Conférence Hydrographique du Canada, Québec 21-23 juin 2010

Qualité acoustique intrinsèque des mesures bathymétriques par SMF

(Définition d'un Facteur de Qualité)

Intrinsic Acoustic Quality of Bathymetry Measurements by MBES

(Definition of a Quality Factor)

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Summary

1. Why a sounding quality estimator ?
2. Bathymetry measurement and accuracy
3. Proposition of a Quality Factor
4. Application/Validation upon real data
5. Discussion, conclusions and prospects

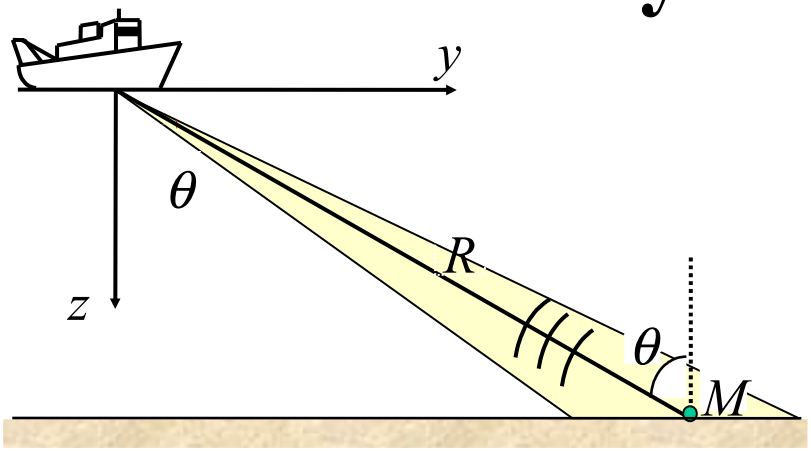
Why a *Sounding Quality Estimator?*

- Customers'request = a bathymetry ***« Quality Factor »***
  - ***Quantified***, objective, and possibly universal
  - Directly indicative of the ***sounding quality (accuracy)***
  - Easy to interpret and exploit (post-processing)

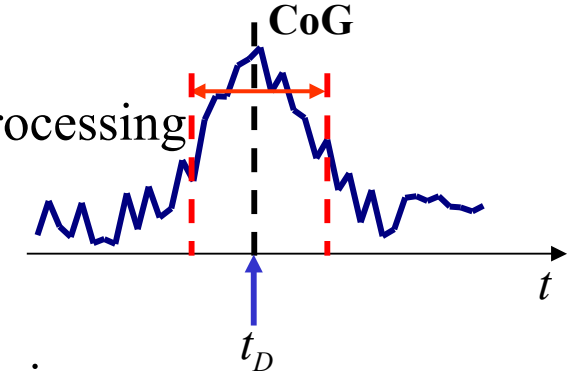
- Constructors'answers = various attempts…
  - Often obscure definitions – not always relevant
  - Indicative of the ***signal*** quality, not of the ***sounding***
  - Linked to ***one particular system***

*N.B. This paper is only concerned by the **acoustical signal** component of the bathymetry measurement (no SVP, MRU…)*

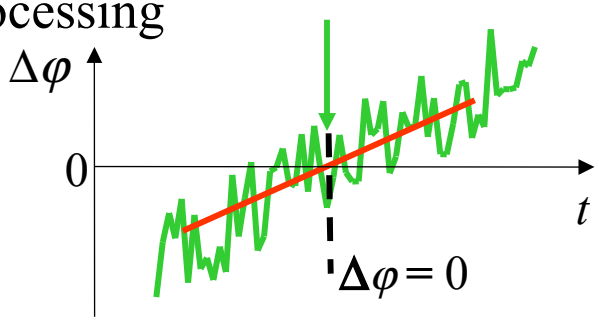
Sonar Bathymetry Fundamentals



•Amplitude processing



•Phase processing



MBES :
- θ fixed
- t measured
  - •Amplitude
  - •Phase

ISSS :
- t fixed
- θ measured
  - •Phase

Angle θ

Range $R=ct/2$

$$\begin{cases} y = R.\sin\theta \\ z = R.\cos\theta \end{cases}$$

Bathymetry error budget

(see e.g. Hare, Godin & Mayer, 1995)

- Sonar head motion
  - Roll, heave…
- Sound speed at the arrays
  - Beam steering angle
- Sound speed profile
  - Geometrical refraction
- Sonar head geometry
- Acoustic processing
  - Signal / Noise
  - Measurement configuration
  - Processing applied

Bias-like
(Short- to long-term)

Noise-like
Random fluctuations

Bathymetry Accuracy / Phase

Neglecting errors / time sampling, motion, SVP…

Degradation of measurement quality w/ NOISE

- Signal intrinsic fluctuations & decorrelation
- Additive noise

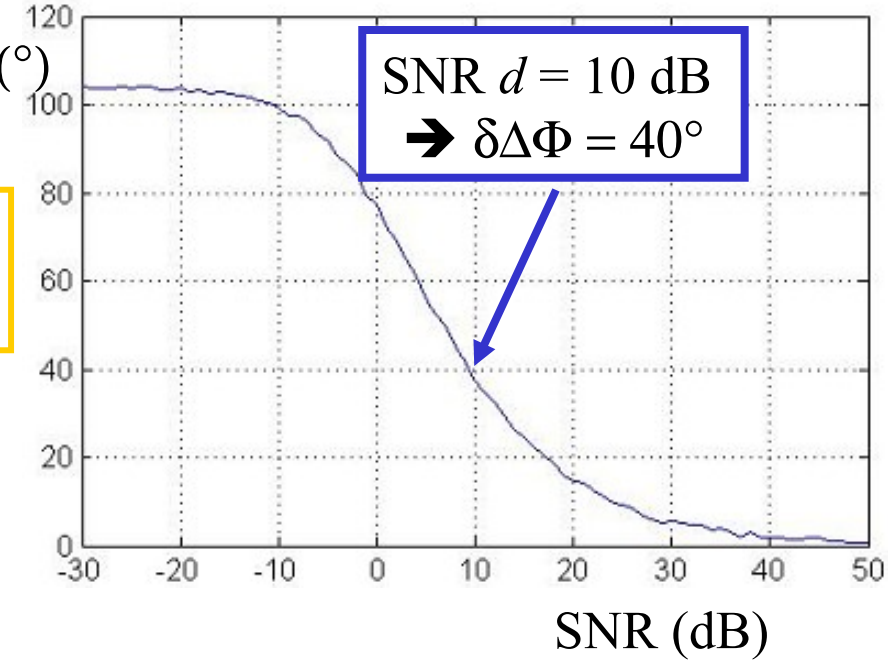
Phase-diff. error $\delta\Delta\Phi$

MBES
Time error δt

ISSS
Angle error $\delta\theta$

Bathymetry error δz

$$\frac{\delta z}{z} = \frac{\delta t}{t} \qquad \frac{\delta z}{z} = \tan\theta \,.\delta\theta$$



Bathymetry Accuracy / Phase (2)

- Improvement of $\delta\Delta\Phi$ = averaging over N realisations
  - In radar : *multi-look* (several snapshots of a scene)
  - In sonar : averaging of **N neighbouring samples**

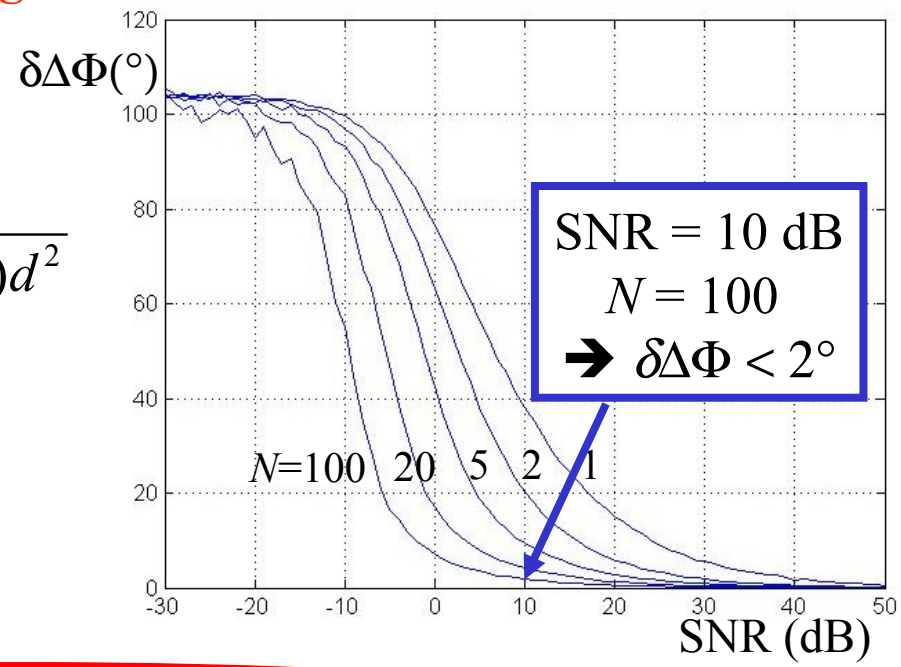
- For a fluctuating signal in noise:

$$\delta\Delta\Phi_N^2 = \frac{1}{(N-1)d} + \frac{N}{2(N-1)(N-2)d^2}$$

(Lurton, IHR 2003)

- Improvement by N-averaging

$$\frac{\delta z}{z} \propto \delta\Delta\Phi_N \propto \frac{1}{\sqrt{N}} \quad \text{(large } N\text{)}$$

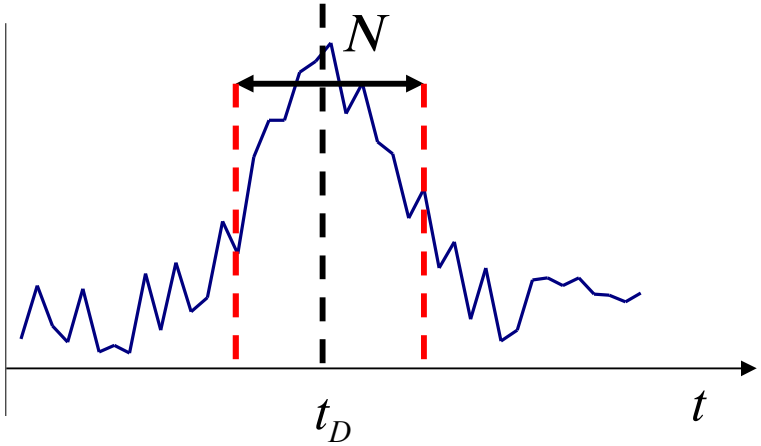


The Trade-Off :

Gain of $\sqrt{N}$ in **accuracy** ⇔ **resolution** degradation by N

Bathymetry Accuracy / Amplitude

- Time signal in central beams
- Bell-shaped time envelope
- **Center of gravity** over N samples (at $-X$ dB below max value)



- Fluctuating signal ➔ std dev. δt_D of arrival time t_D
- Theoretical analysis (see paper by Ladroit et al., this conf):
  - Square envelope, Rayleigh noise, signal duration T ➔ exact solution
  - Bell-shaped ➔ multiplicative factor $B \approx 0.7$ on δt_D

$$\delta t_D^2 = B^2 \frac{4-\pi}{\pi} \frac{N(N+2)T^2}{12(N+1)} \Rightarrow \delta t_D \approx 0.15 B T \sqrt{N} \approx 0.11 T \sqrt{N}$$

(estimation over N independent samples)

Ifremer

Ifremer 's proposition

(First version presented at Shallow Survey'08, Portsmouth, NH)

➔ Definition of a **Bathymetry Quality Estimator** $\delta z/z$ for:

- Objective assessment of soundings
- Data flagging

➔ Based upon :

- Elementary modelling of $\delta t/t$ (for MBES)
- Measured **individual** signal characteristics

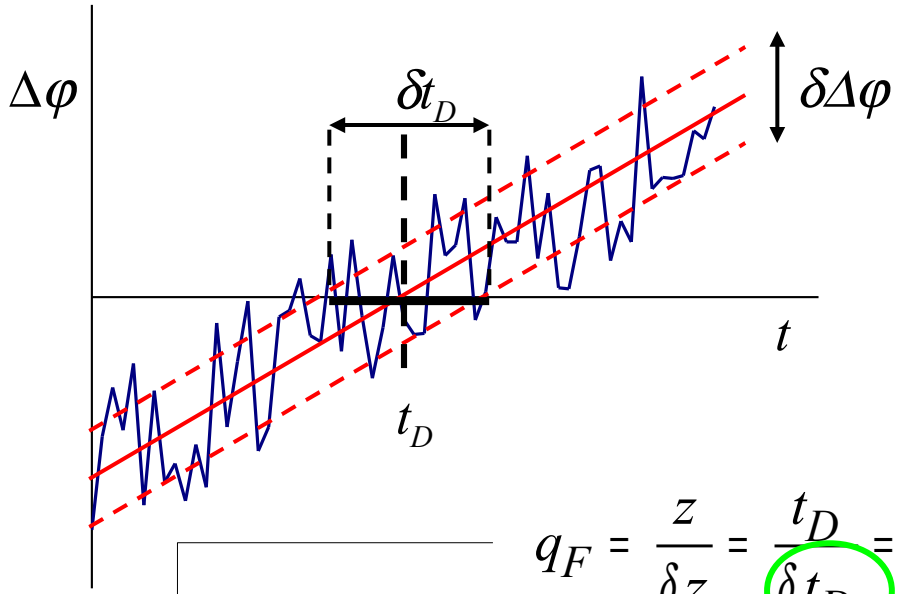
$$q_F = \frac{\delta t}{t} = \frac{\delta z}{z} \quad \rightarrow \quad QF = \log(q_F)$$

QF	< 2.0	2.5	> 3.0
$\delta z/z$	$> 1\%$	0.3%	$< 0.1\%$

Concept = independent of the sonar type / model

Quality Factor / Phase

- Time (depth) accuracy ⇔ Phase fluctuation



Measured / N indep.samples

- Phase std. dev. $\frac{\delta\Delta\varphi}{\sqrt{N}}$
- Phase slope A

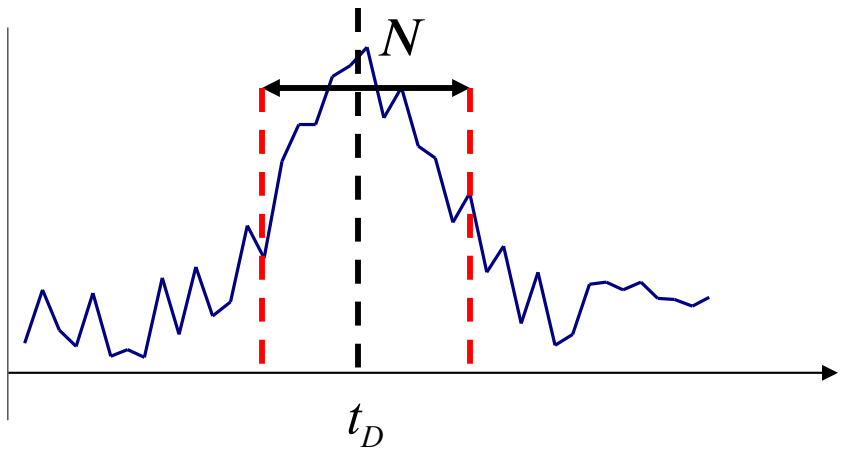
$$q_F = \frac{z}{\delta z} = \frac{t_D}{\delta t_D} = \frac{A.t_D\sqrt{N}}{\delta\Delta\varphi}$$

$$QF = \mathrm{Log}_{10}(q_F)$$

Including : squared summation of the pulse length to δt_D

Quality Factor / Amplitude

- Arrival time = center of gravity (intensity, or amplitude)



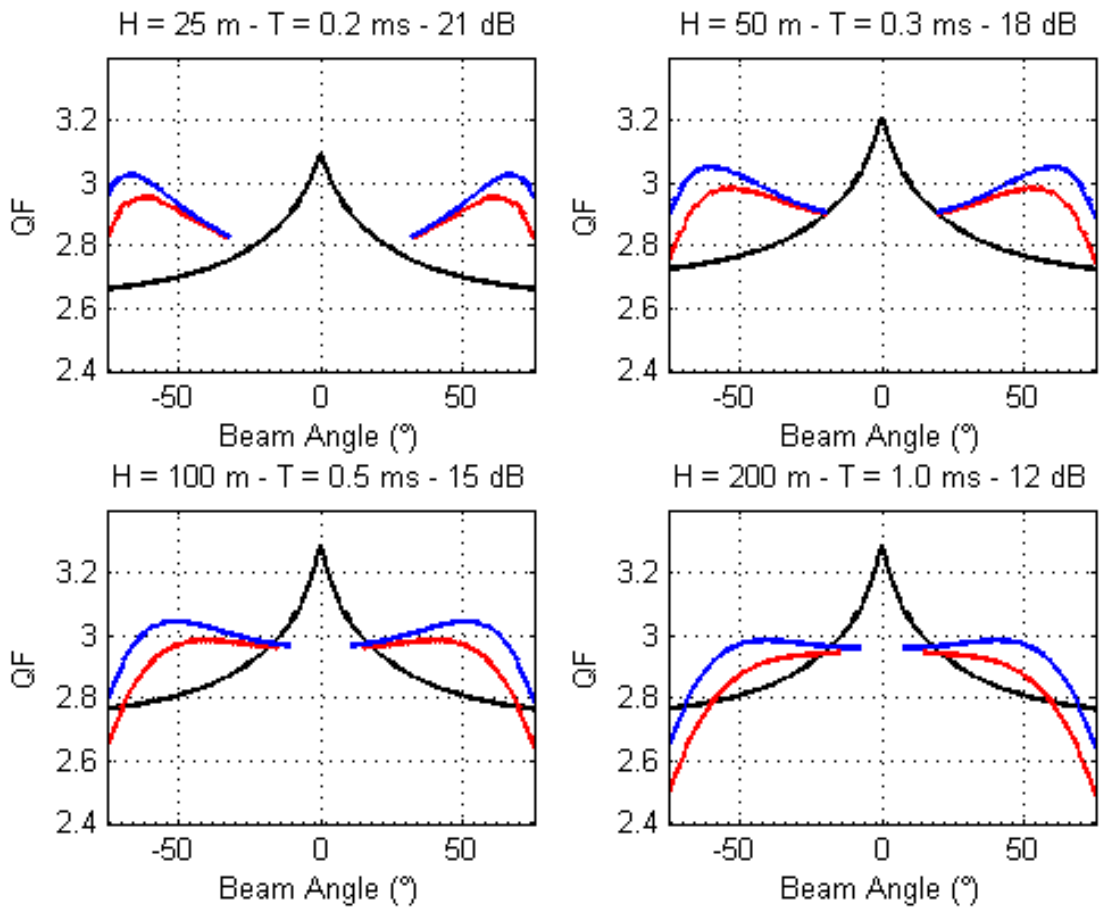
$$q_F = \frac{z}{\delta z} = \frac{t_D}{\delta t_D} \approx \frac{t_D}{AT\sqrt{N}}$$

$$QF = \mathrm{Log}_{10}(q_F)$$

- N = number of signal samples
- T = pulse duration
- $A \approx 0.11$ (for bell-shaped amplitude c.o.g.)

QF simulation / Shallow

MBES 100 kHz; 201 beams 2°; circular array; equidist. δx; 5kHz



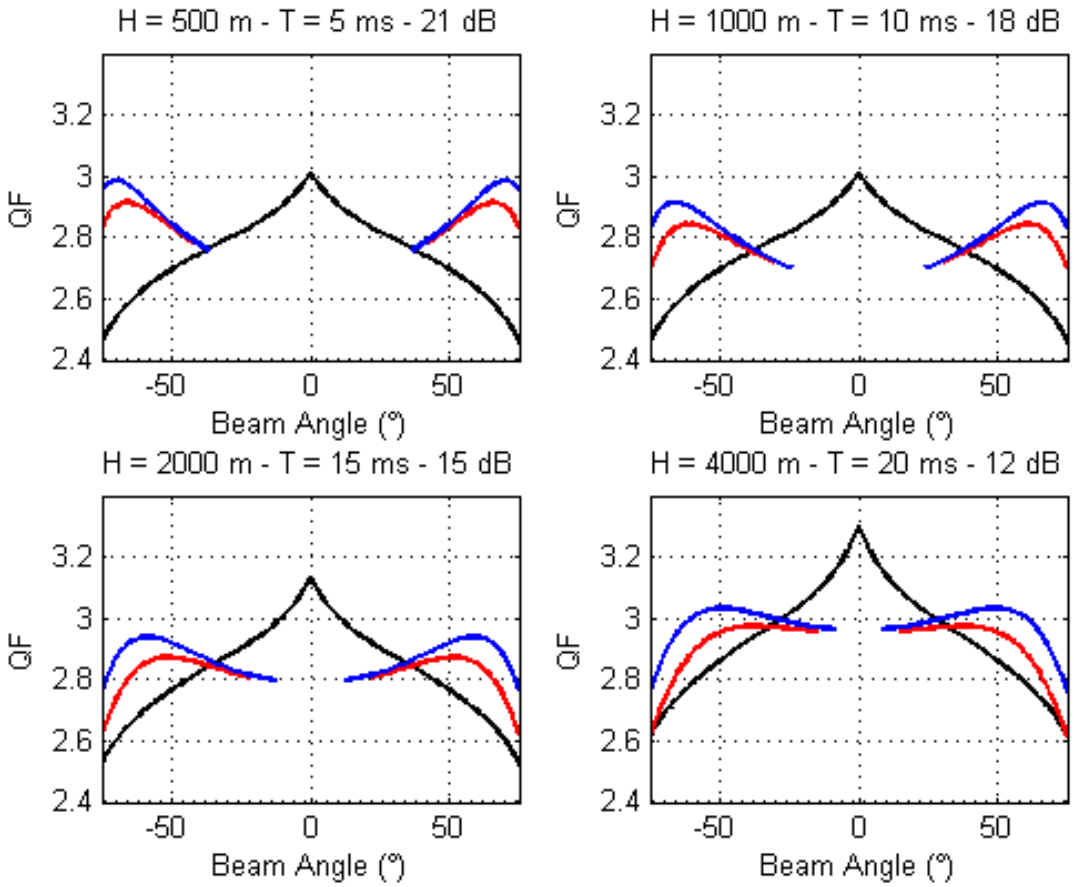
Amplitude QF

Phase QF, phase-ramp=4δx

Phase QF, phase-ramp=2δx

QF simulation / Deep

MBES 12 kHz; 201 beams 1°; flat array; equidist. δx; 500 Hz



Amplitude QF

Phase QF, phase-ramp=4δx

Phase QF, phase-ramp=2δx

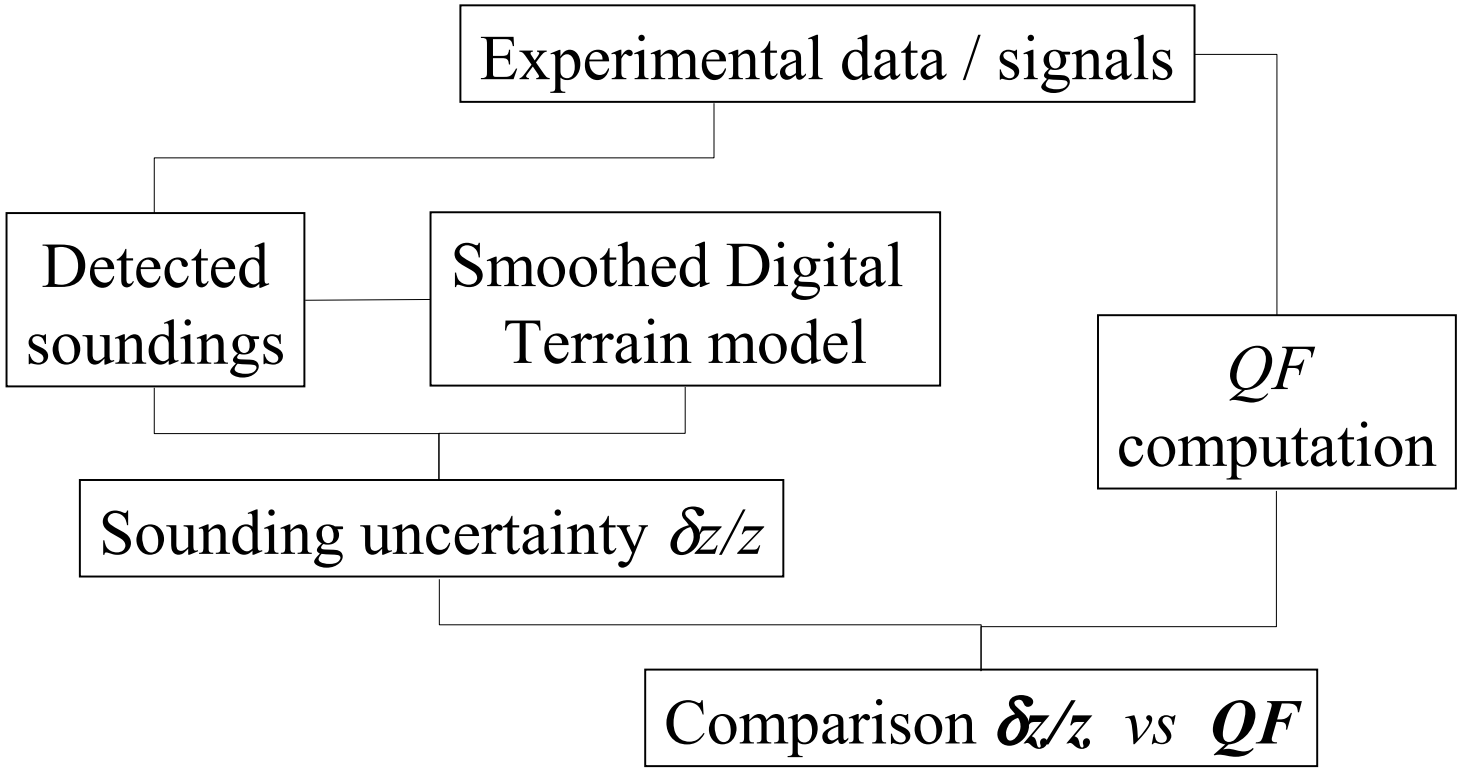
QF : results and values

- Typical values **[2.3 – 3.3]** ($\delta z/z$ = 0.5% – 0.05 %)
- Amplitude QF :
  - Higher at nadir
  - Decreases at oblique incidences
  - Limiting value for circular array
- Phase QF :
  - Higher than amplitude outside central sector
  - Optimal at one oblique incidence
  - Decreases at swath ends
- Lower values: swath ends + amplit./phase junction

All points confirm the common experience in MBES data

Concept validation upon real data

- Evaluation of the ***QF* relevance** for comparing with the **actual level** of sounding fluctuations
- Works by Y.Ladroit (UNH-2009; PhD Ifremer, 2009-2012)



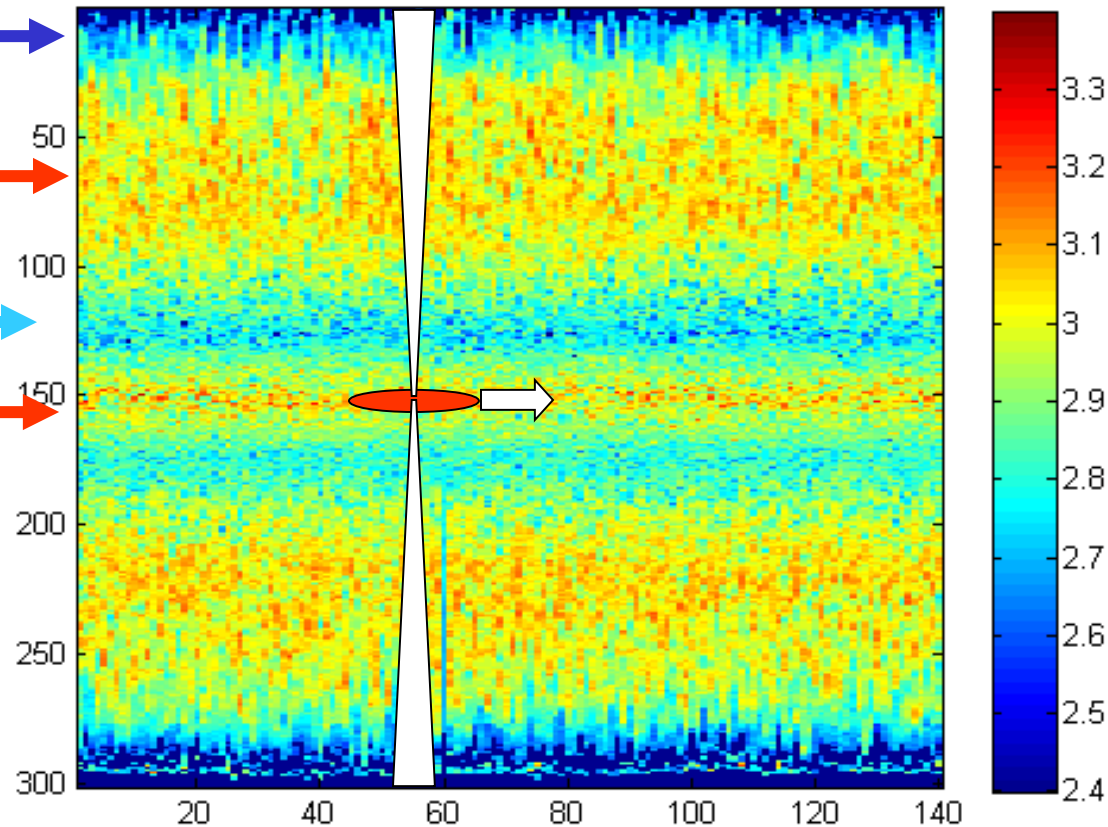
Real data (1) : shallow flat (30 m)

Lo QF: Swath ends

Hi QF:Phase /Oblique

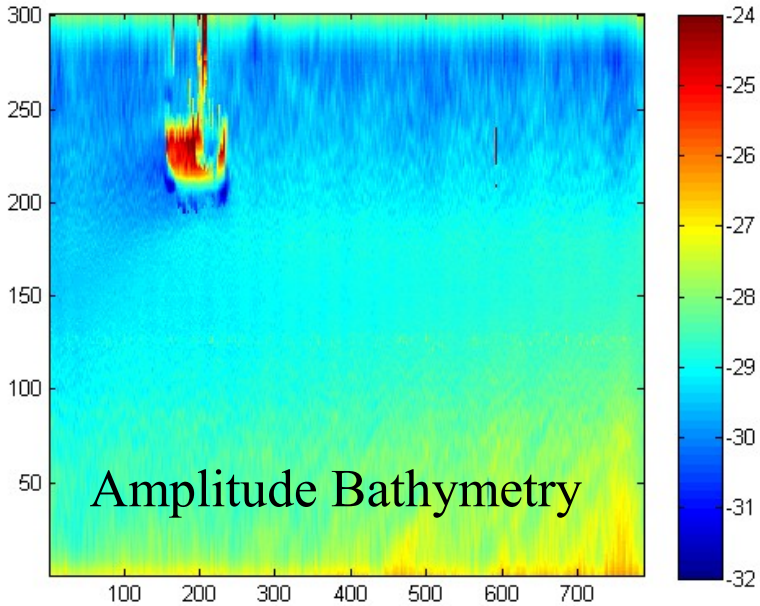
Med QF: Junction

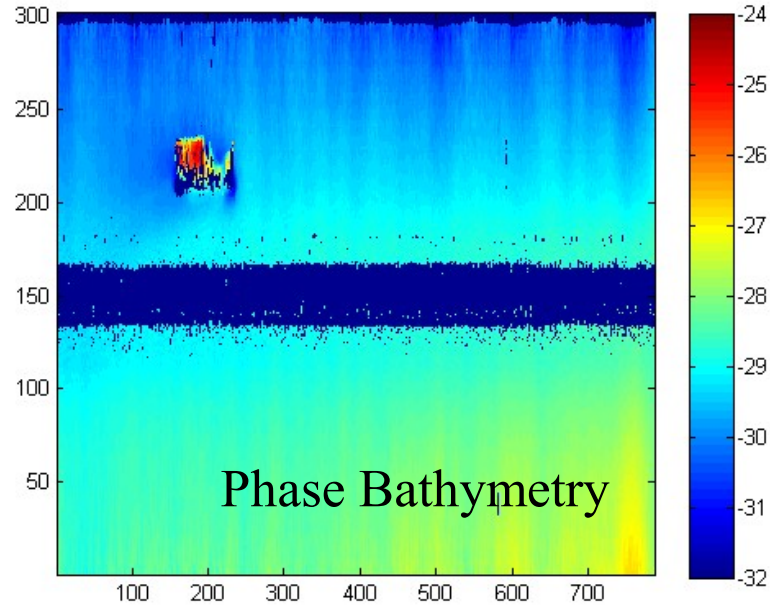
Hi QF: Ampl. /Nadir

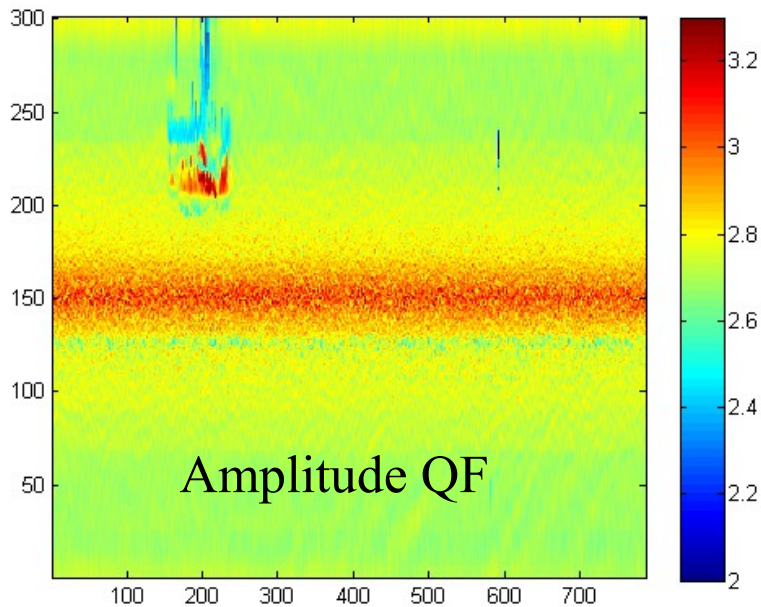


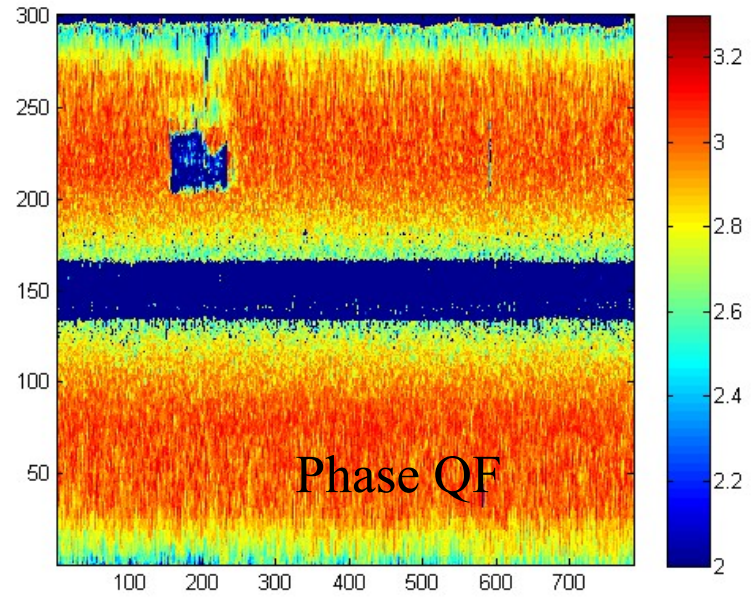
QF phase ⇔ *z*/*δz* phase *QF* amplitude ⇔ *z*/*δz* amplitude

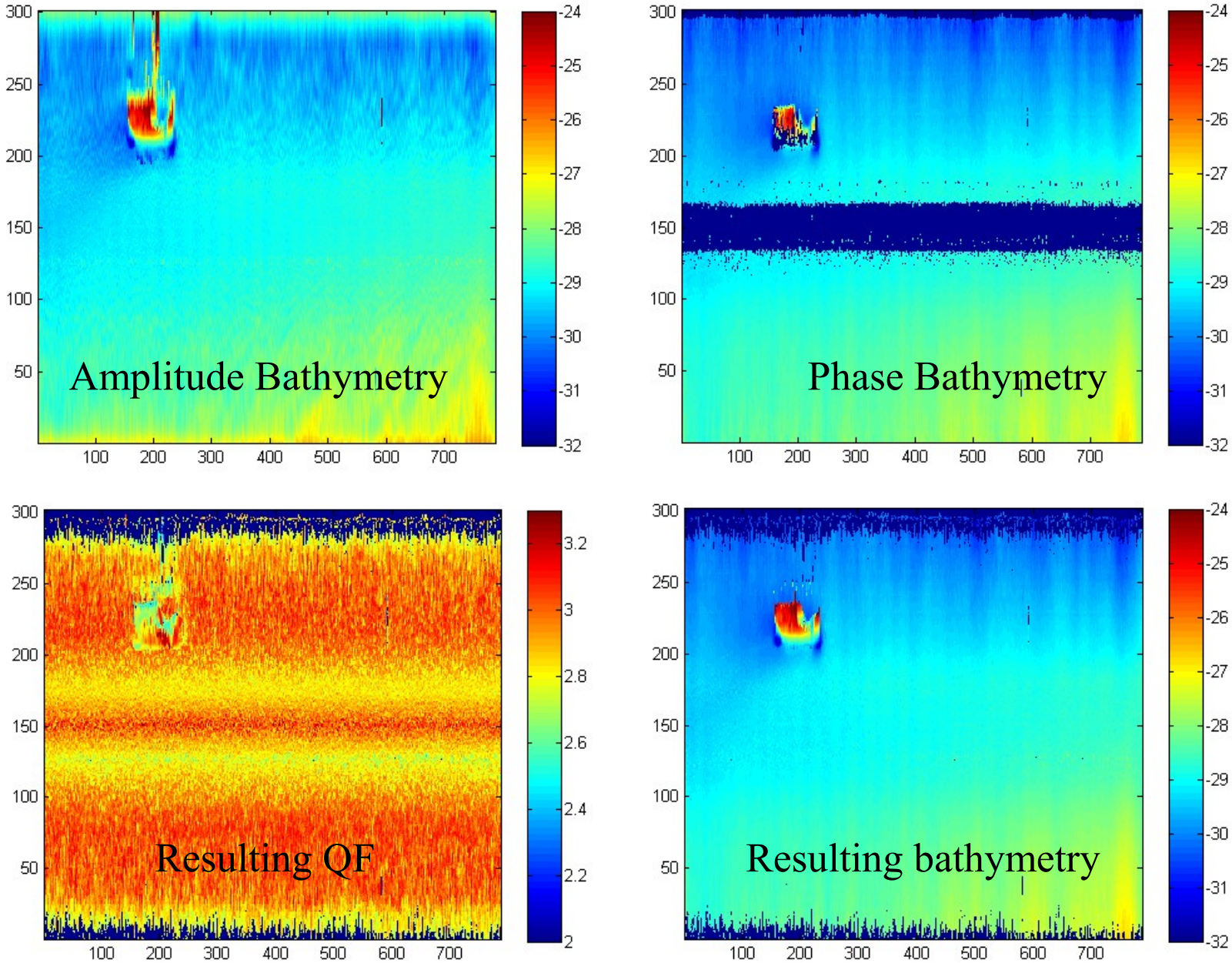
- Reson Seabat 7111 – 100 kHz - *RV Pourquoi pas?*


Amplitude Bathymetry
300
250
200
150
100
50
100 200 300 400 500 600 700
-24 -25 -26 -27 -28 -29 -30 -31 -32

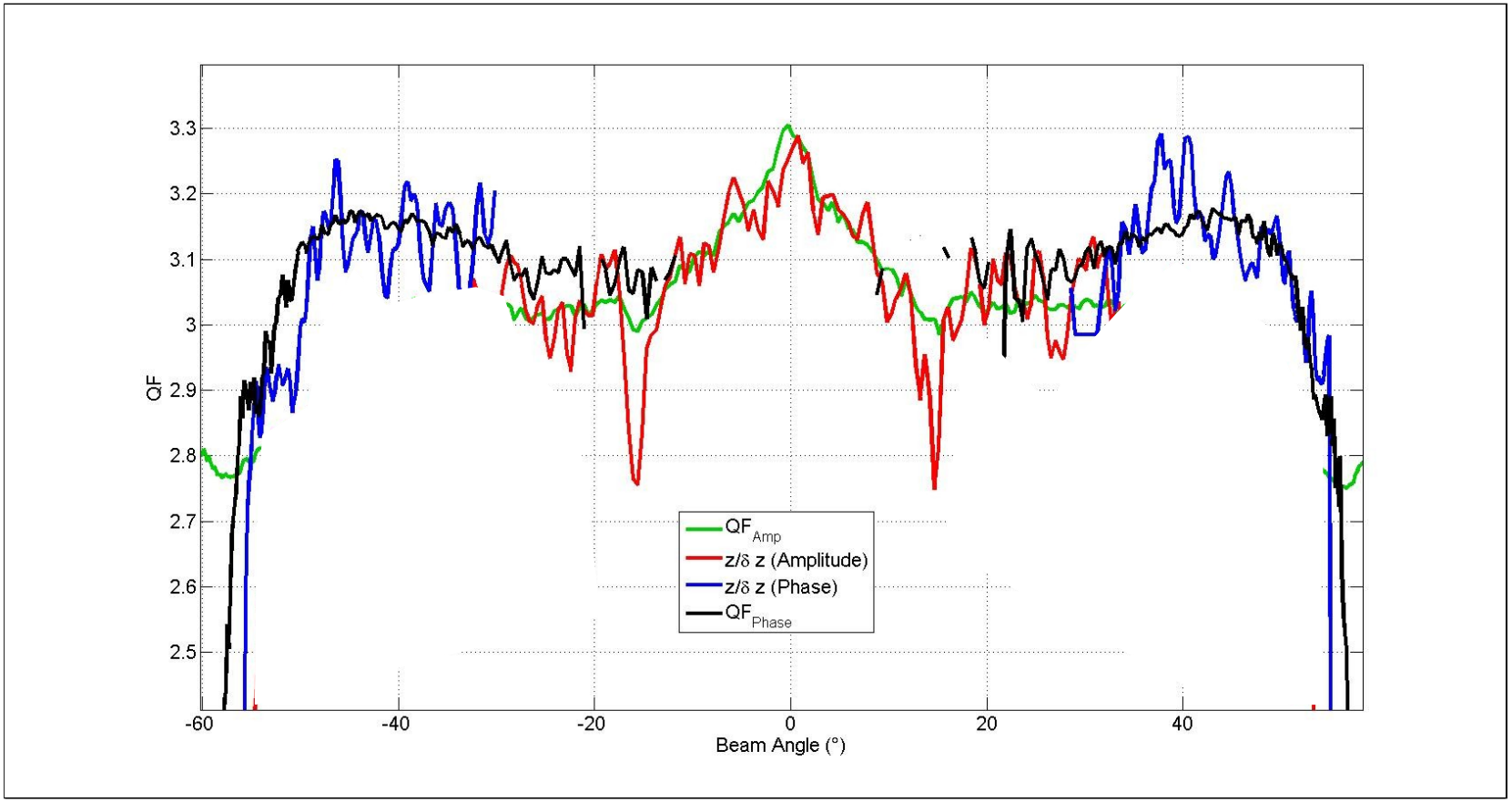

Phase Bathymetry
300
250
200
150
100
50
100 200 300 400 500 600 700
-24 -25 -26 -27 -28 -29 -30 -31 -32


Amplitude QF
300
250
200
150
100
50
100 200 300 400 500 600 700
3.2 3 2.8 2.6 2.4 2.2 2


Phase QF
300
250
200
150
100
50
100 200 300 400 500 600 700
3.2 3 2.8 2.6 2.4 2.2 2


Amplitude Bathymetry
Phase Bathymetry
Resulting QF
Resulting bathymetry

Real data (2) : deep flat (2100 m)



QF amplitude ⇔ *z*/*δz* amplitude *QF* phase ⇔ *z*/*δz* phase

- Reson Seabat 7150 – 24 kHz - *RV Pourquoi pas?*

Results & Discussion

- Very good agreement of ***QF*** estimates with statistical results
  - to be consolidated by more data processing

- ***QF*** = a **valuable local quality estimator** (per sounding)
  - Gives direct access to bathymetry quality (what e.g. SNR does NOT)
  - Defined from phase/amplitude objective signal features
  - Only the « acoustical side » of the sounding issue
  - A global quality indicator of Bottom Detector AND acoustic signals
  - Universal : based on classical detection methods
    - ➔ independent of the sonar type, brand, model…
    - ➔ depends on details of the detection algorithms

- ***QF*** **cannot**:
  - Detect ambiguities in phase determination
  - Account for specular return influence
  - Identify interferences from other systems

Conclusions and prospects

- Algorithm easily implemented / computed. Applicable to:
  - Bottom detection algo : choice between amplitude / phase candidates
  - Datagram content : Flagging of recorded soundings
  - Quality control : local bathymetry accuracy-resolution assessment
  - Post-processing : **hi-density data using quality criteria (*CUBE*)**

- First implementations:
  - 2008: Preliminary version ➔ Seabat 7111/7150 *RV Pourquoi pas?*
  - 2009: Updated version on Kongsberg EM 122/710 *RV L'Atalante*
  - 2010: Final design & post-processing works; updated implementation?
  - ? Application to interferometers

- Our expectation : ***QF*** implemented in OTS bathymetry sonars
  ➔ standard feature of datagrams and post-processing SW tools

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