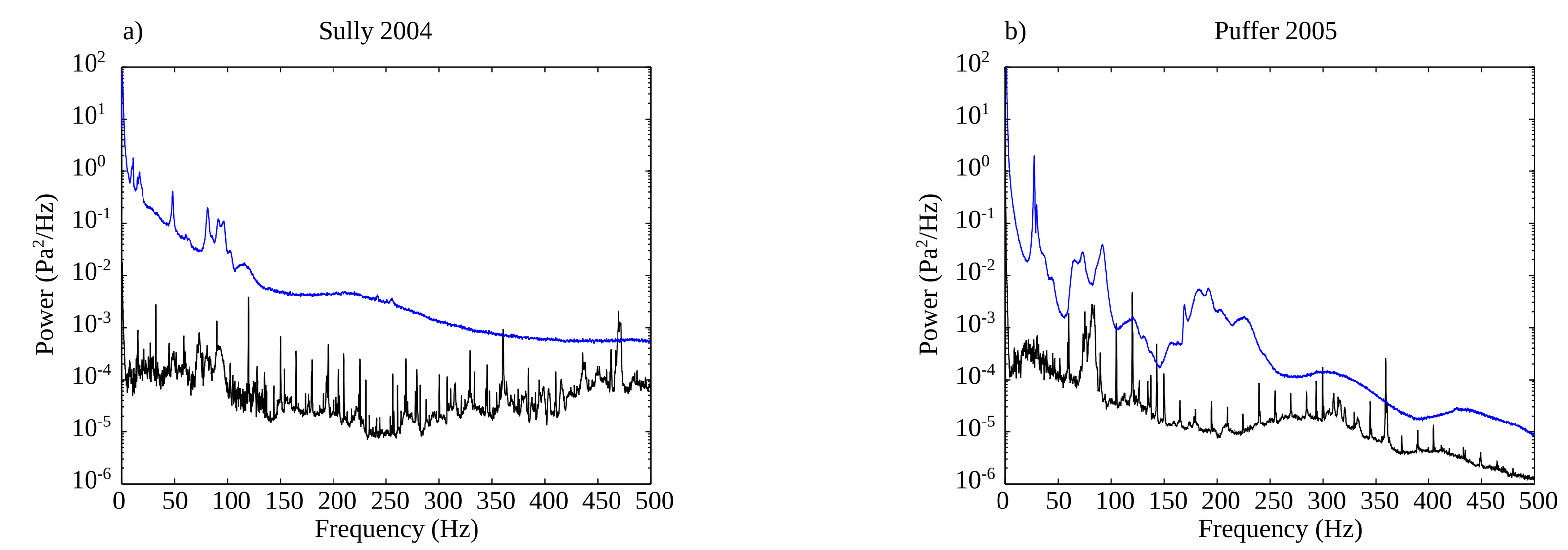

Figure 6. Typical hour-long average power spectra for a) the Sully vent in September 2004, and b) the Puffer Vent in September 2005. Black traces depict the spectra of background recordings collected at a distance of several tens of meters from the vents. Sharp peaks on these curves are associated with ship noise. Blue traces depict the spectra of recordings collected at a distance of about 1/2 meter from the vent orifice. Both Sully and Puffer radiate broad-band acoustic energy at levels significantly higher than background at all measured frequencies. Their spectra also contain sharp peaks at distinct frequencies. Different source mechanisms are likely responsible for the broad-band and the narrow-band signals. In some frequency bands, acoustic power levels are 30 dB higher than background. Depending on the sound source mechanism, signals in these bands would be detectable at distances of ~3-15 m from the vent orifice.

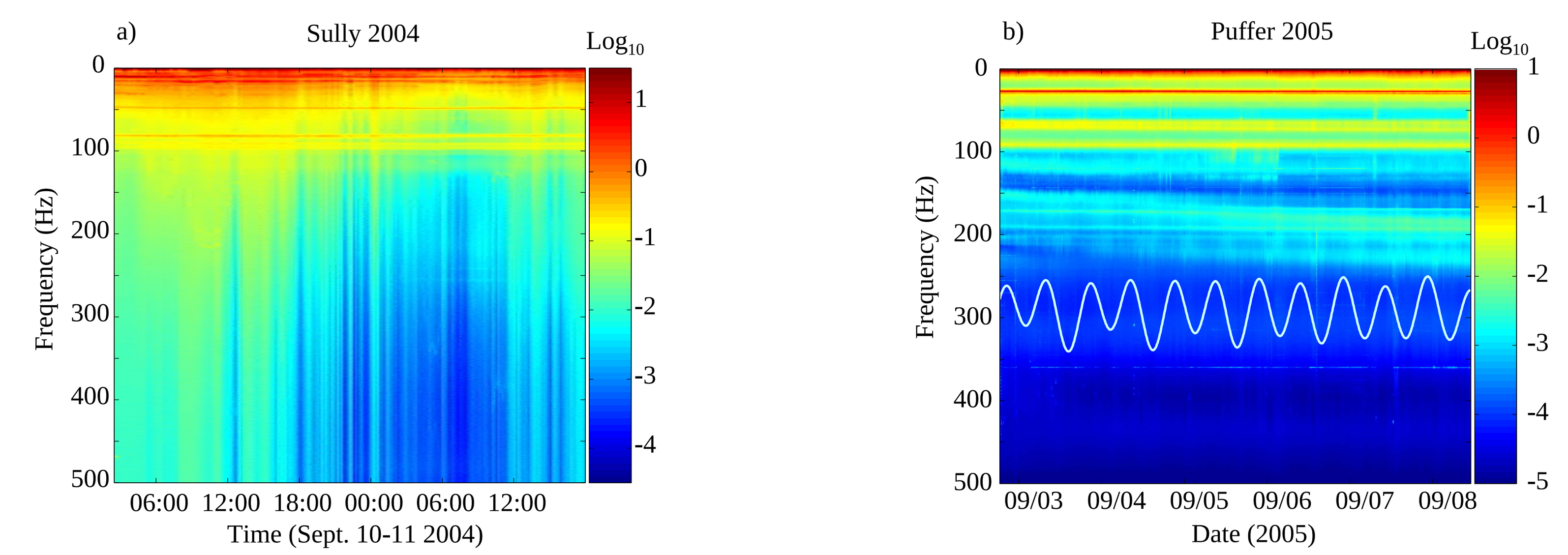

Figure 7. Spectrograms showing the temporal evolution of the power spectra for a) Sully in 2004, and b) Puffer in 2005. The light blue trace in b) depicts the predicted tidal heights (~ ±1 m) plotted on an arbitrary scale during the Puffer deployment [Mofjeld, et. al., 1995]. At both vents the broad-band signal and the narrow-band peaks vary in time. Peaks are observed to wander, consolidate, and split in two. At puffer, broadband signals in certain frequency bands are modulated by tides.

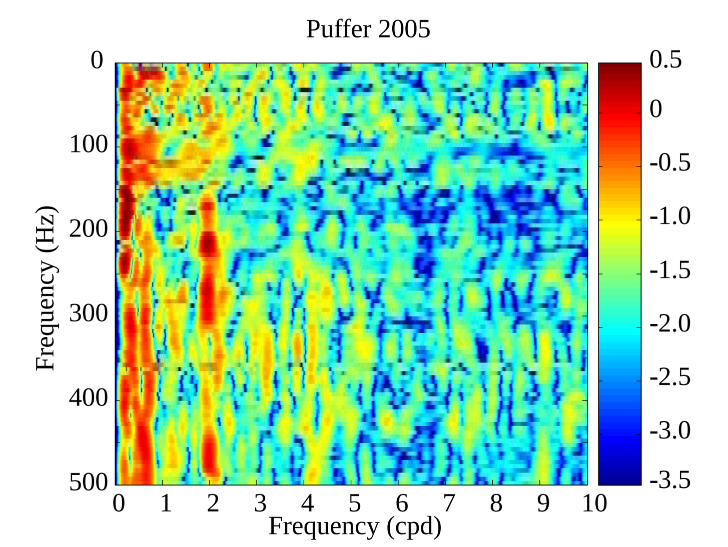

Figure 8. Shaded contours of the normalized power spectral density computed from the time-series of acoustic intensity in different frequency bands from the Puffer 2005 data. Within certain frequency bands, Puffer's acoustic intensity is periodic at semi-diurnal frequencies. There is little evidence for diurnal, or 6-hour periodicity.

Band (Hz)	Phase Lag (°)
~165 – 190	~125
~200 – 225	~121
~260 – 300	~119
~450 – 480	~122

Table 2. Phase lag relative to high tide of the acoustic intensities in the frequency bands that show semi-diurnal periodicity. Maximal acoustic intensity lags high tide by about 119 to 125 degrees. Numerical models predict that fastest outflow lags the tide by a similar amount (see Figure 2b).

VI. Conclusions

1) Black smokers radiate significant and detectable acoustic energy.

2) Each vent appears to have its own acoustic signature.

3) To generate both narrow- and broad-band signals, more than one acoustic source mechanism is likely operating within these systems. Mechanisms might include: boiling, cavitation, chimney vibration, subseafloor cavity resonance, pipe resonance, pulsating flow, turbulent dissipation, and mixing-induced density perturbations.

4) The acoustic signals vary in time and can contain tidal periodicity in isolated frequency bands.

5) In frequency bands with tidal periodicity, maximal acoustic intensity lags high tide by ~119-125°. Poroelastic models of tidally-driven flow fluctuations predict similar lags for maximal flow rates.

6) Because these sound signals may be detectable at distances of order 10 m, we speculate that black smoker acoustics may have a variety of implications for the macrofauna at seafloor hydrothermal systems.

References

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