



Acoustic Source

- Air gun (5 in³ [also available 20 in³]):

Source Level 165 to 175 dB/micro Pa

Calibration Hydrophone @ 1m

Frequency band 30 Hz to 500 Hz

Advantages:

- a) Very sharp pulse, provide a very good source for modal analysis
- b) Compact, mobile, easy to use
- c) Available and calibrated already

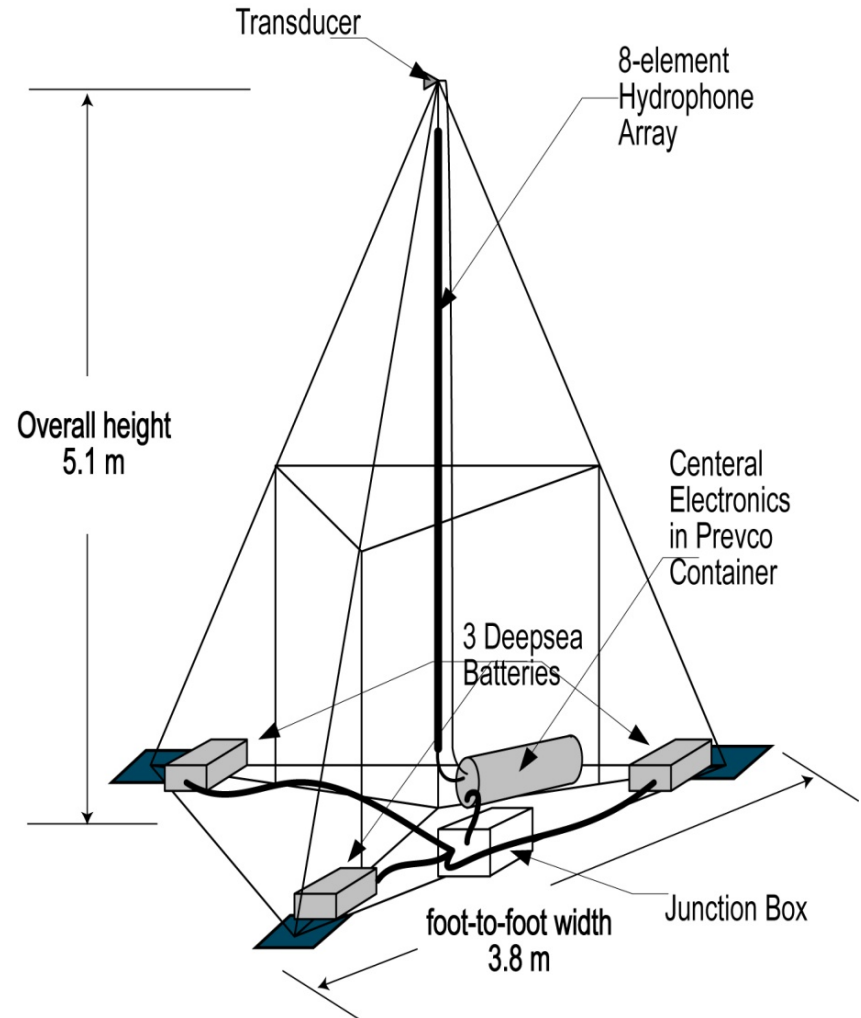
Disadvantage:

- a) Need to apply for permit “soon” in advance to the experiment.



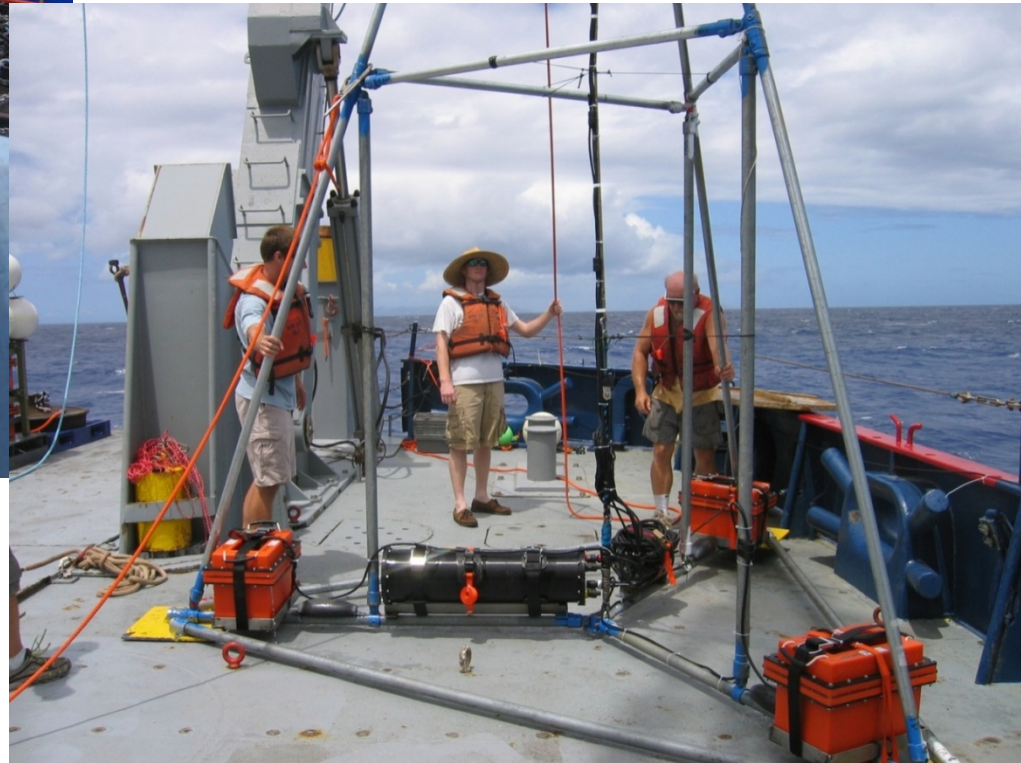
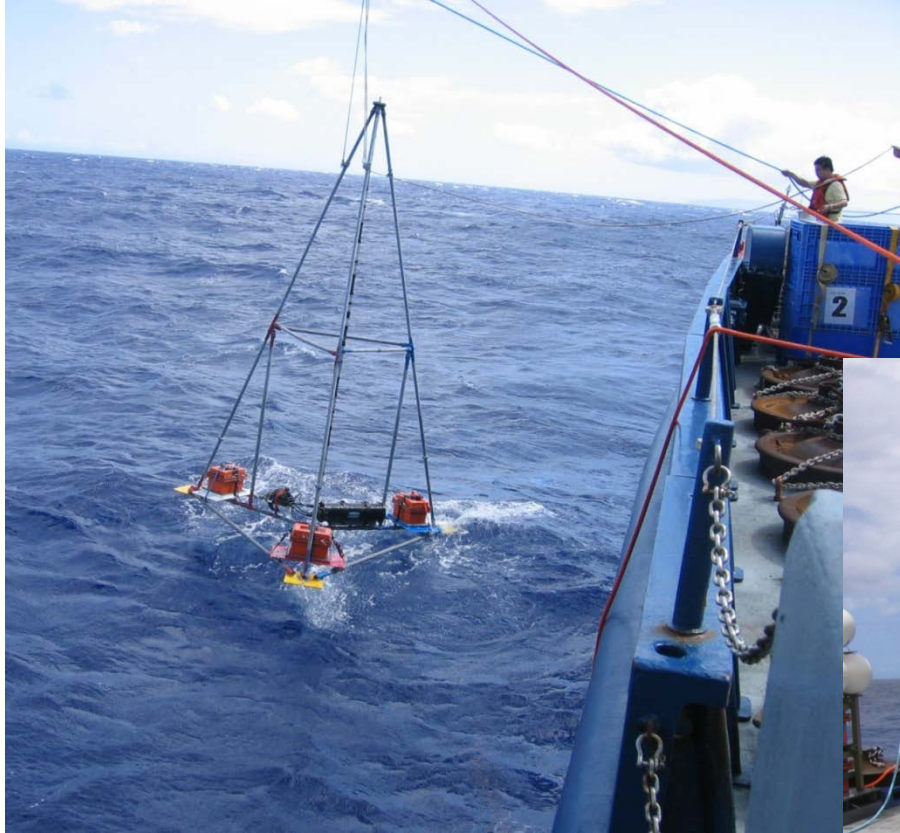
Tripod Acoustic Systems

- Tripod VLA:
 - Eight receiving elements
 - 80 kHz sampling frequency
 - ~50 hours of underwater lifetime
- Single Source
 - ITC3013 source near the top (~4 m from the sea floor)





Tripod operations during KAM08





Geo-acoustic parameter estimation using a multi-step inversion technique based on normal mode method

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Known: water SSP, density, WD, SD, RD

Broadband acoustic signals

Known: water SSP, $\Psi(0) = 0$

Normal mode code

Time Frequency Analysis

Cross Spectral Density Matrix

Depth-separated finite difference wave equation
 $\Psi(z_{i+1}) = \Psi(z_{i-1}) + \{2 - h^2 (\omega^2/c^2(z_i) - k_n^2)\} \Psi(z_i)$ (3)

Calculated modal arrival time $T_n(f, c_b)$

Measured modal arrival time $\widehat{T}_n(f)$

Singular Value Decomposition

The impedance from the mode function
 $Z_w = -\rho \Psi / \frac{\partial \Psi}{\partial z}$ (4)

Cost Function: $F1(c_b, f) = \sqrt{\sum_n (\widehat{T}_n(f) - T_n(f, c_b))^2}$ (1)

Cost Function: $F2(k_n) = \sqrt{\sum (\widehat{\Psi}(z_i) - \Psi(z_i, k_n))^2}$ (2)

The impedance from bottom
 $Z_b = -\rho_b / \sqrt{k_n^2 - (\omega/c_b)^2}$ (5)

F1 is minimized by a optimization algorithm to obtain c_b as a function of frequency

F2 is minimized by a optimization algorithm to obtain k_n

matching

Inverted c_b

$c_b = \omega / \sqrt{k_n^2 - (\rho_b \frac{\partial \Psi}{\partial z} / -\rho \Psi)}$ (6)

Method 1

Method 2

Step 1

Normal mode code

Calculated vertical coherence (9)
 $\gamma_{VL}(\alpha_b) = \frac{\sum_n |\Psi_n(z_s)|^2 |\Psi_n(z)|^2 \cos[k(z)\Delta z \sin\theta_n(z)] k_n \exp(-2\beta_n r)}{\sum_n |\Psi_n(z_s)|^2 |\Psi_n(z)|^2 k_n \exp(-2\beta_n r)}$

Calculated modal attenuation coefficient
 $\beta_n(\alpha_b) = \frac{\omega}{k_n} \int_{WD}^{\infty} \frac{\alpha_b}{c_b} \rho_b \Psi_n^2(z) dz + \frac{\omega}{k_n} \int_0^{WD} \frac{\alpha}{c(z)} \rho \Psi_n^2(z) dz$ (7)

Calculated modal amplitude ratios
 $R_{n1}(\alpha_b) = \sqrt{\frac{k_i}{k_n} \left| \frac{\Psi_n(z_s) \Psi_n(z)}{\Psi_1(z_s) \Psi_1(z)} \right|} e^{(\beta_1 - \beta_n)r}$ (8)

Calculated longitudinal horizontal coherence (10)
 $\gamma_{HL}(\alpha_b) = \frac{\sum_n |\Psi_n(z_s)|^2 |\Psi_n(z)|^2 k_n \exp(-2\beta_n r) \times \exp(-ik_n \Delta L)}{\sum_n |\Psi_n(z_s)|^2 |\Psi_n(z)|^2 k_n \exp(-2\beta_n r)}$

Cost Function: $F3(\alpha_b, f) = \sqrt{\sum_n (\widehat{\beta}_n(\alpha_b) - \beta_n(\alpha_b, f))^2}$ (11)

Cost Function: $F4(\alpha_b, f) = \sqrt{\sum_n (\widehat{R}_{n1}(\alpha_b) - R_{n1}(\alpha_b, f))^2}$ (12)

Cost Function: $F5(\alpha_b, f) = \sqrt{\sum_n (\widehat{\gamma}_{HL}(\alpha_b) - \gamma_{HL}(\alpha_b, f))^2}$ (13)

Cost Function: $F6(\alpha_b, f) = \sqrt{\sum_n (\widehat{\gamma}_{VL}(\alpha_b) - \gamma_{VL}(\alpha_b, f))^2}$ (14)

F3-F6 are minimized by a optimization algorithm to obtain α_b as a function of frequency

Inverted α_b

Inverted α_b

Inverted α_b

Inverted α_b

Method 1

Method 2

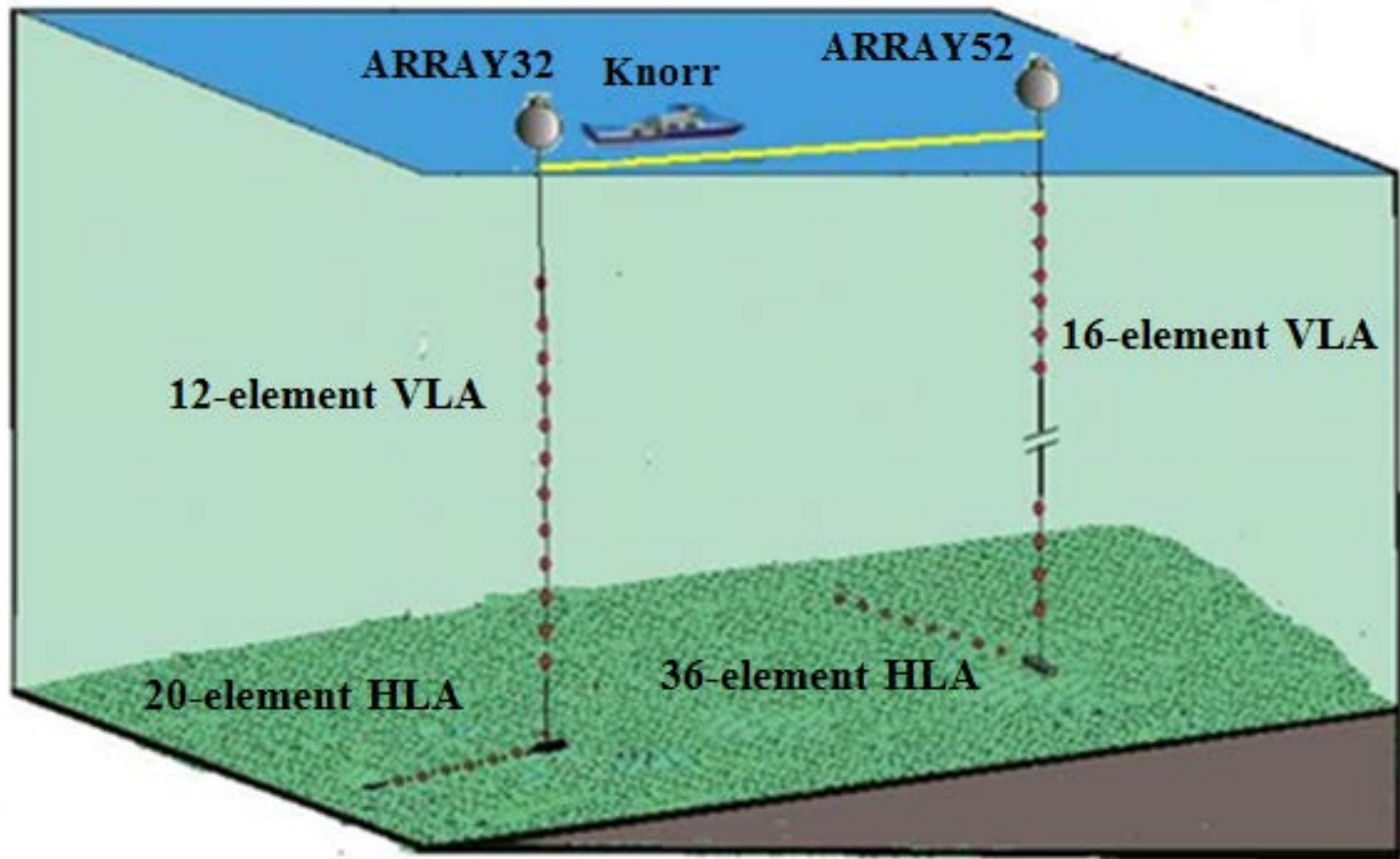
Method 3

Method 4

Step 2

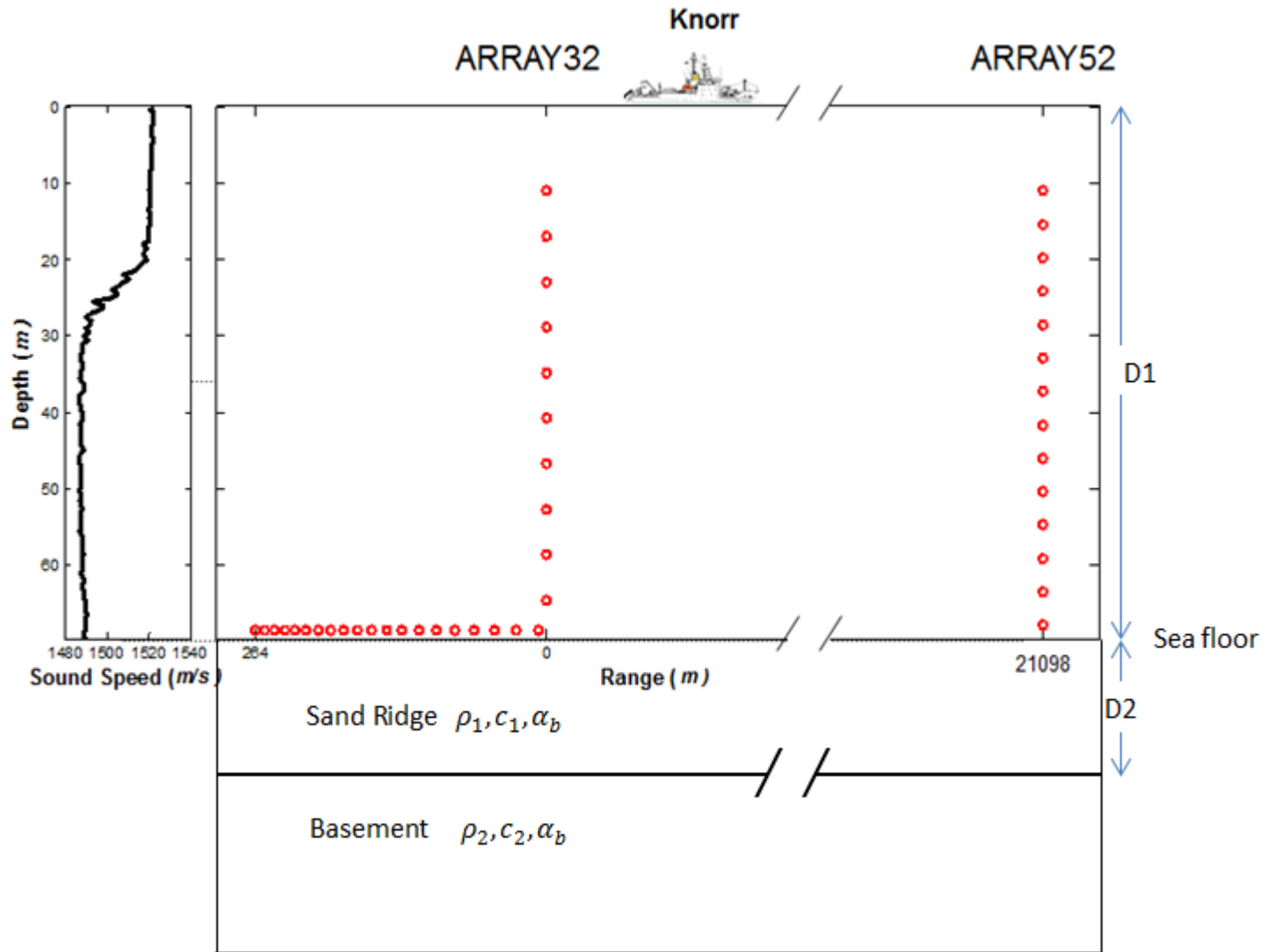


Experimental Description



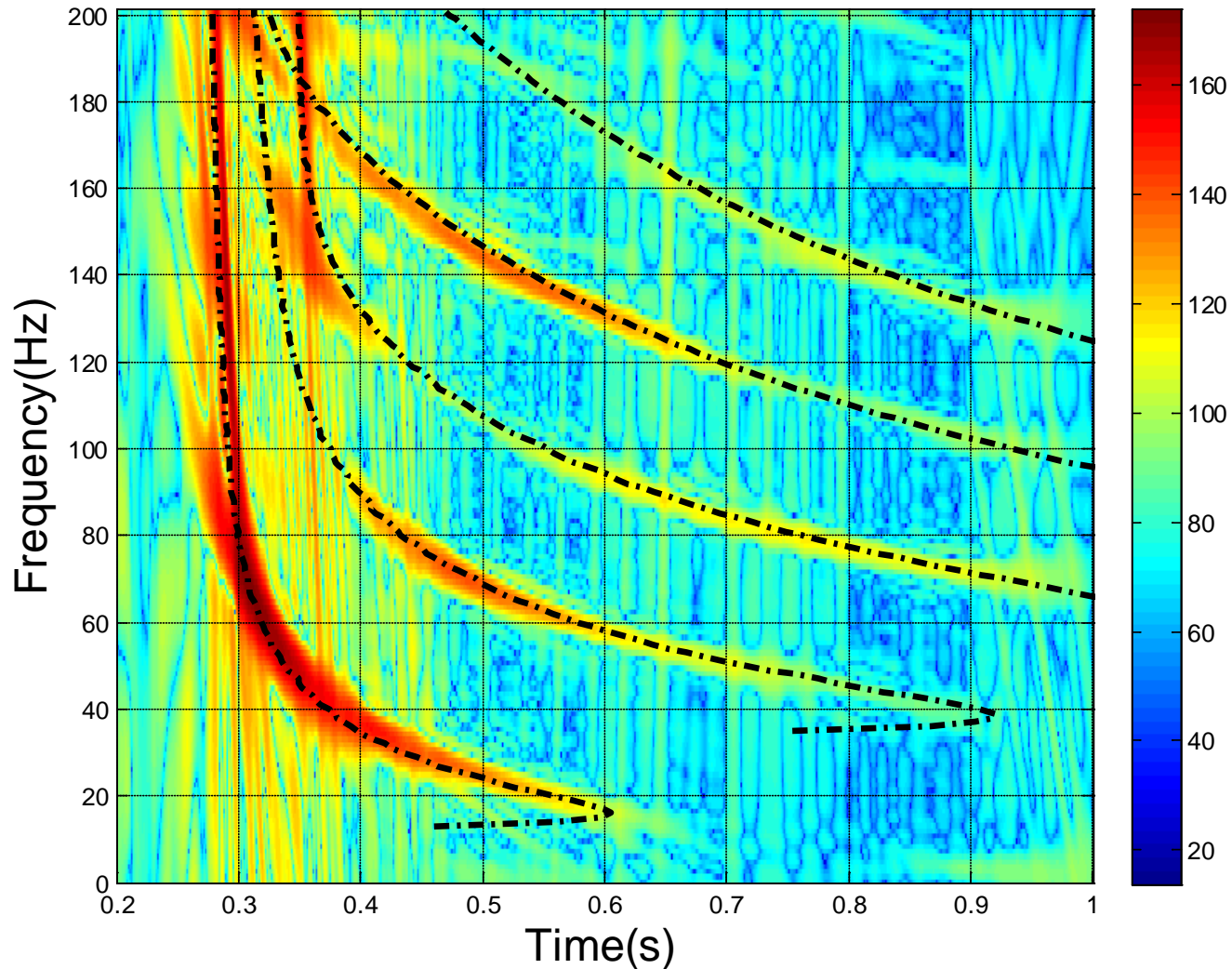


Experimental Description





Data-model comparison of modal dispersion curves





Seabed attenuation inversion using LHC

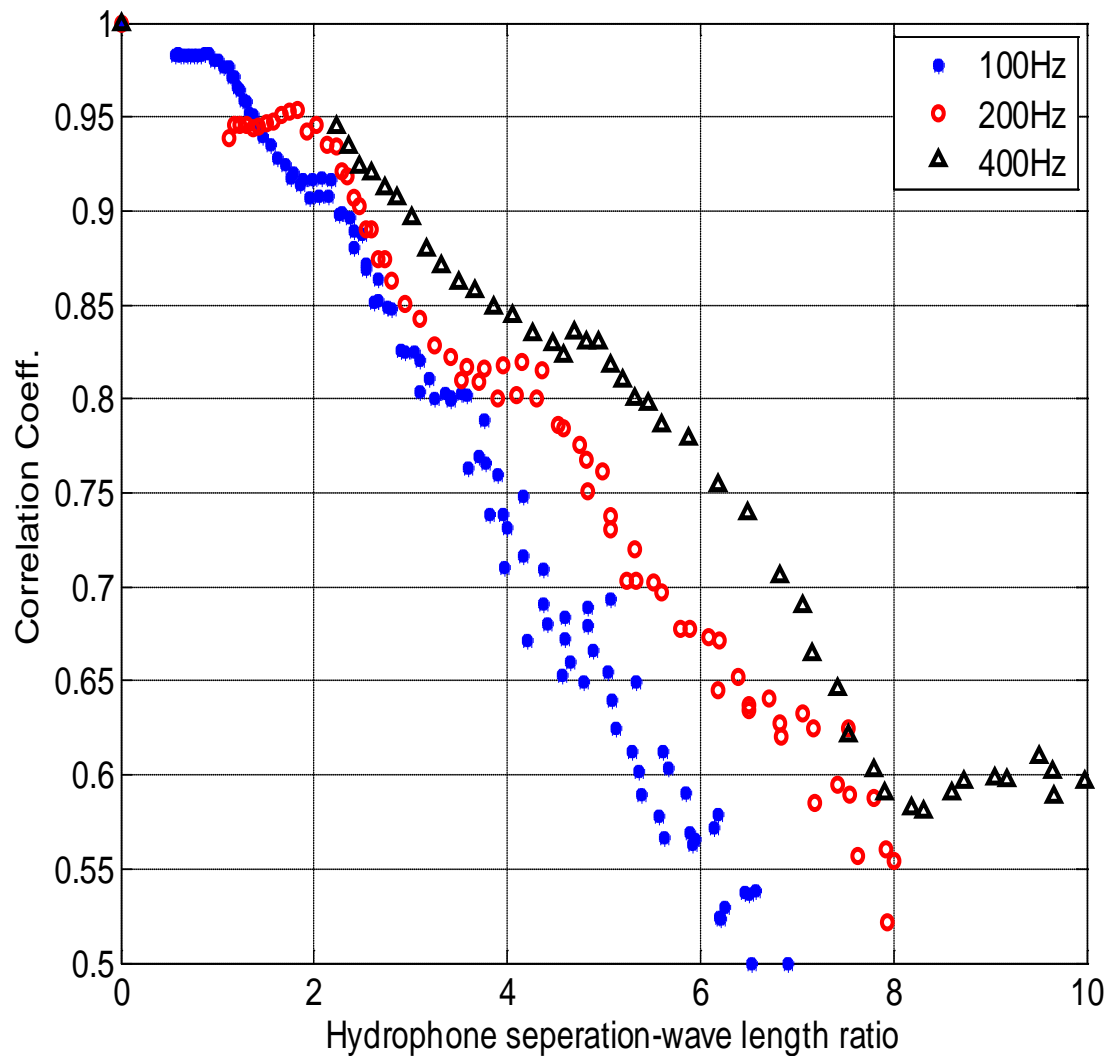
The experimental longitudinal horizontal coherence

$$\rho(\Delta T, \tau) = \frac{\int_t^{t+\Delta T} p_1(t) p_2(t - \tau) dt}{\sqrt{\int_t^{t+\Delta T} p_1^2(t) dt \times \int_t^{t+\Delta T} p_2^2(t) dt}} \quad (1)$$

Where $\tau = L/c$ is the time delay and ΔT is the integration time.



LHC as a function of hydrophone separation-wave length ratio





Seabed sound attenuation inversion using LHC

Using the normal mode expression for sound pressure generated by a harmonic point source, we obtain the mathematical expression in terms of normal modes for the theoretical normalized longitudinal horizontal coherence:

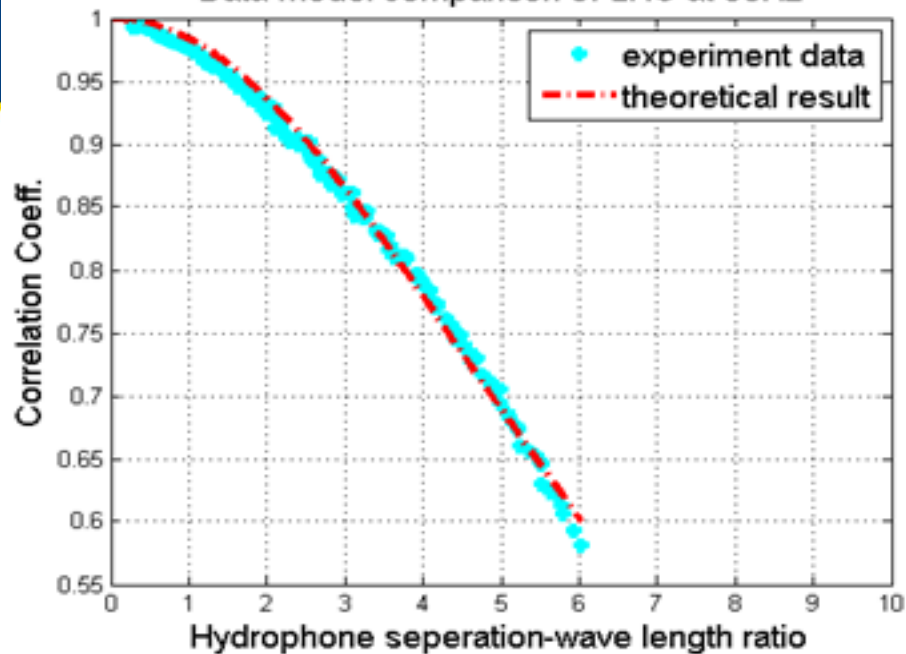
$$\gamma_{HL}(z_s, z, \Delta L, r) = \frac{\left| \sum_n \overline{|\Psi_n(z_s)|^2 |\Psi_n(z)|^2 k_n \exp(-2\beta_n r) \times \exp(-ik_n \Delta L)} \right|}{\sum_n \overline{|\Psi_n(z_s)|^2 |\Psi_n(z)|^2 k_n \exp(-2\beta_n r)}} \quad (2)$$

where, r is range, z_e is source depth, z is receiver depth, ΔL is the horizontal separations of the pair of hydrophones, Ψ_n is the mode depth function of the n th mode, k_n is the horizontal wave number of the n th mode, β_n is the modal attenuation coefficient, and S_n is the cycle distance of the n th mode. The square-average depth function can be calculated

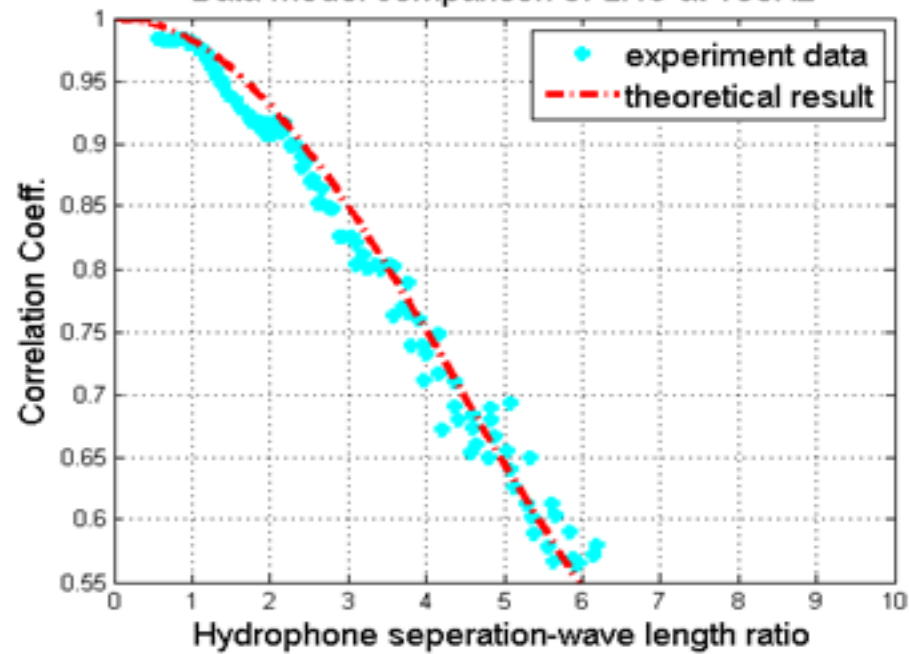
$$\overline{\Psi_n(z)^2} = \frac{1}{S_n \sqrt{k^2(z)F(z) + k^2(z) - k_n^2}} \quad (3)$$

$$F(z) = 0.875 \left| \frac{1}{\pi f} \frac{dc(z)}{dz} \right|^{2/3} \quad (4)$$

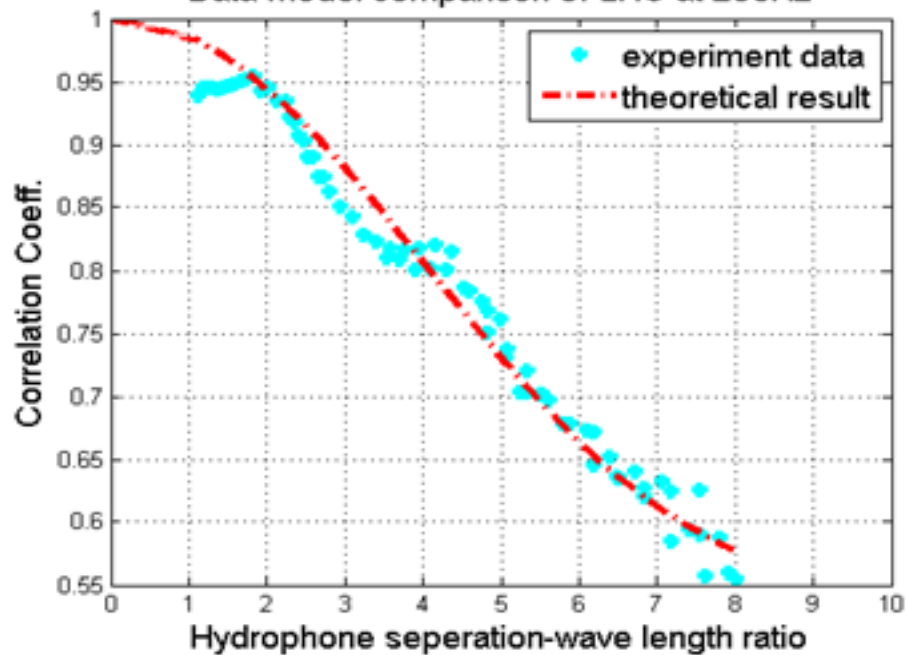
Data-model comparison of LHC at 50Hz



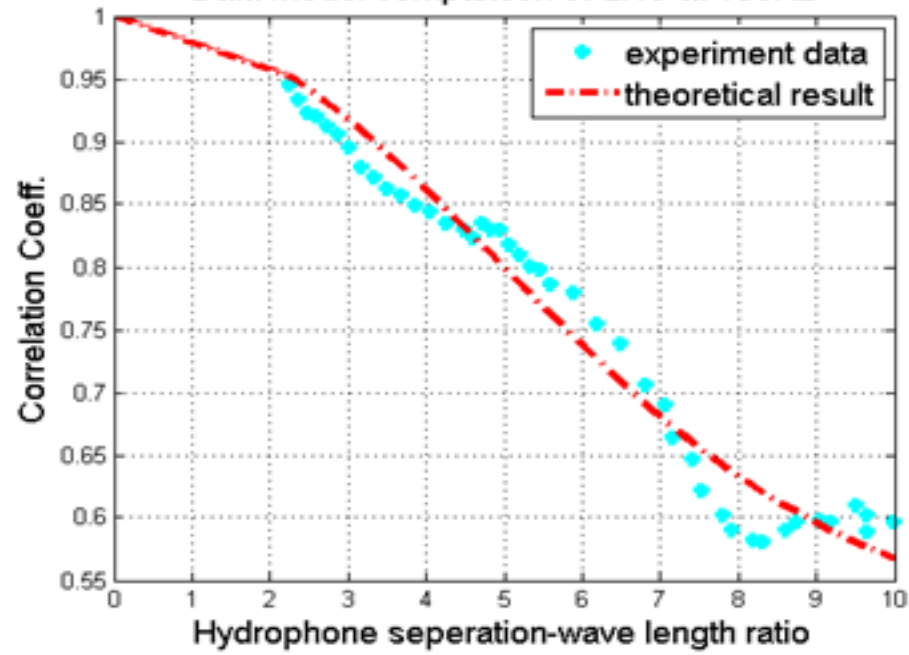
Data-model comparison of LHC at 100Hz



Data-model comparison of LHC at 200Hz



Data-model comparison of LHC at 400Hz





Inverted bottom attenuation in SW06 area

