Presentation at the

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by

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Optimal and sub-optimal matched field correlators

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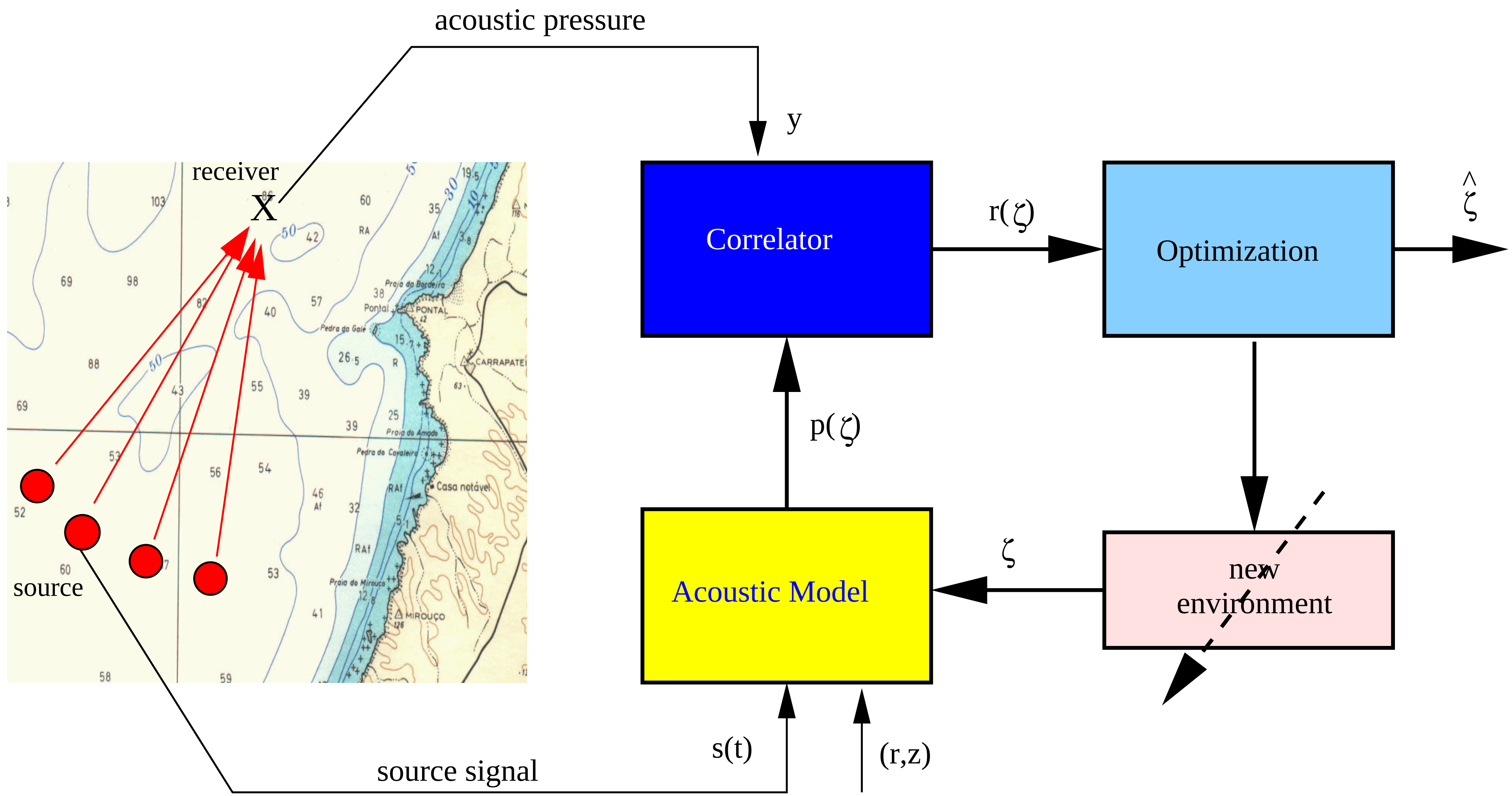
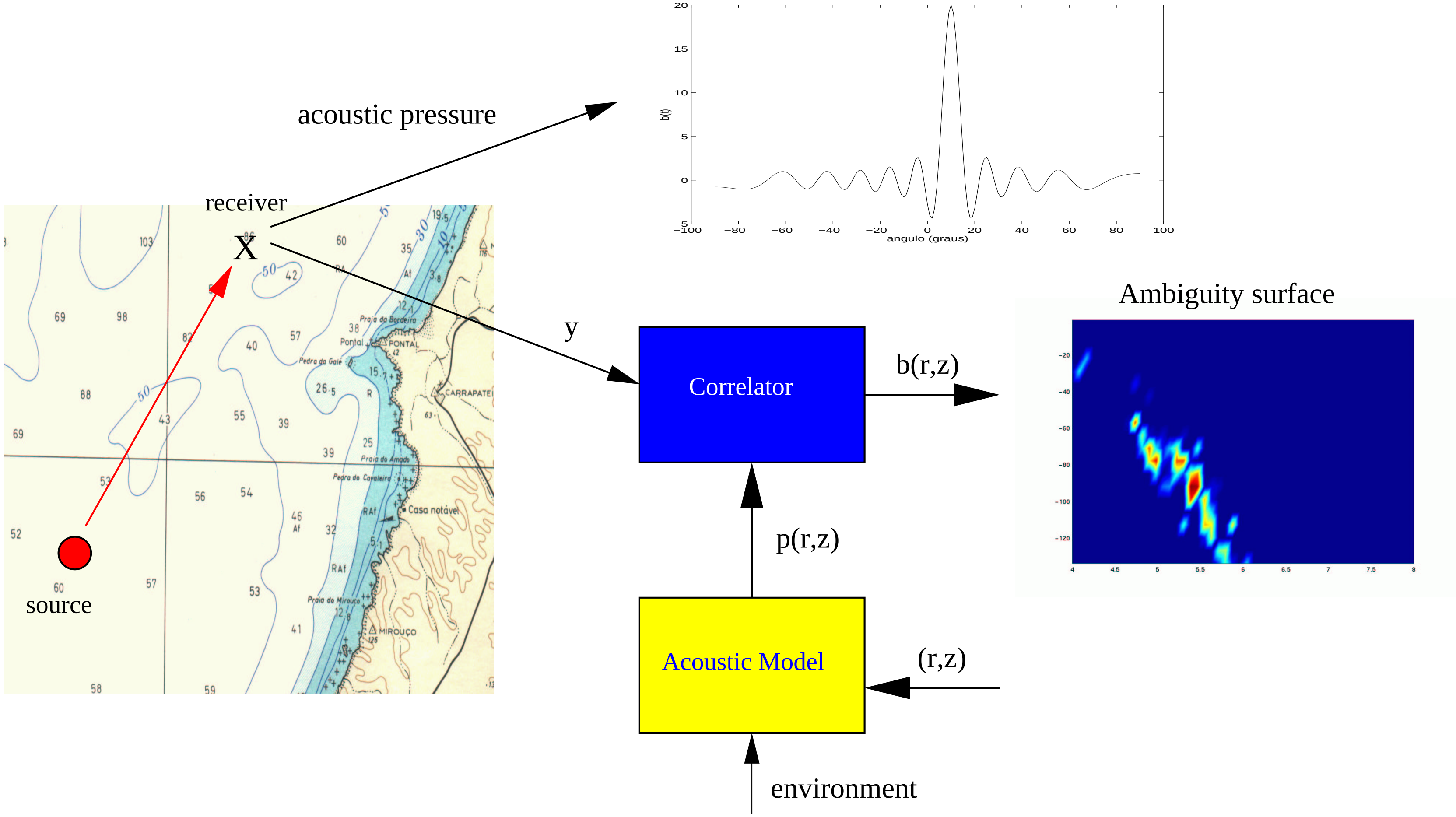
Issues

- source localization
- ocean acoustic tomography
- geoacoustic inversion
- underwater communications

Ocean Acoustic Tomography - synoptic

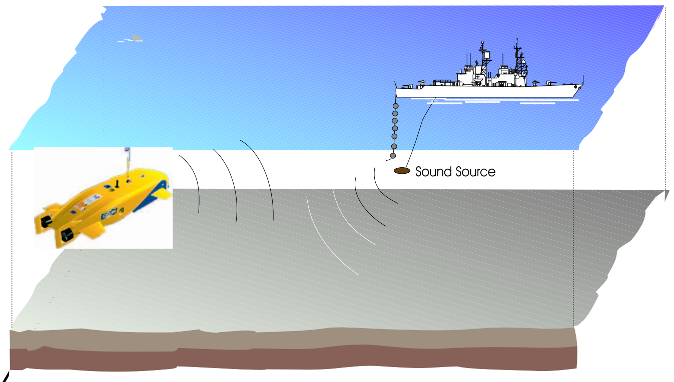


Source localization (MFP) - synoptic



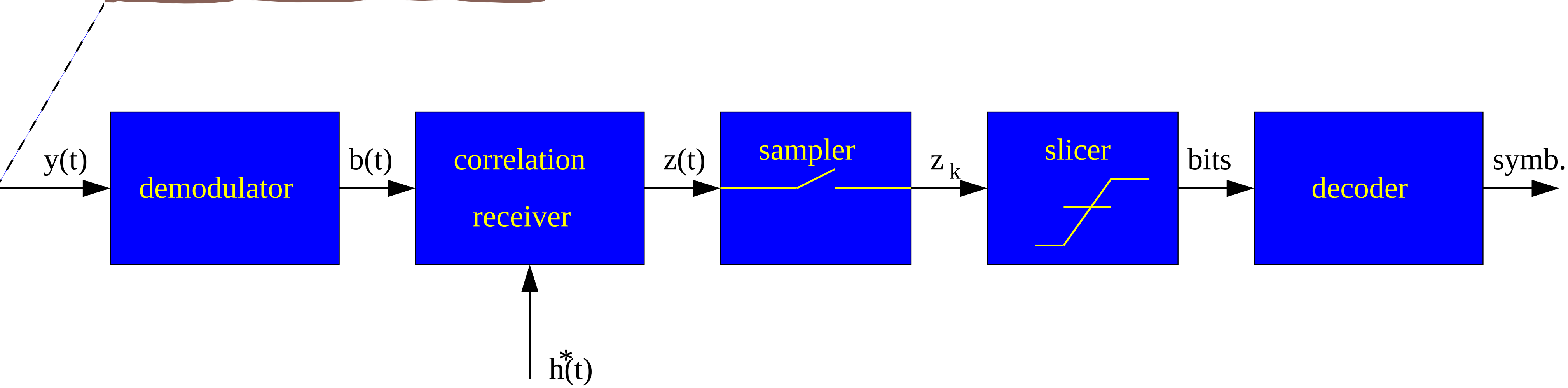
Underwater Acoustic Communications

ACom Experimental Setup

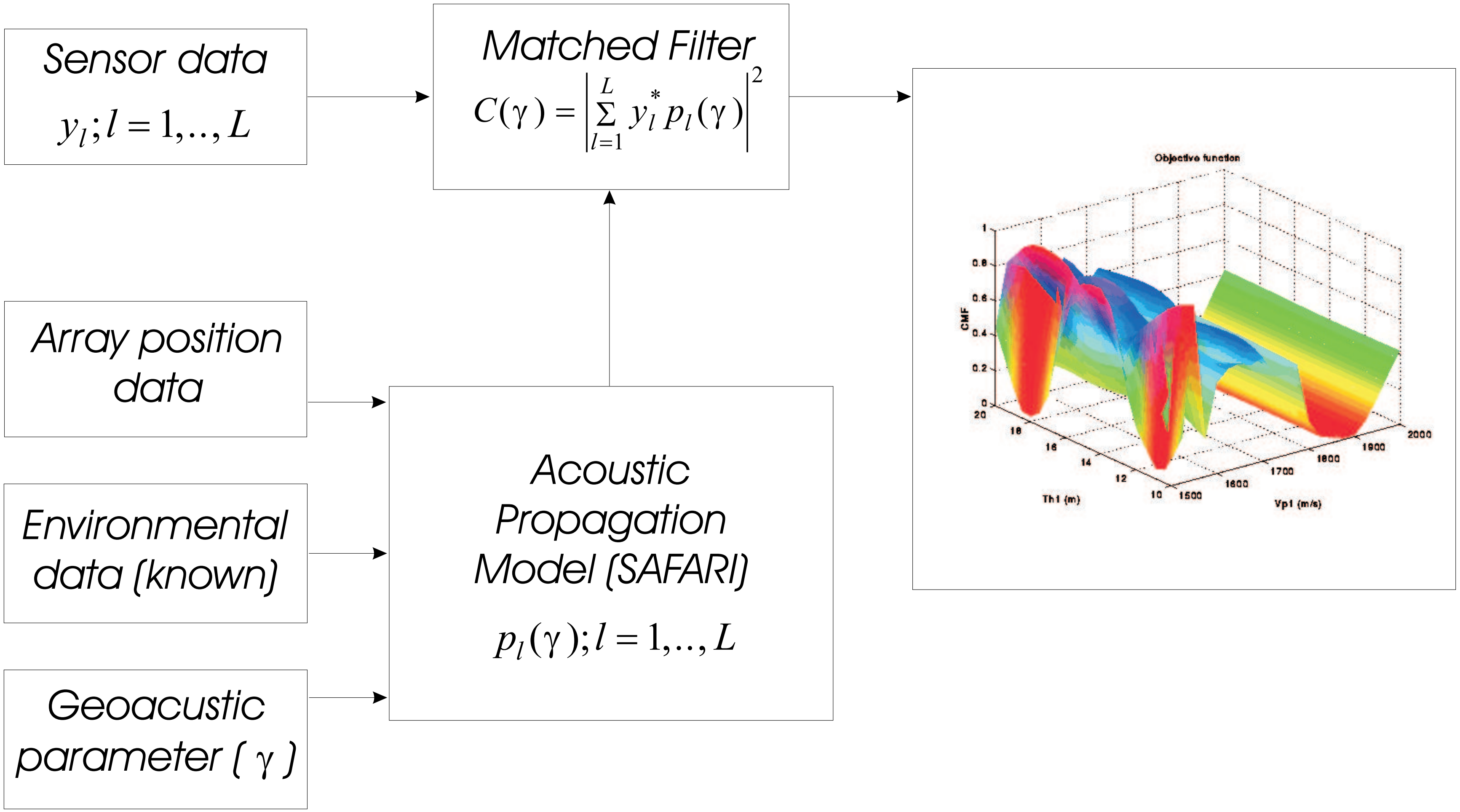


Problem: intersymbol interference due to the channel multipath

h(t) is a "guess" of the channel impulse response



DATA INVERSION STRATEGY



Data-model and the problem

Data model:

$$\begin{aligned} y(t,\mathbf{r}) &= x(t,\mathbf{r}) + n(t) \\ x(t,\mathbf{r}) &= g(t,\mathbf{r}) * s(t) \end{aligned}$$

Problem: find the filter $h(t,\mathbf{r})$

$$\begin{aligned} z(t,\mathbf{r}) &= h(t,\mathbf{r}) * y(t,\mathbf{r}) \\ &= z_0(t,\mathbf{r}) + n_0(t) \end{aligned}$$

that maximizes the SNR $\rho(t,\mathbf{r})$

$$\rho(t,\mathbf{r}) = \frac{|z_0(t,\mathbf{r})|^2}{< n_0^2 >}$$

Generalized Matched Filter

Signal-to-noise ratio (SNR): $$\rho(t,\mathbf{r}) = \frac{1}{2\pi}\frac{\left|\int_\Omega H(\omega,\mathbf{r})G(\omega,\mathbf{r})S(\omega)e^{j\omega t}d\omega\right|^2}{\int_\Omega \left|H(\omega,\mathbf{r})\right|^2 P_{nn}(\omega)d\omega}$$

Minimized by: $$H(\omega,\mathbf{r}) = H_0\frac{G^*(\omega,\mathbf{r})S^*(\omega,\mathbf{r})}{P_{nn}(\omega)}e^{-j\omega\tau}$$

Max SNR: $$\rho_{\max}(\mathbf{r}) = \frac{1}{2\pi}\int_\Omega \frac{|G(\omega,\mathbf{r})|^2|S(\omega)|^2}{P_{nn}(\omega)}d\omega$$

Performance of the GMF

Considering white-noise, i.e., $\mathbf{P}_{nn}(\omega) = \frac{N_0}{2}\mathbf{I}$,

$$\rho(t, \mathbf{r}) = \rho_{\max}(\mathbf{r})|\Lambda(t, \mathbf{r})|^2$$

with

$$\Lambda(t, \mathbf{r}) = \frac{\int_\Omega \hat{G}^*(\omega, \mathbf{r}) G(\omega, \mathbf{r}) |S(\omega)|^2 e^{j\omega(t-\tau)} d\omega}{\left[\int_\Omega |\hat{G}(\omega, \mathbf{r})|^2 |S(\omega)|^2 d\omega\right]^{1/2} \left[\int_\Omega |G(\omega, \mathbf{r})|^2 |S(\omega)|^2 d\omega\right]^{1/2}}$$

$$\rho_{\max}(\mathbf{r}) = \frac{2\epsilon_x}{N_0}$$

GMF vs. MF

Known channel response: $\hat{G}(\omega, \mathbf{r}) = G(\omega, \mathbf{r})$

$$\rho_{\mathrm{GMF}}(\mathbf{r}) = \rho_{\max}(\mathbf{r})$$

Unknown channel response: $\hat{G}(\omega, \mathbf{r}) = 1$

$$\rho_{\mathrm{MF}}(\mathbf{r}) = \rho_{\max}(\mathbf{r})\alpha(\mathbf{r})$$

$$\alpha(\mathbf{r}) = \frac{\max_t \left| \int_\Omega G^*(\omega, \mathbf{r}) |S(\omega)|^2 e^{j\omega(t-\tau)} d\omega \right|^2}{\int_\Omega |S(\omega)|^2 d\omega \int_\Omega |G(\omega, \mathbf{r})|^2 |S(\omega)|^2 d\omega.}$$

Gain GMF / MF

Gain of including environmental information is

$$\text{Gain} = \frac{\rho_{\text{GMF}}(\mathbf{r})}{\rho_{\text{MF}}(\mathbf{r})} = \frac{\max_t |\Lambda(t, \mathbf{r})|^2}{\alpha(\mathbf{r})}.$$

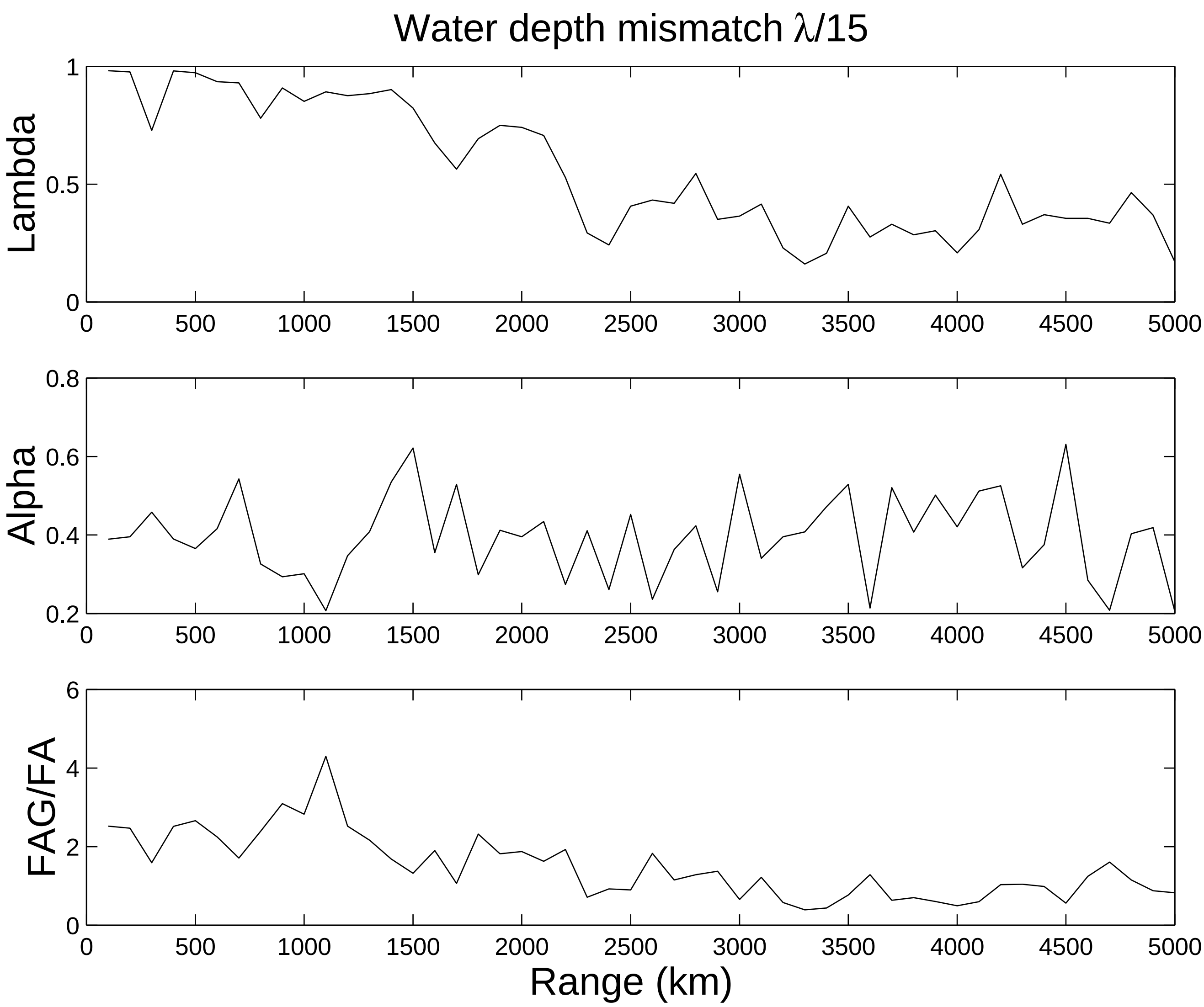
$$\max_t |\Lambda(t, \mathbf{r})|^2 \leq 1$$

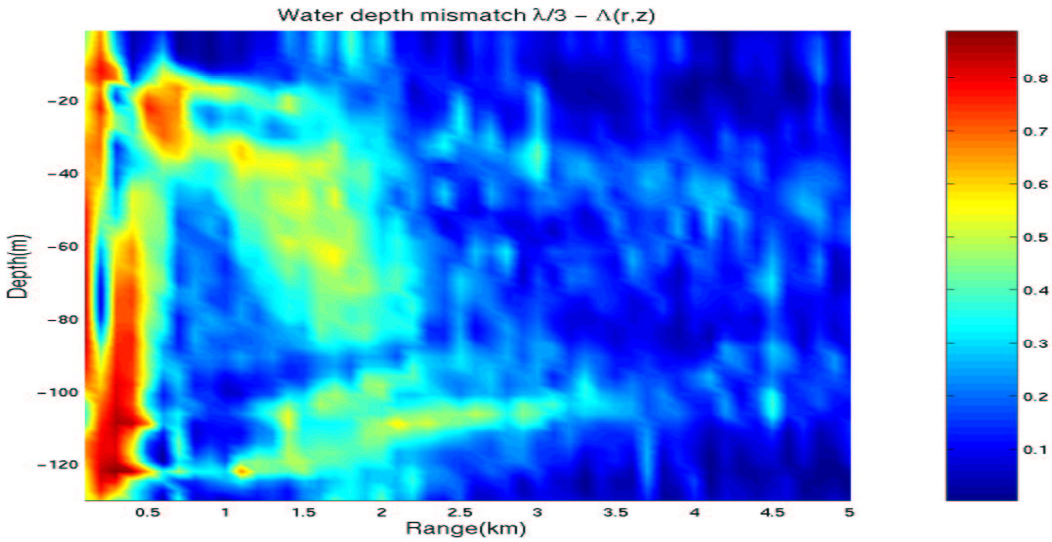
$$\alpha(\mathbf{r}) \leq 1$$

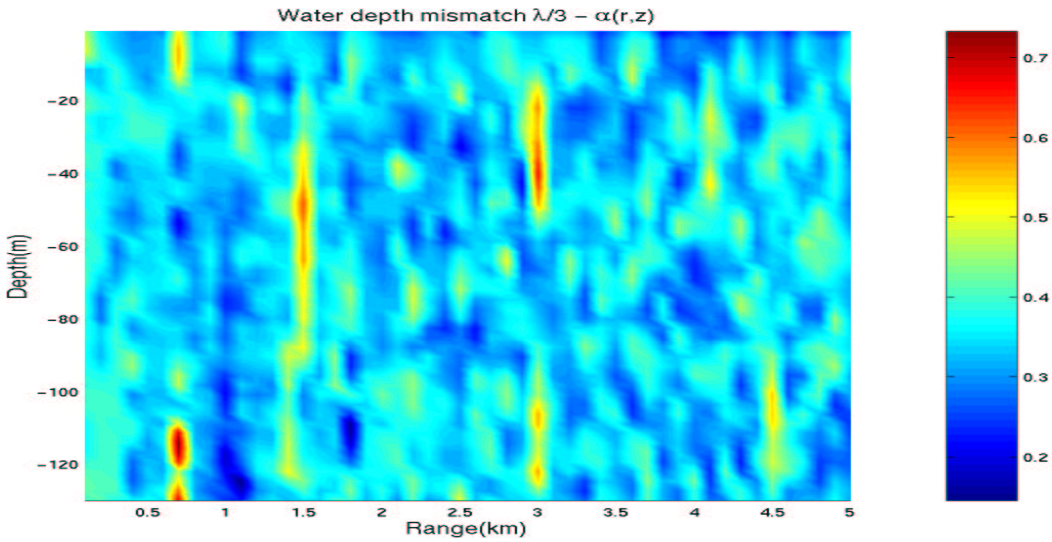
$$\Rightarrow \text{Gain can be} < 1 \text{ !}$$

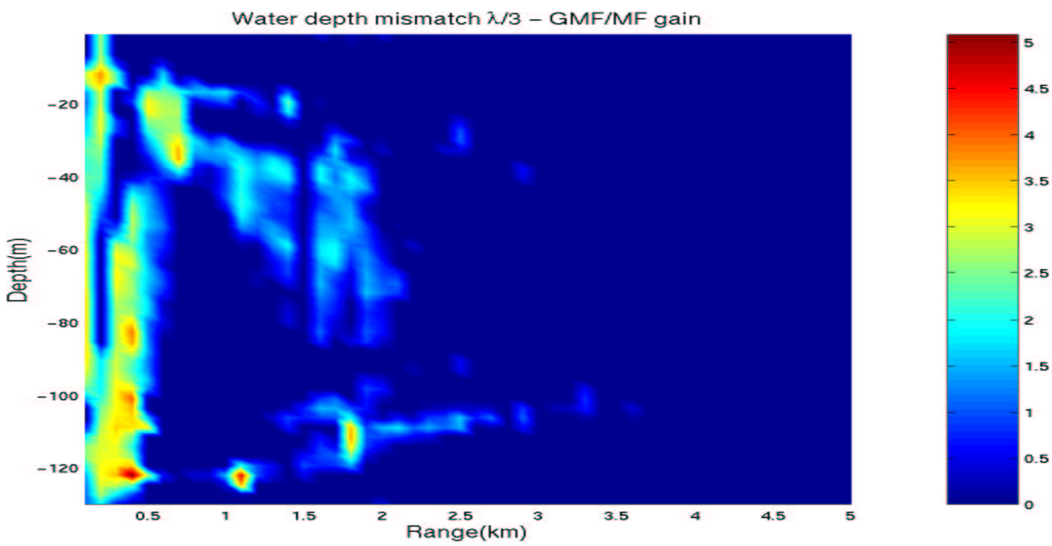
Simulations

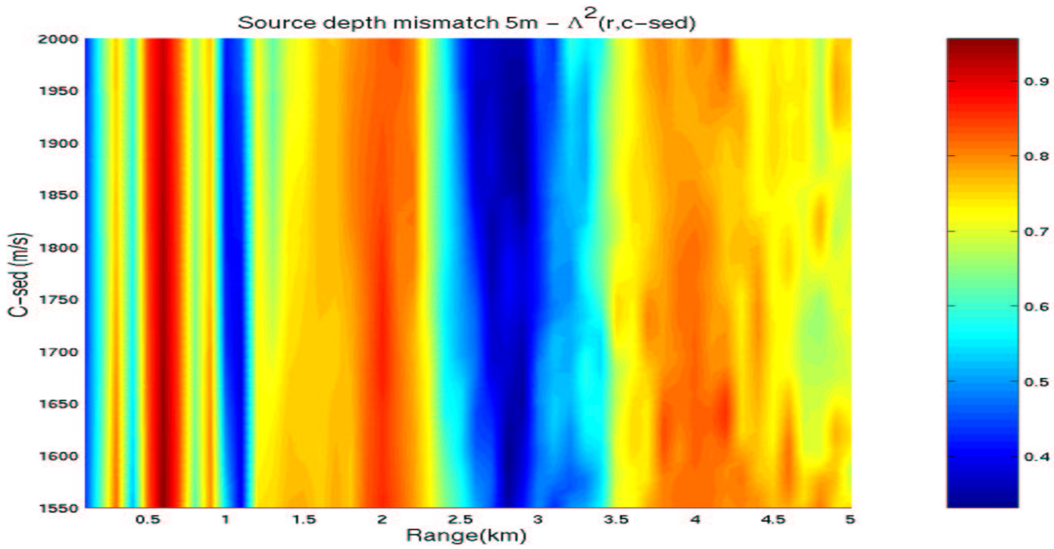
- range independent case: 135 m water depth, INTIMATE'96
- normal-mode model SNAP
- $f \in [50, 150]$ Hz



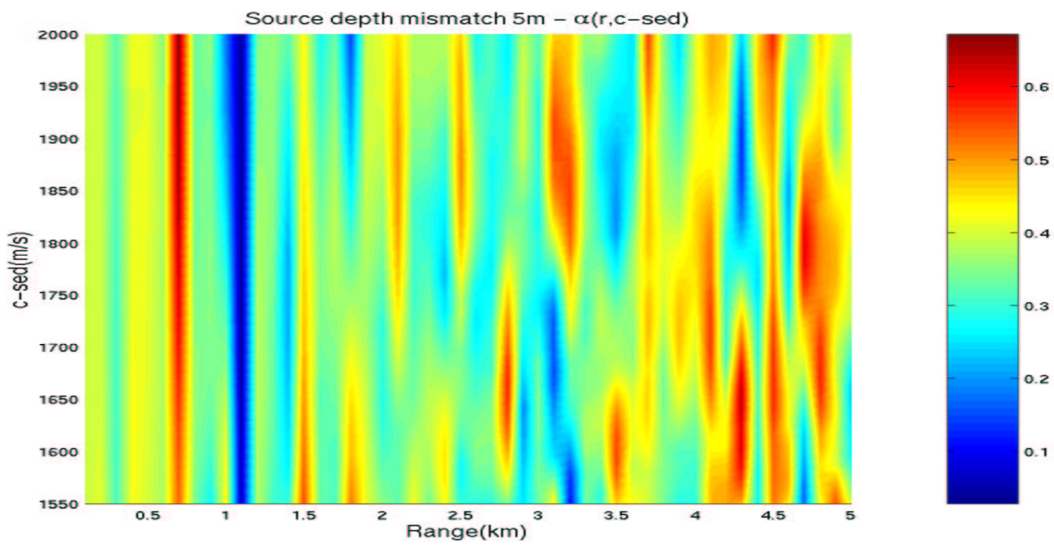

Water depth mismatch λ/3 – Λ(r,z)
Depth(m)
-20
-40
-60
-80
-100
-120
0.5 1 1.5 2 2.5 3 3.5 4 4.5 5
Range(km)
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1


Water depth mismatch λ/3 – α(r,z)
Depth(m)
-20
-40
-60
-80
-100
-120
0.5 1 1.5 2 2.5 3 3.5 4 4.5 5
Range(km)
0.7
0.6
0.5
0.4
0.3
0.2

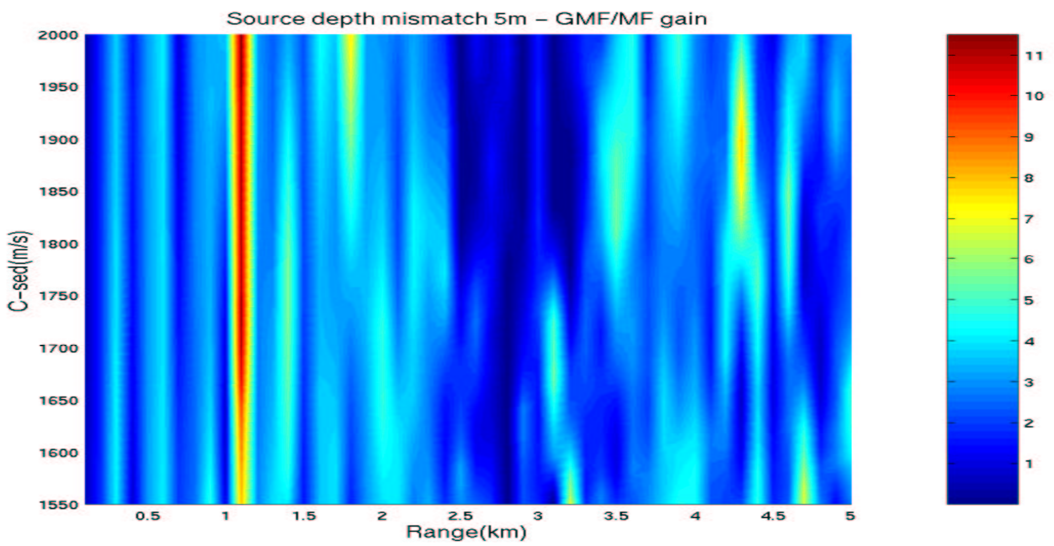

Water depth mismatch λ/3 – GMF/MF gain
Depth(m)
-20
-40
-60
-80
-100
-120
0.5 1 1.5 2 2.5 3 3.5 4 4.5 5
Range(km)
5
4.5
4
3.5
3
2.5
2
1.5
1
0.5
0



Source depth mismatch 5m – Λ²(r,c–sed)
C–sed (m/s)
2000
1950
1900
1850
1800
1750
1700
1650
1600
1550
0.5
1
1.5
2
2.5
3
3.5
4
4.5
5
Range(km)
0.9
0.8
0.7
0.6
0.5
0.4



Source depth mismatch 5m – α(r,c–sed)
c–sed(m/s)
2000
1950
1900
1850
1800
1750
1700
1650
1600
1550
0.5
1
1.5
2
2.5
3
3.5
4
4.5
5
Range(km)
0.6
0.5
0.4
0.3
0.2
0.1



Source depth mismatch 5m – GMF/MF gain
C–sed(m/s)
2000
1950
1900
1850
1800
1750
1700
1650
1600
1550
0.5
1
1.5
2
2.5
3
3.5
4
4.5
5
Range(km)
11
10
9
8
7
6
5
4
3
2
1

Conclusions

- generalized matched-filtering (GMF) can be very rewarding:
  - increase parameter space
  - estimation/detection capabilities
- simple matched-filtering (MF) can have higher SNR output than GMF depending on signal time spread and environmental characteristics mismatch
- tests for optimality to be performed for each case

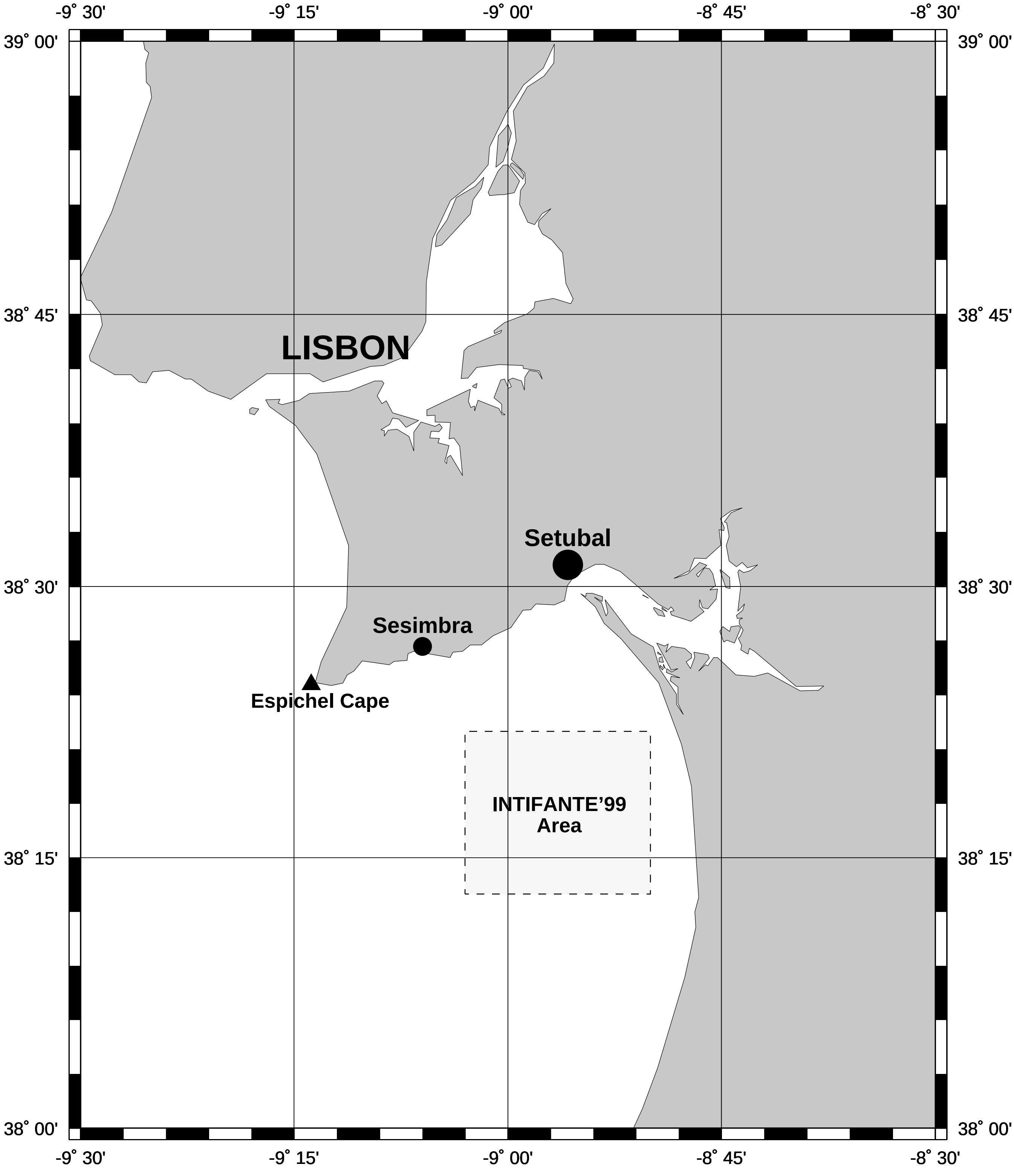
INTIFANTE'00 Sea Trial
Setúbal, 9-29/Oct/2000

Objectives

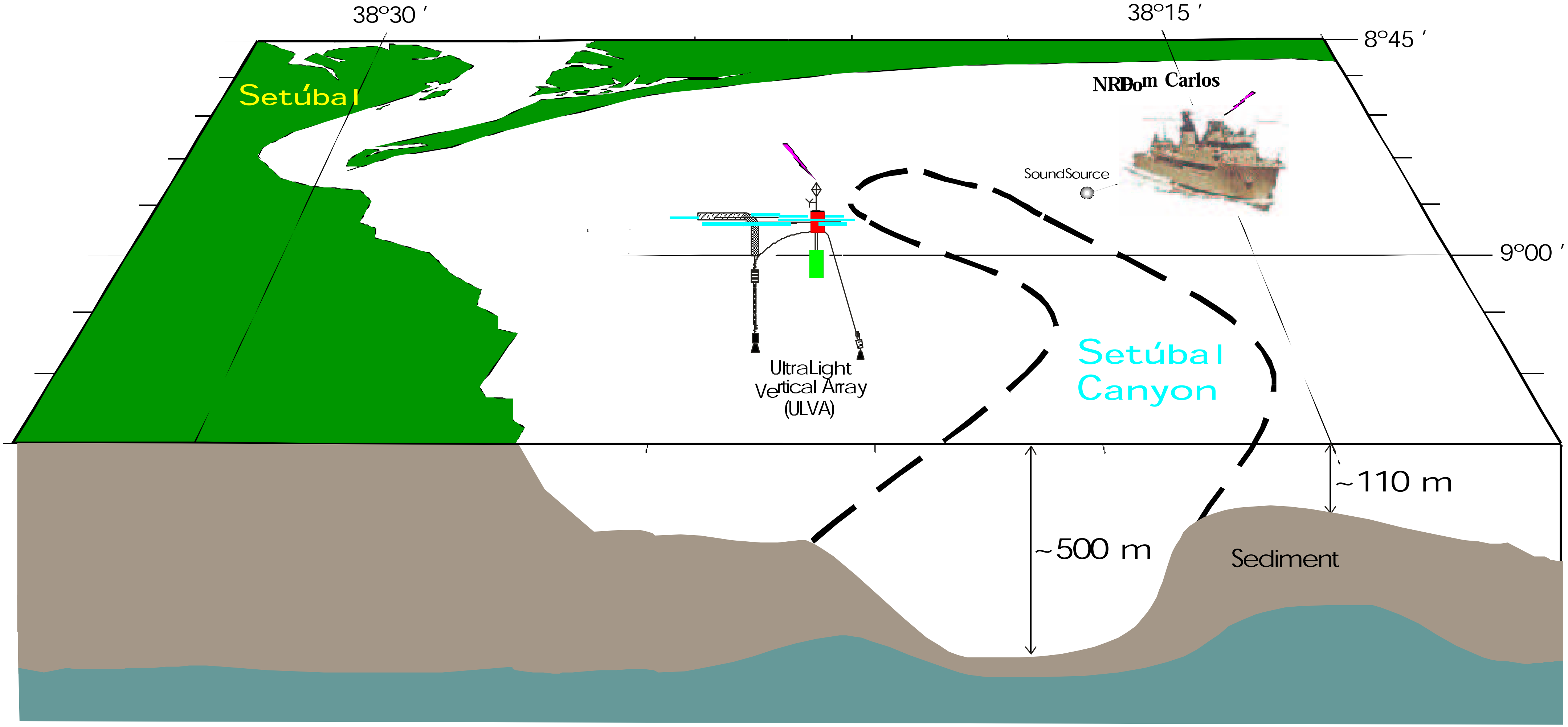
- INFANTE'00
  1. underwater communications (UWA modem)
  2. surface autonomous vehicle navigation (DELFIM)
  3. environmental effects in underwater communications (vTRM)
- INTIMATE'00
  1. acoustic observations of internal tide effects
  2. single sensor source localization in highly variable environments
  3. acoustic tracking of non-linear effects (solitary waves)
  4. passive tomography (TOMPACO - ship noise)

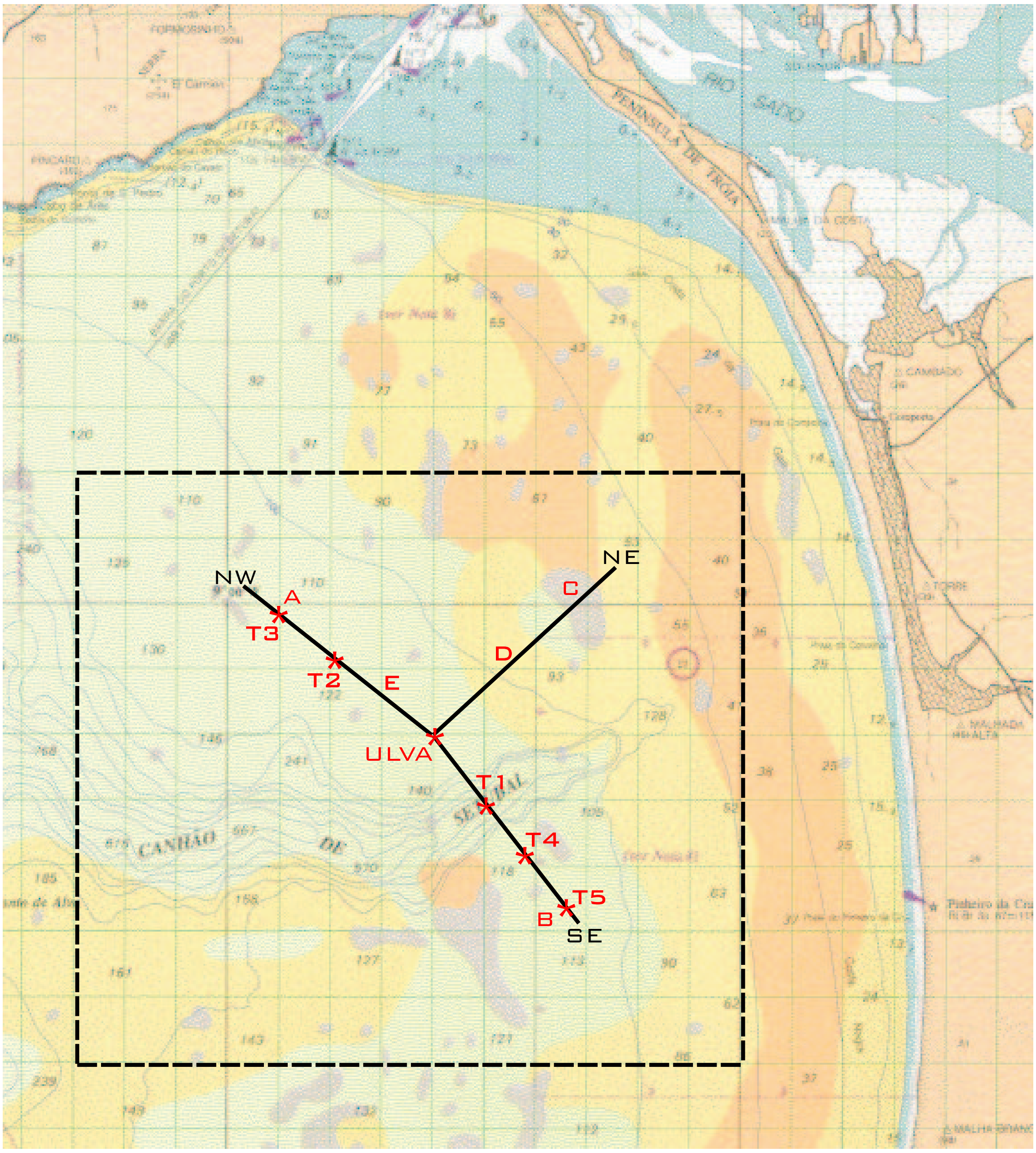
Ressources

- 4 institutions (IH, IST, CINTAL/UALg, ENEA)
- two vertical arrays (LF 16-hyd, HF 4-hyd)
- CTD's, currentmeters, bathymetry, sidescan sonar, seismic (Uniboom), HF (50 Khz) underwater acoustic modems, DGPS, LF acoustic source (NATO-SACLANTCEN), SST, SAR, thermistor chains, XBT's, etc...


-9˚ 30'
-9˚ 15'
-9˚ 00'
-8˚ 45'
-8˚ 30'
39˚ 00'
38˚ 45'
38˚ 30'
38˚ 15'
38˚ 00'
LISBON
Setubal
Sesimbra
Espichel Cape
INTIFANTE'99
Area

Real Data Acquisition Scenario
INTIMATE'00, OUT 2000 - SW Setubal site





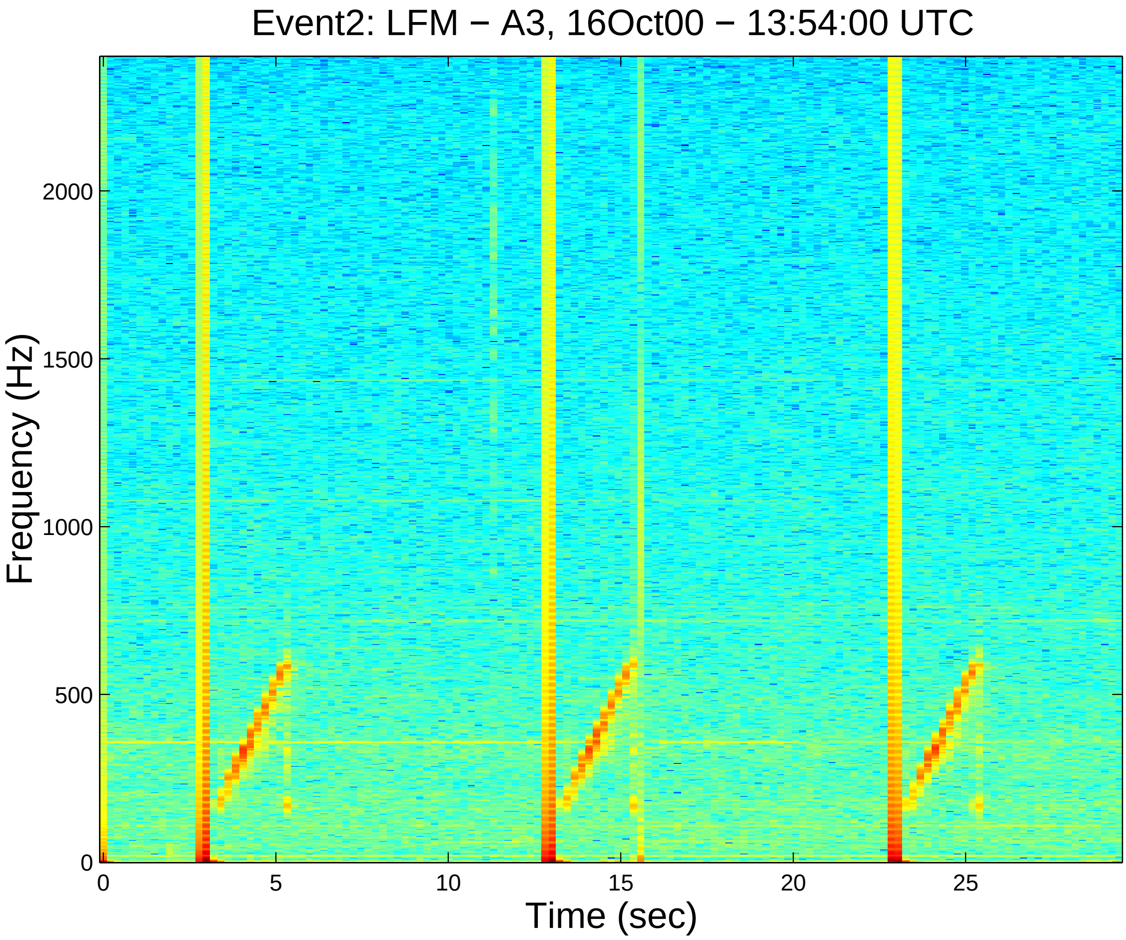
NW
NE
SE
A
B
C
D
E
T1
T2
T3
T4
T5
ULVA
CANHÃO
DE
SETÚBAL
RIO SADO
PENINSULA DE TROIA

INTIFANTE'00 Sea Trial

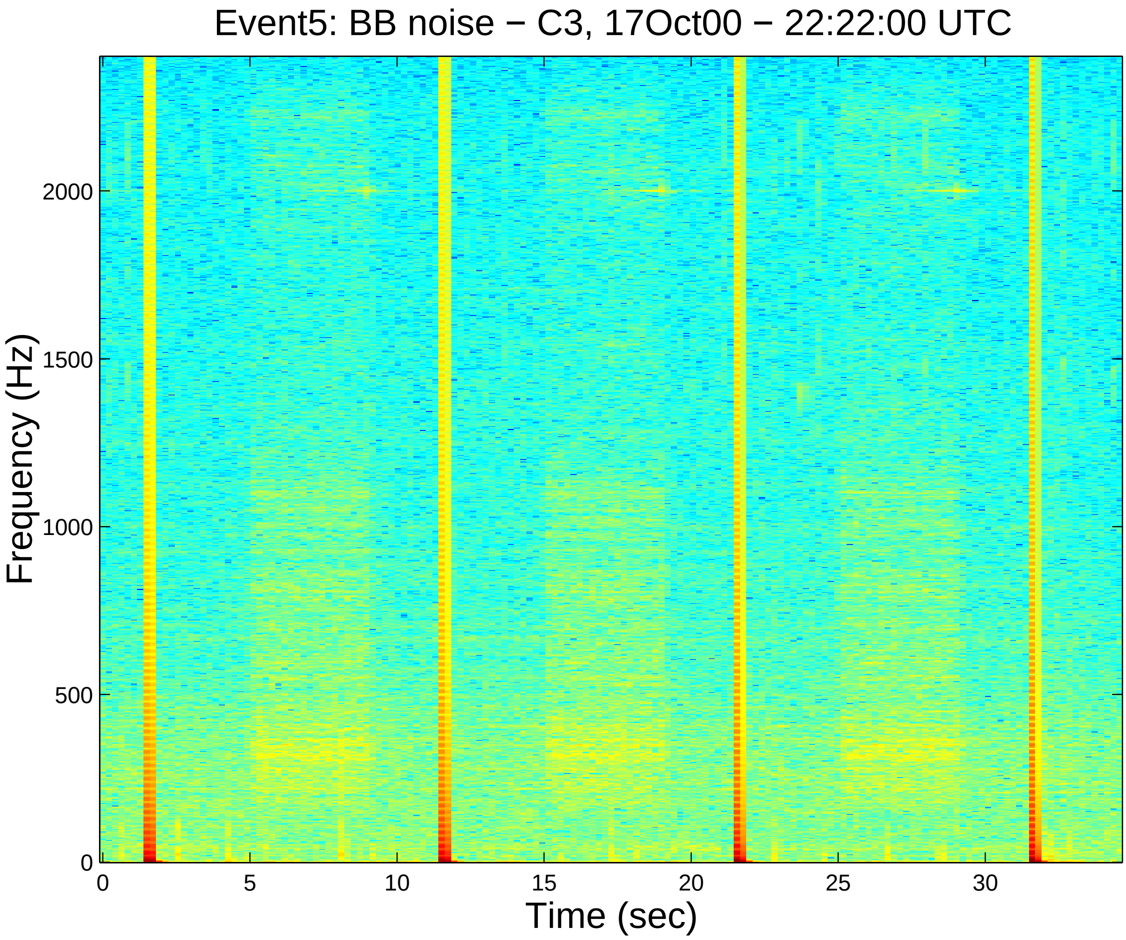
Setúbal, 9-29/Oct/2000

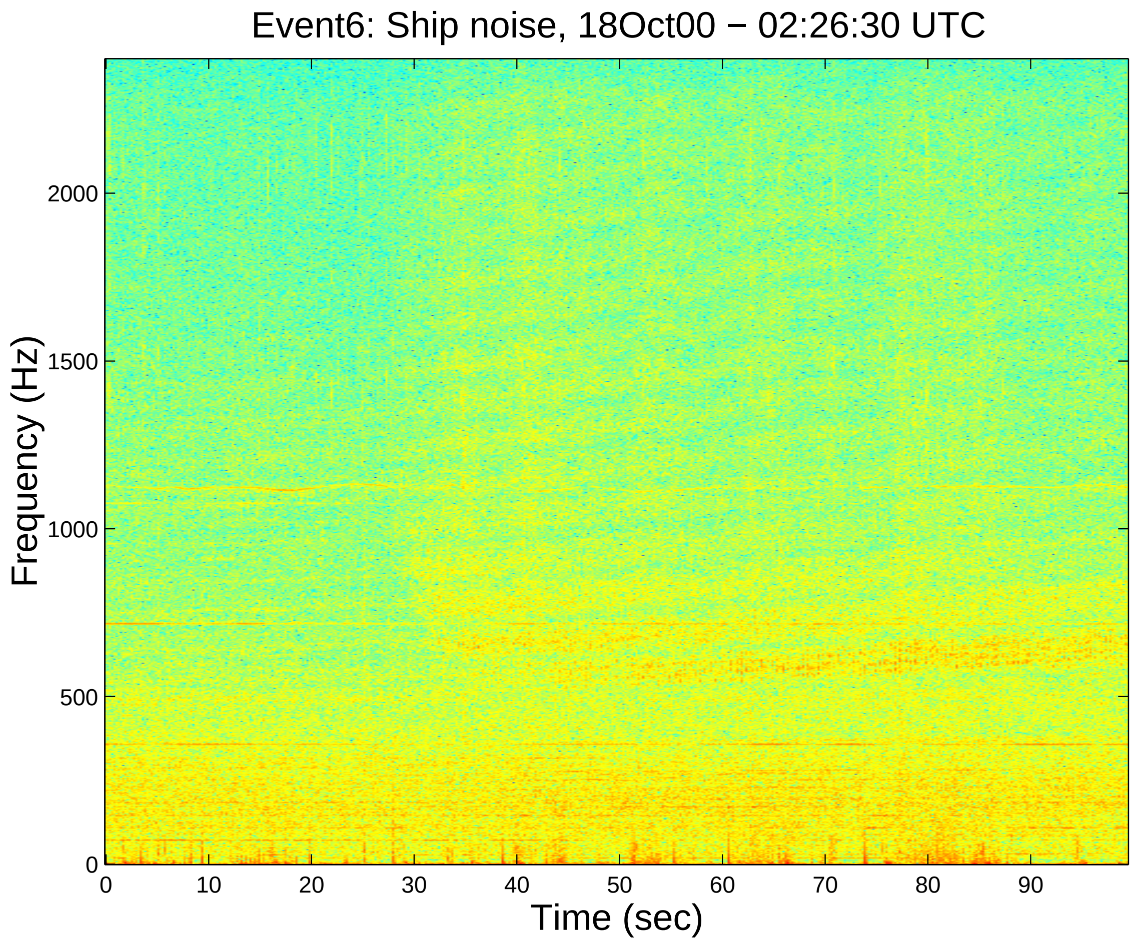
Event list

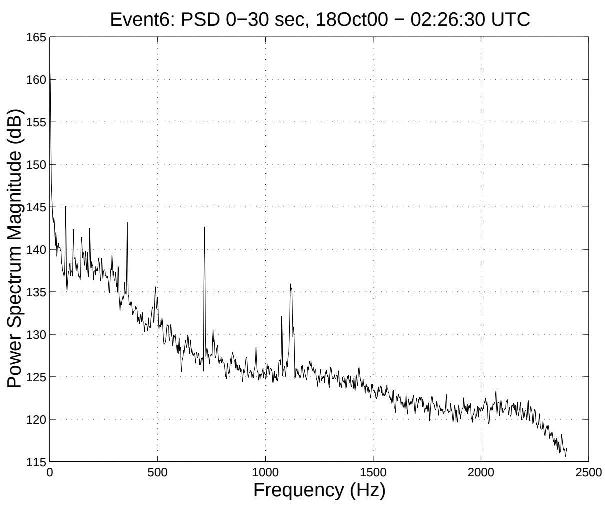
Event	description	Success
	INFANTE'00	
I	underwater acoustic modem directivity (50 kHz)	N
II	bottom module - HFA communication (50 kHz)	N
III	surface module - HFA communication (20 kHz)	Y
IV	DELFIM catamaran navigation for AUV data communication	Y
	INTIMATE'00	
I	PSK,FSK,probe (1.8 kHz) virtual time-reversal mirror	Y
II	LFM (170-600 Hz) range-independent transmissions - internal tide	Y
III	LFM (170-600 Hz) range-dependent transmissions - localization	Y
IV	LFM (170-600 Hz) across-canyon transmissions - localization	Y
V	BB noise transmissions for passive tomography	Y
VI	Ship noise transmissions for passive tomography	Y

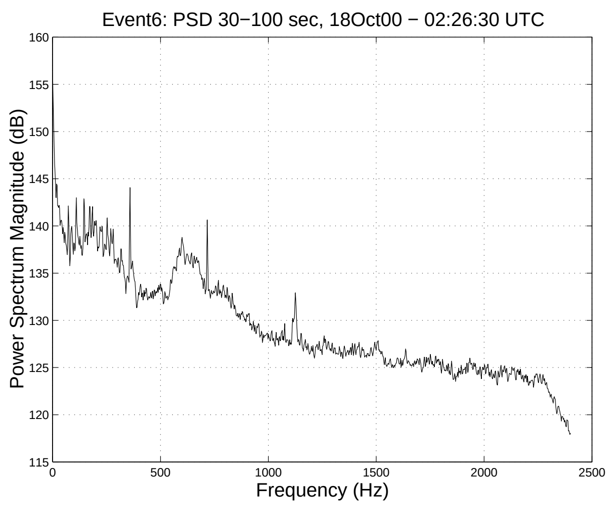


Event2: LFM − A3, 16Oct00 − 13:54:00 UTC
Frequency (Hz)
0
500
1000
1500
2000
Time (sec)
0
5
10
15
20
25


Event5: BB noise − C3, 17Oct00 − 22:22:00 UTC
Frequency (Hz)
2000
1500
1000
500
0
0
5
10
15
20
25
30
Time (sec)


Event6: Ship noise, 18Oct00 − 02:26:30 UTC
Frequency (Hz)
Time (sec)
0
500
1000
1500
2000
0 10 20 30 40 50 60 70 80 90


Event6: PSD 0−30 sec, 18Oct00 − 02:26:30 UTC
Power Spectrum Magnitude (dB)
Frequency (Hz)
115 120 125 130 135 140 145 150 155 160 165
0 500 1000 1500 2000 2500


Event6: PSD 30−100 sec, 18Oct00 − 02:26:30 UTC
Power Spectrum Magnitude (dB)
Frequency (Hz)
115 120 125 130 135 140 145 150 155 160
0 500 1000 1500 2000 2500