

Bottom reflection phase shift parameter estimation from ASIAEX data

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Main Scientific Objective

- **Inversion of the bottom parameters through reflection phase shift of sea bottom**

Step 1: Extract modal depth function from acoustic data

Step 2: Estimate km from extracted modal depth function

Step 3: Calculate reflection phase shift of sea bottom

Step 4: Estimate bottom parameters by use of reflection phase shift of sea bottom

- **Study the possibility of extracting modal depth function from reverberation data collected by a VLA**

Relation between the phase shift of sea bottom and modal wavenumber

$$\Phi_b = B_l = 2mp - B_u - 2 \int_{Z_u}^{Z_l} \sqrt{k^2(z) - k_m^2} dz$$

The bottom reflection phase shift can be retrieved if the real part of the modal wavenumber and the SSP in water column are known.

The relation used for extraction of modal depth function

- **The reverberation field received by a hydrophone**

$$p(r_c, z; z_s) = [p_0 / k_0 r_c] \sum_m^M \sum_n^M \mathbf{j}_m(z_s) \mathbf{j}_n(z) S_{mn} \int dv_1 \mathbf{h}(R_1) \exp\{i(k_m + k_n)r_1\}$$

$$= ?(z)' ?(r_c, z_s)$$

- **The expression of the scattering field received by a VLA**

$$\mathbf{p} = \overline{? ?}$$

where

$$\overline{?} = \begin{bmatrix} ?(z_1)' \\ ?(z_2)' \\ \vdots \\ ?(z_N)' \end{bmatrix}$$

$$\overline{?} = [?(r_{c1}) \quad ?(r_{c2}) \quad \cdots \quad ?(r_{cL})]$$

The relation used for extraction of modal depth function

**CSDM of reverberation
VLA data**

$$\mathbf{R} = \mathbf{p}\mathbf{p}^+ = \overline{?} \overline{\mathbf{K}\mathbf{K}^+} \overline{?}^+$$

**SVD of the CSDM of
reverberation VLA data**

$$\mathbf{R} = \mathbf{U}\mathbf{S}\mathbf{V}$$

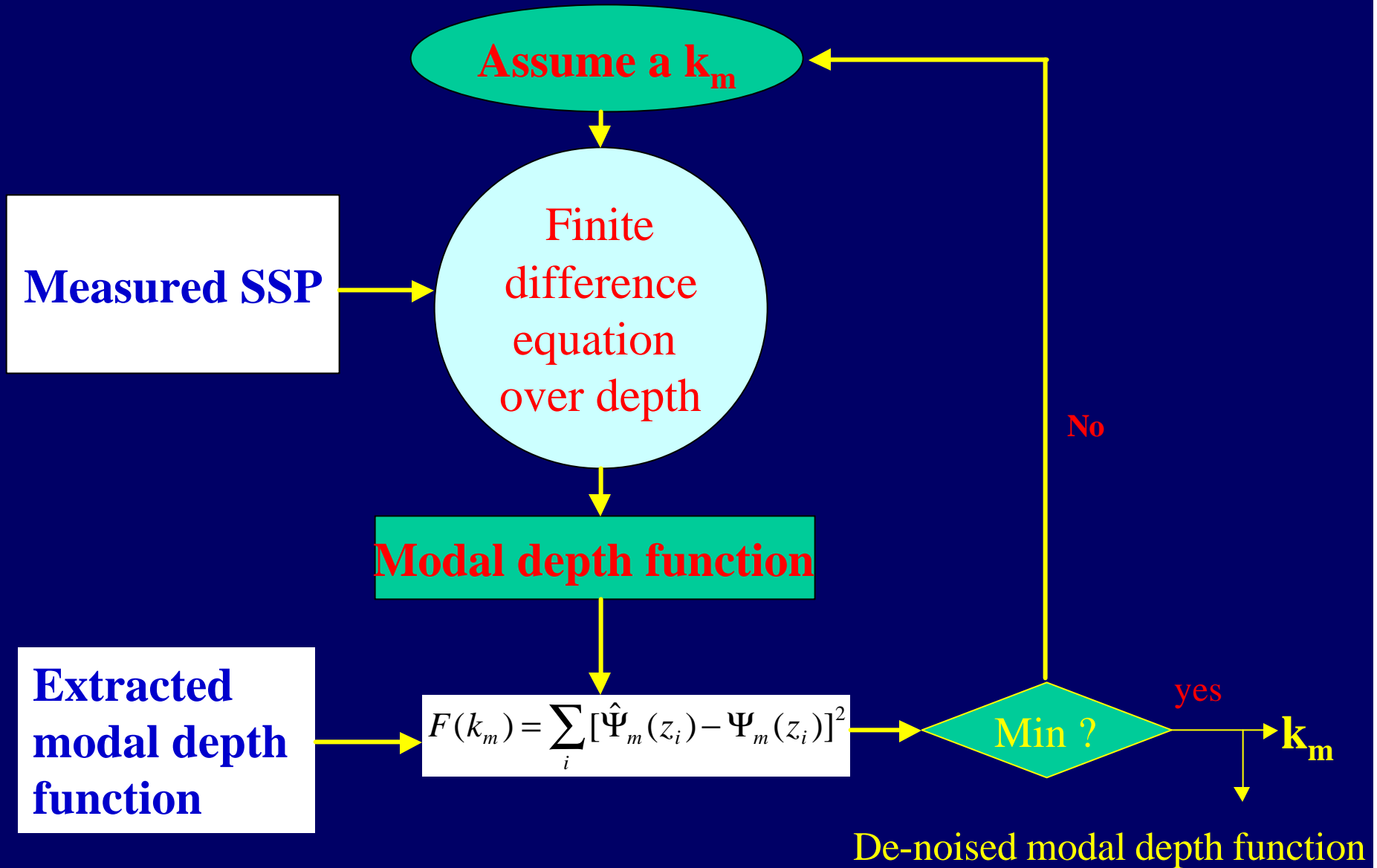
compare

$$\overline{?} = \mathbf{U} = \mathbf{V}$$

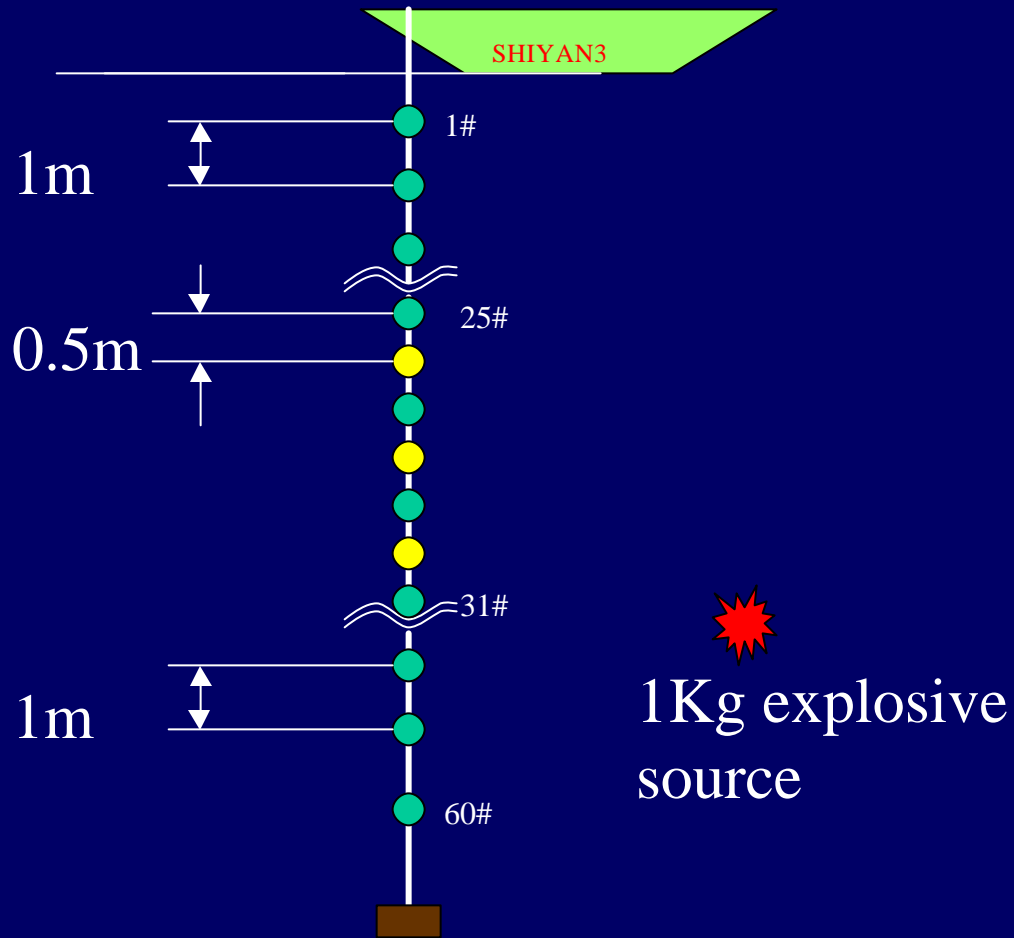
(if $\overline{\mathbf{K}\mathbf{K}^+}$ is diagonal matrix)

* These relations are going to be verified in detail later

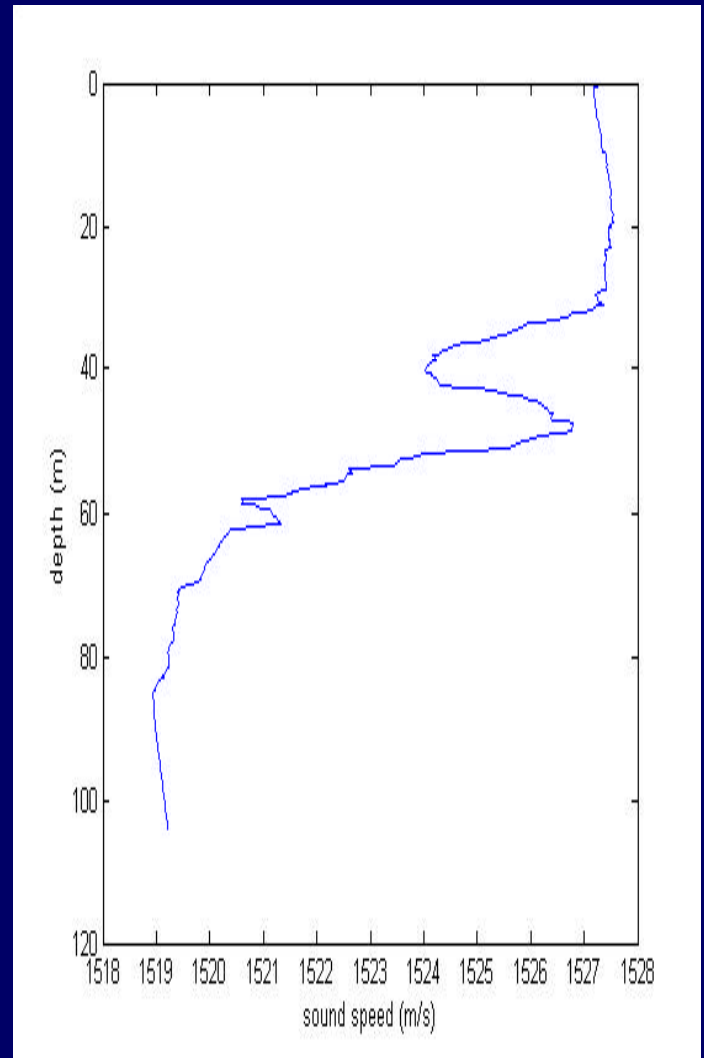
Estimation from extracted modal depth function (shooting)



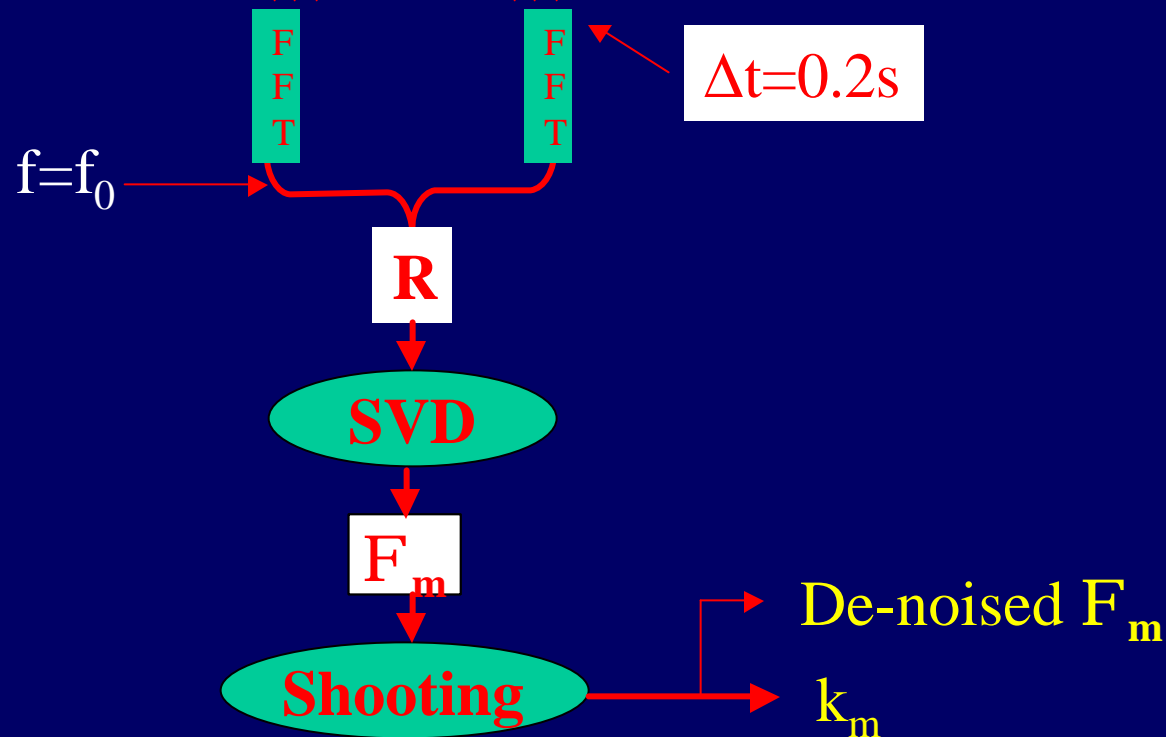
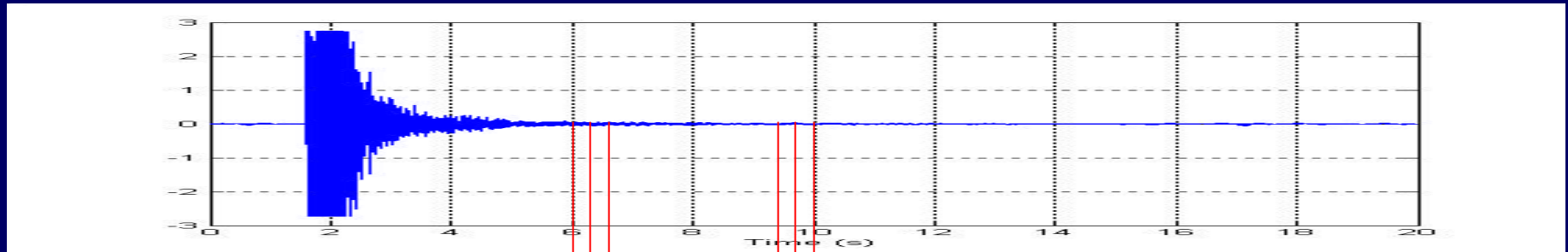
Experiment setup



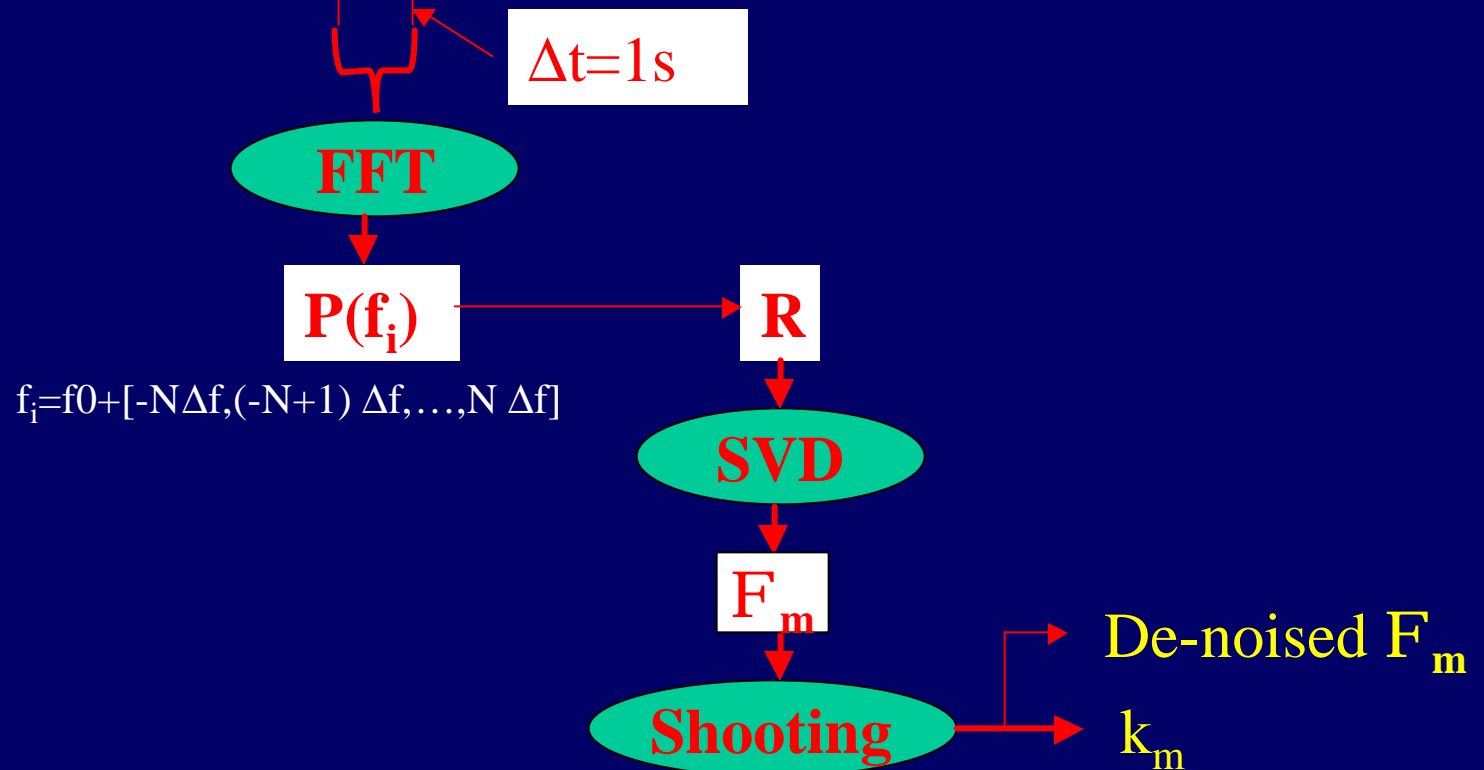
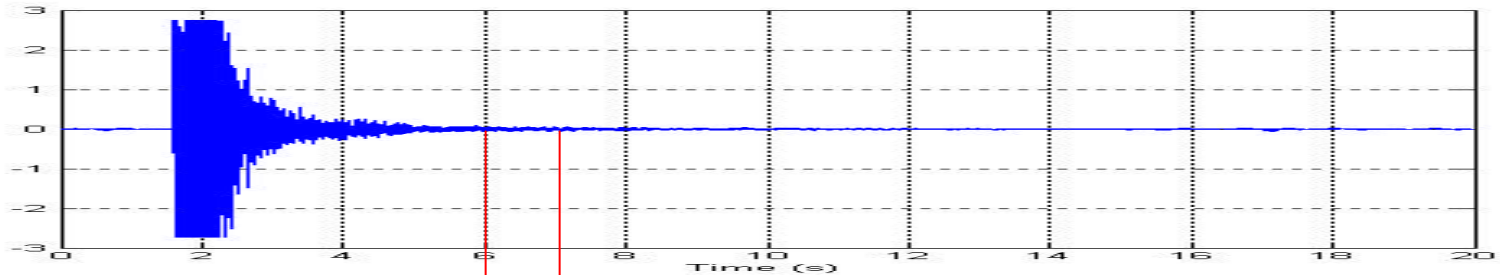
● Not used in this paper



Extracting modal depth function from reverberation data method I: Different Time-segment Method



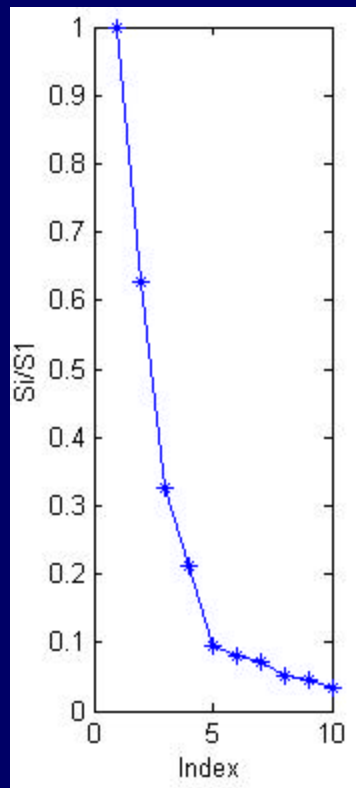
Extracting modal depth function from reverberation data method II: Different Frequency Method



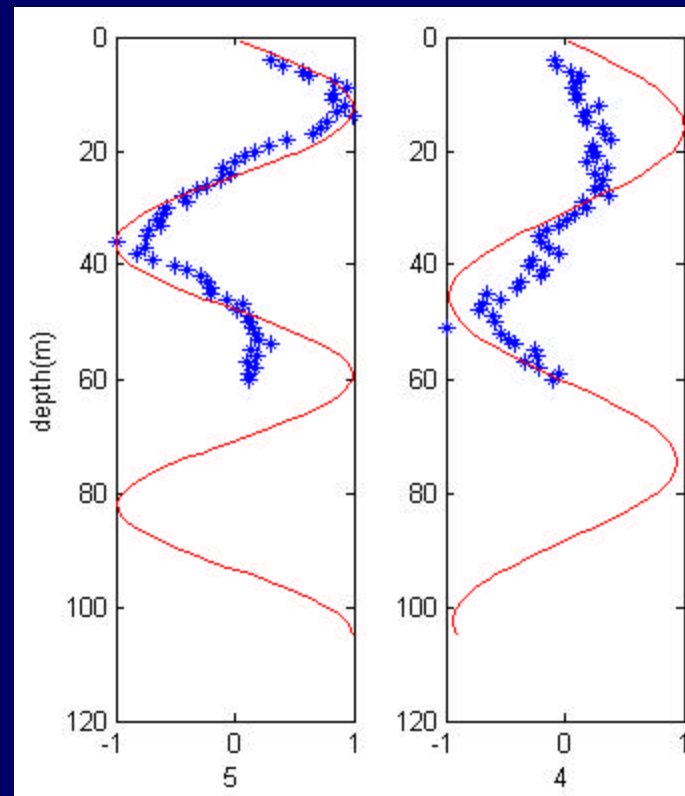
Example of extracted mode depth function

- Different time-segment method
- $f_0=100\text{Hz}$

Relative singular value



Extracted modal depth function

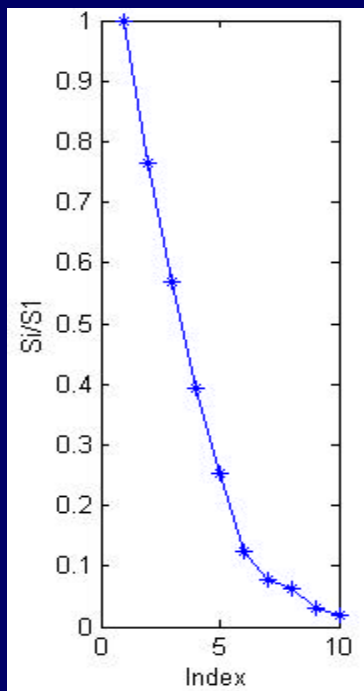


* extracted
— shooting

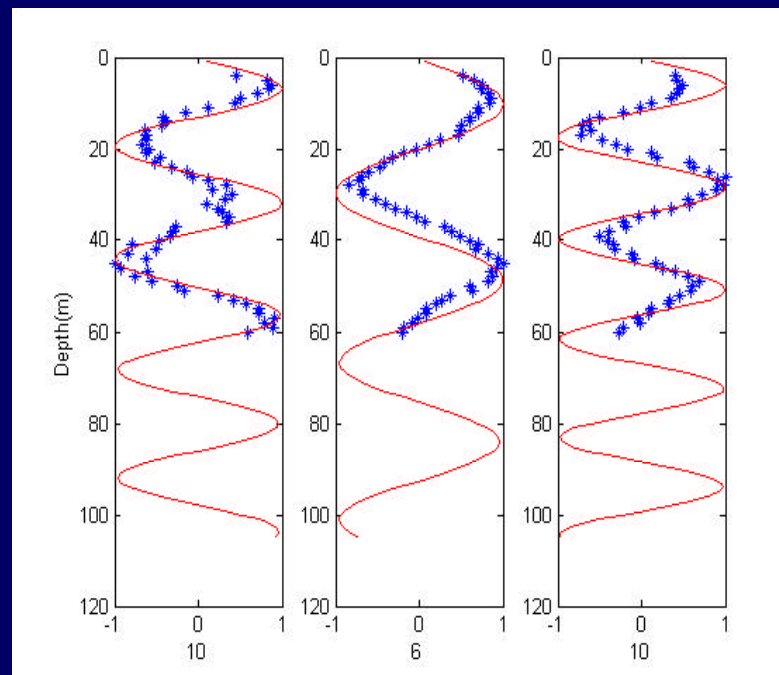
Example of extracted mode depth function

- Different Frequency method
- $f_0=200\text{Hz}$, $\Delta f=1\text{Hz}$, $N=20$

Relative singular value



Extracted modal depth function



* extracted
— shooting

Retrieved modal phase and verify

Example	m	k_m	Φ_b	Pa_m	a_m	P
100Hz Multi-r _c	4	0.3980	-0.072	3.0698	0.2754	11.016
	5	0.3896	0.632	3.774	0.3436	10.984
200Hz Multi-f	6	0.8066	-0.689	2.453	0.2238	10.961
	9	0.7833	0.581	3.723	0.3276	11.36
	10	0.7734	1.11	4.2516	0.3630	11.71

From WKB approximation, the reflection phase shift is linear with grazing angle when the grazing angle is far smaller than 1.

$$\arg[R(\mathbf{q})] = \Phi_b = -\mathbf{p} + Pa_m$$

where

$$\mathbf{a}_m = \cos^{-1} \sqrt{1 - \left(\frac{k_m}{k(H)} \right)^2}$$

$$P \approx \frac{\mathbf{r}}{\sqrt{1 - (c_H / c_b)^2}}$$



Inversed geoacoustic parameters of sea bottom

What does P value means?

Table 2 Hamilton's typical sediment parameters and $P^{[9]}$

Type	Sediment parameters			P	Q	Critical angle(°)
	Density(g/cm ³)	Sound speed(m/s)	K			
1	2.03	1836	0.479	7.3	0.22	34
2	1.97	1753	0.510	7.9	0.34	29
3	1.87	1697	0.670	8.5	0.63	26
4	1.81	1668	0.692	9.0	0.80	24
5	1.79	1664	0.756	9.0	0.90	23
6	1.77	1623	0.673	10	1.27	20
7	1.58	1580	0.113	13	0.52	15
8	1.47	1546	0.090	20	2.27	9
9	1.42	1520	0.073		25.1	7

Average inverted P:11.2

A specific P value corresponds a specific type of sediment! The inverted P value is about 11, it is very close to the P of type 6(sand silt). So we know the density and sound speed are close to 1.7 and 1623, respectively.



Error Analysis

$$\Delta\Phi_b(m) \cong S_m \cdot \Delta k_m$$

where

$$S_m = \frac{2p}{k_m - k_{m+1}}$$

By using of KRAKEN model, we get:

$$S_m \approx 7 \times 10^2$$

The error of estimated k_m : $\Delta k_m \sim \text{between } 1 \times 10^{-4} \text{ and } 1 \times 10^{-3}$

We use :

$$\Delta k_m \sim 5 \times 10^{-4}$$

Then:

$$\Delta\Phi_b \sim \pm 0.4$$

$$\Delta P \sim \pm 1.0$$

Summary

- ✓ **The modal depth function can be extracted by use of reverberation VLA data.**
- ✓ **The modal wavenumber can be estimated from extracted modal depth function by shooting method. The error of estimated modal wavenumber is about $10^{-4} \sim 10^{-3}$.**
- ✓ **A consistent P value can be obtained from the retrieved modal reflection phase shift.**
- ✓ **From the inverted P value, the sediment type of the sea bottom where the reverberation experiment was conducted in ASIAEX is corresponded to the 'type 6' of the Hamilton's classification (sand silt:density= 1.7g/cm^3 , sound speed= 1623m/s).**
- ✓ **In this paper, we only extracted higher order modes, we think it is because the VLA is short and span only the upper half of the water.**



APPENDIX

Ambiguity of inversion by using matched field process

Example:

VLA : 1~103m with spacing 1m

Sea Depth: 105m

Sea bottom: Half-infinite

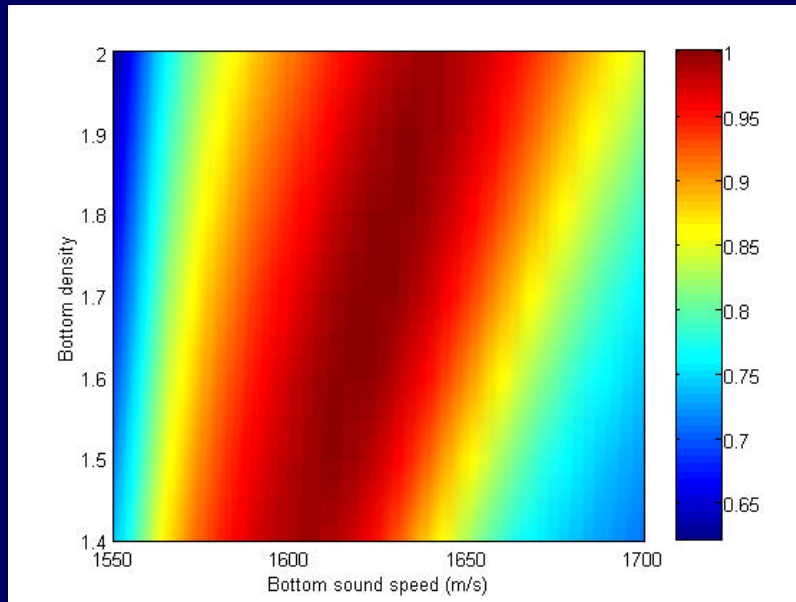
Parameters for Measured field:

density=1.7g/cm³

Sound speed=1623m/s



Ambiguity of inversion by using matched field process



Ambiguity surface for the correlation coefficient

Comparing with our result, MFP inversion has a large ambiguity. In our method, the ambiguity is significantly reduced by taking Hamilton's empirical data as a "constraint".



Thanks!