Shearwater GeoServices

Increasing survey productivity and enhancing data quality

February 2017

Steve Hepburn – Acquisition Geophysicist

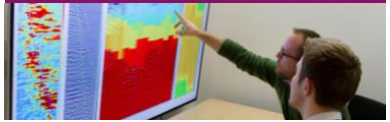
Shearwater GeoServices - Full Geophysical Service Company

Marine

Modern, Powerful Fleet

- Modern 3D Vessels
- **Low Cost Base**
- Global Operational Experience
- Organisations of Shearwater & GCR Shipping experienced with operating these assets
- Increased Productivity through powerful solutions and wide tow configurations

Processing & Imaging



Full Processing & Imaging Capabilities

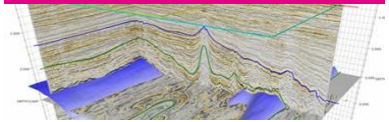
- UK, Houston
- Processing & Re-Processing
- Time & Depth Imaging
- SHarp Broadband
- Dedicated in-house R&D
- Global Experience

Multi-Client

2D & 3D MC

- Majority of ex Dolphin Library sold to 3rd parties
- Intend to build an MC business line, based on partnerships, potential consolidation, and organic growth given high prefunding

OpenCPS Software



Land & Marine Seismic Processing Software

- QC, Time & Depth Imaging
- Interactive Processing
- Advanced 2D & 3D Visualization
- Developer's Environment
- Broadband Technology

Shearwater Fleet and Towed Assets

Polar Empress

Built:	2015
Seismic Configuration:	Up to 22 streamers
Bollard Pull:	> 250 T

Polar Duchess

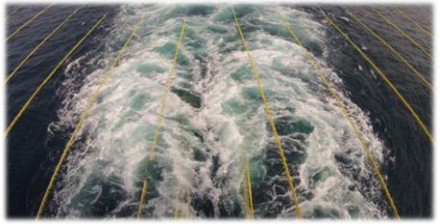
Built:	2011
Seismic Configuration:	Up to 12 streamers
Bollard Pull:	Approx. 200 T

Polar Marquis

Built:	2000/2014
Seismic Configuration:	Up to 16 streamers
Bollard Pull:	Approx. 200 Tonnes

Polar Duke

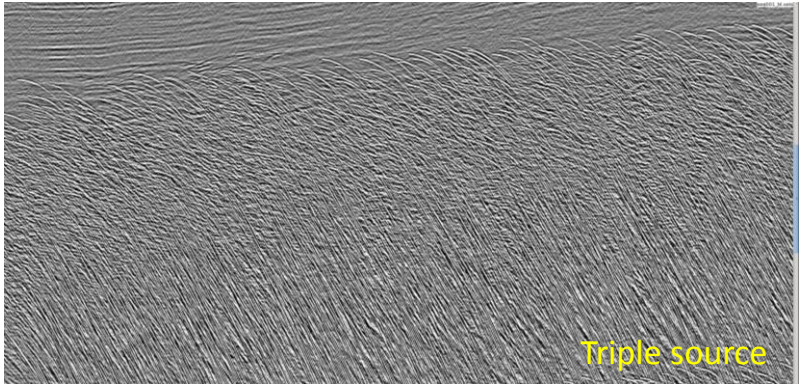
Built:	2010
Seismic Configuration:	Up to 12 streamers
Bollard Pull:	Approx. 200 T

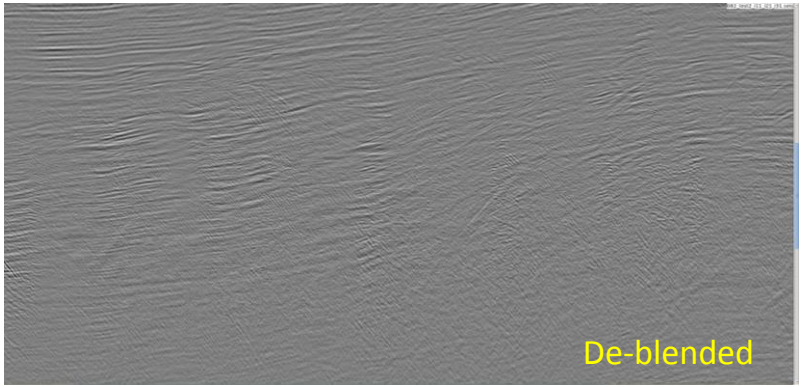


- 360 km of streamer systems from Sercel in good condition and with adequate spares
- 2 streamer sets currently deployed on Polar Duchess and Polar Marquis respectively

Processing & Imaging: Overview

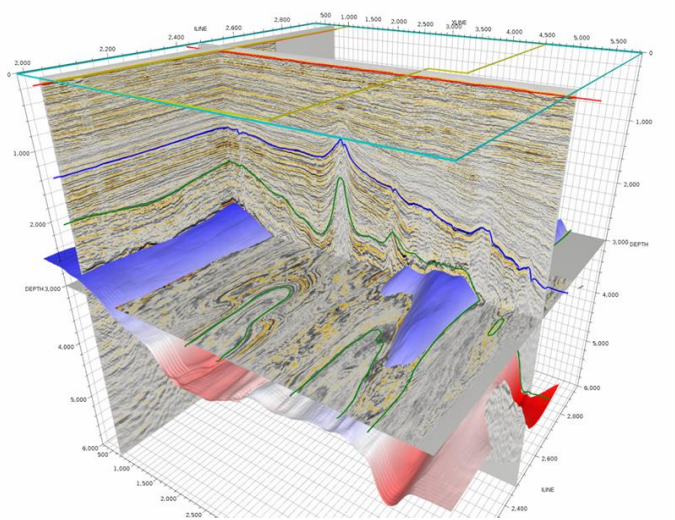
- Time and depth imaging
  - 3D SRME and 3D SWME
  - TTI Kirchhoff, Beam, RTM & tomography
  - Industry-leading broadband de-bubble using the near field hydrophones
  - Dual or triple source de-blending
  - Marine and land
- Centres in the UK and USA
  - 48 geophysicists
  - 384 nodes, 7808 cores, 2.5PB disk
  - Proven use of the cloud for peak capacity
  - Dedicated in-house R&D
- Staff and software on-board 3rd party vessels
- New centre established in India

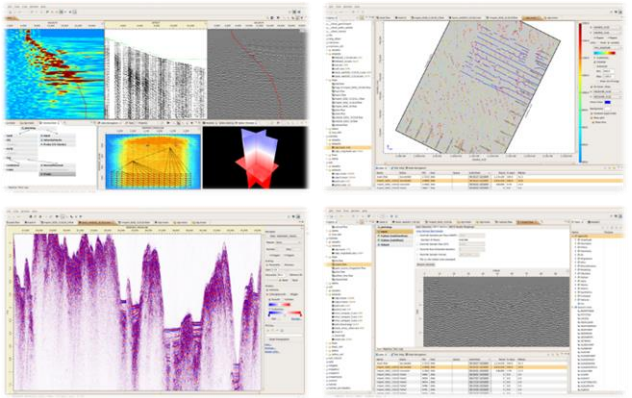




OpenCPS Software Sales

- Licensed by E&P companies including super major, contractors & academia
- Land and Marine
- RTQC, Time & Depth
  - 3D SRME, Hi-res Radon
  - 5D regularisation
  - 2C converted wave binning
  - Azimuthal AVO and velocity analysis
  - TTI Kirchhoff, RTM & tomography
  - Demonstrated well tools for model building at SEG
- Interactive Processing
  - Change parameters and flow in real time
- Advanced 2D and 3D Visualization
- Developer's Environment
- Parallel Processing and Job Management





Content

- Triple source acquisition
- Shot overlap removal
- Broadband Source
- Streamer de-ghosting
- Near field hydrophones for de-signature and de-ghosting

Content

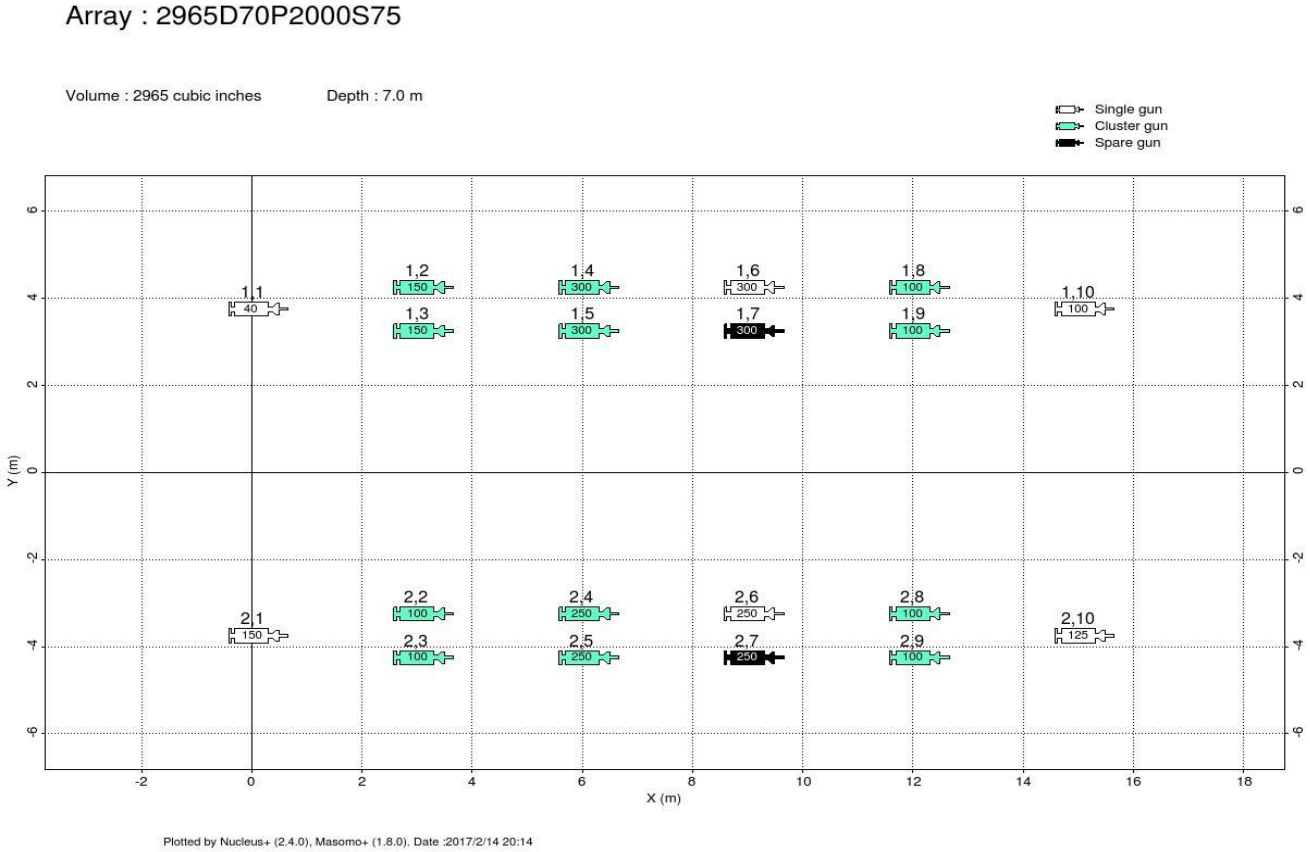
- Triple Source Acquisition

Modelling Parameters

- **2965 cubic-inch Bolt gun Array**

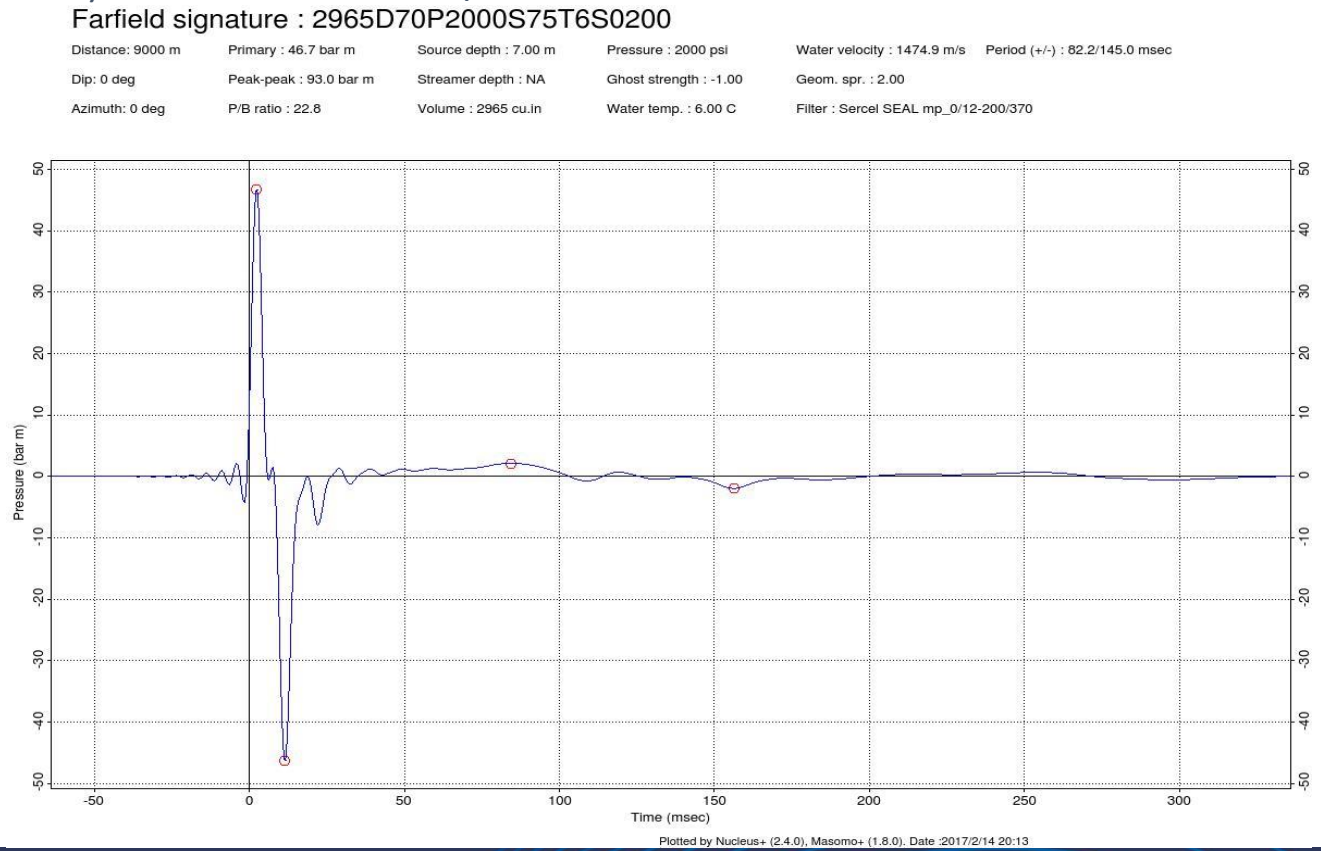
• Source Depth (m)	7.00
• Number of Gun Strings	2
• Total Number of Guns	20
• Spare Guns	2
• Type of Guns:	Bolt 1500 LL and 1900 LLXT
• String Length (m)	15.00
• String Separation (m)	7.5
• Temperature	6°C
• Sound Velocity	1474.9 m/s

Array Diagram - 2965



Source Signature –SEAL 0/12 – 200/370

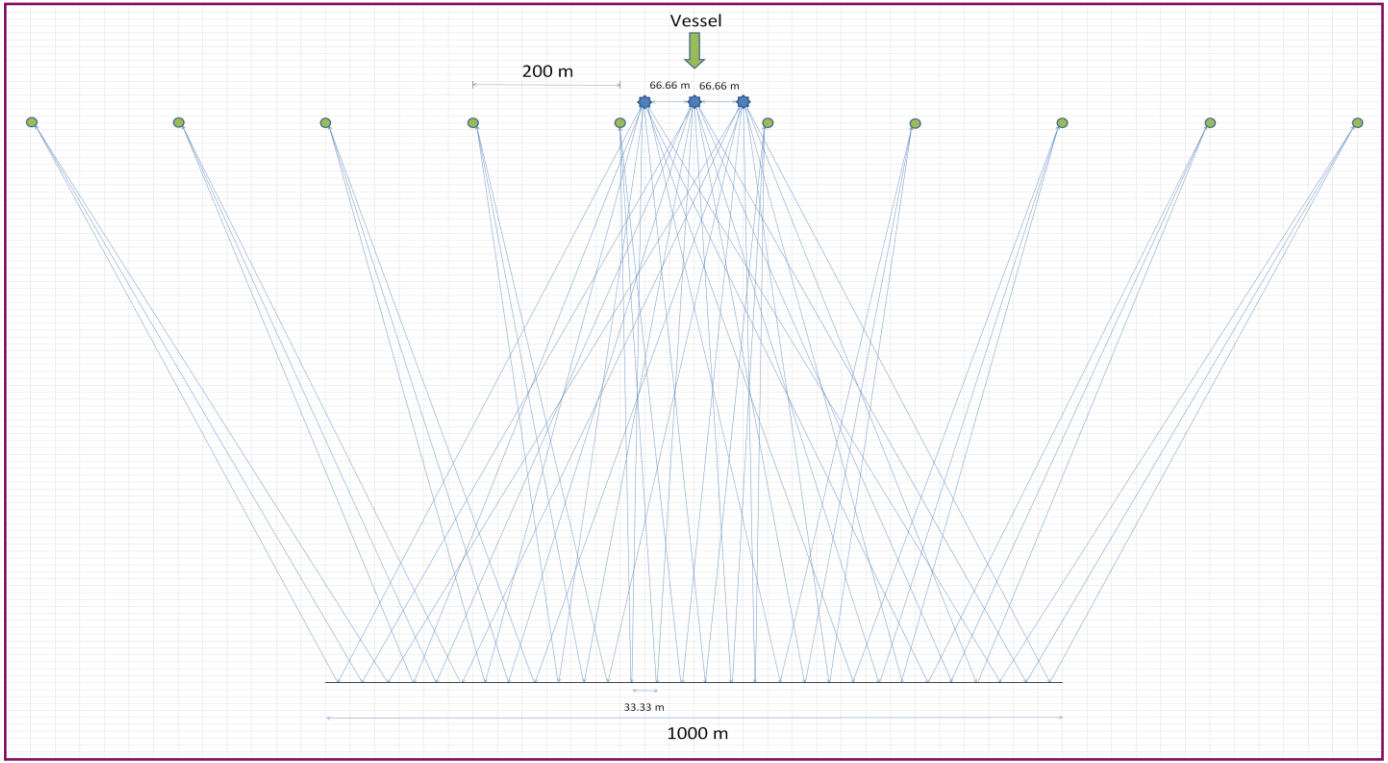
Peak-Peak (bar-m) 93.0 P/B 22.8



Acquisition

Coverage and crossline spacing 10 x 200 x 3 sources

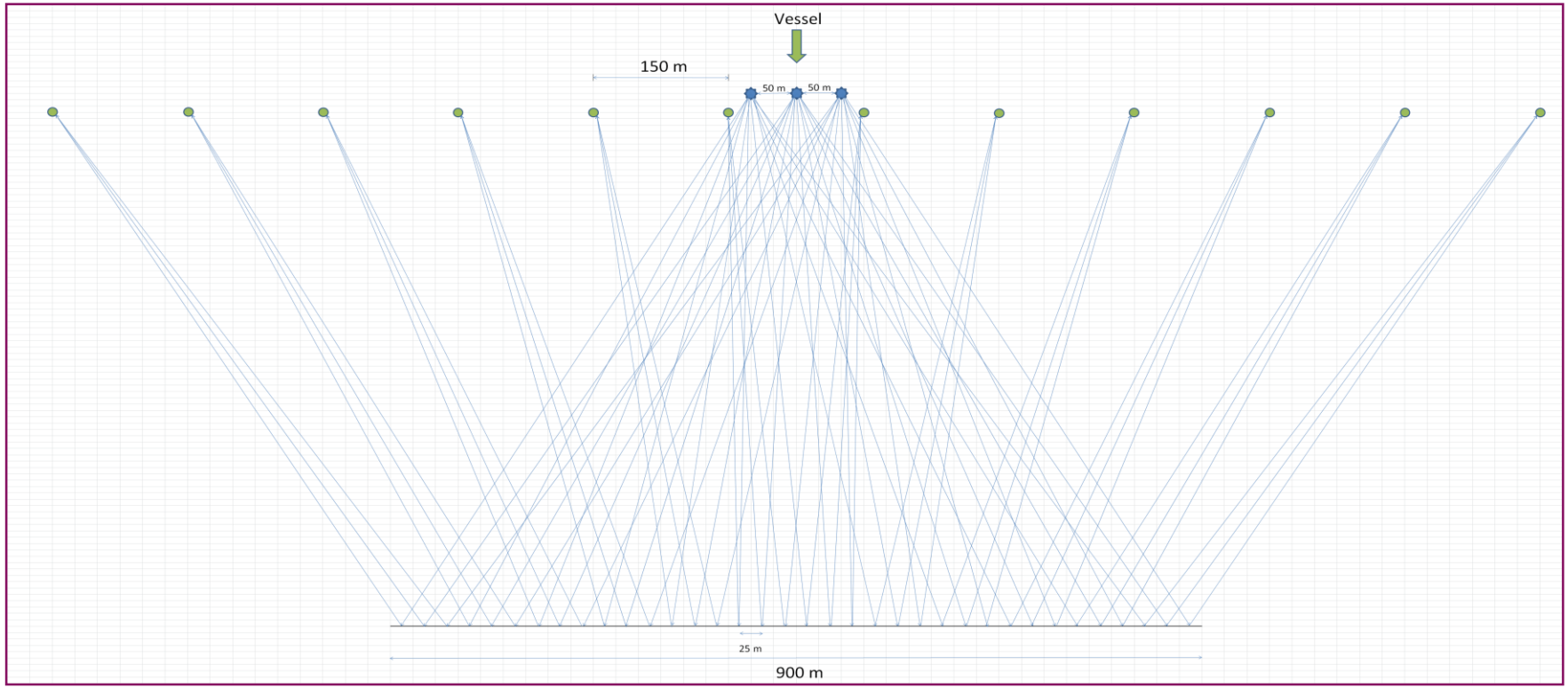
Crossline spacing 33.33m



Acquisition

Coverage and crossline spacing 12 x 150 x 3 sources

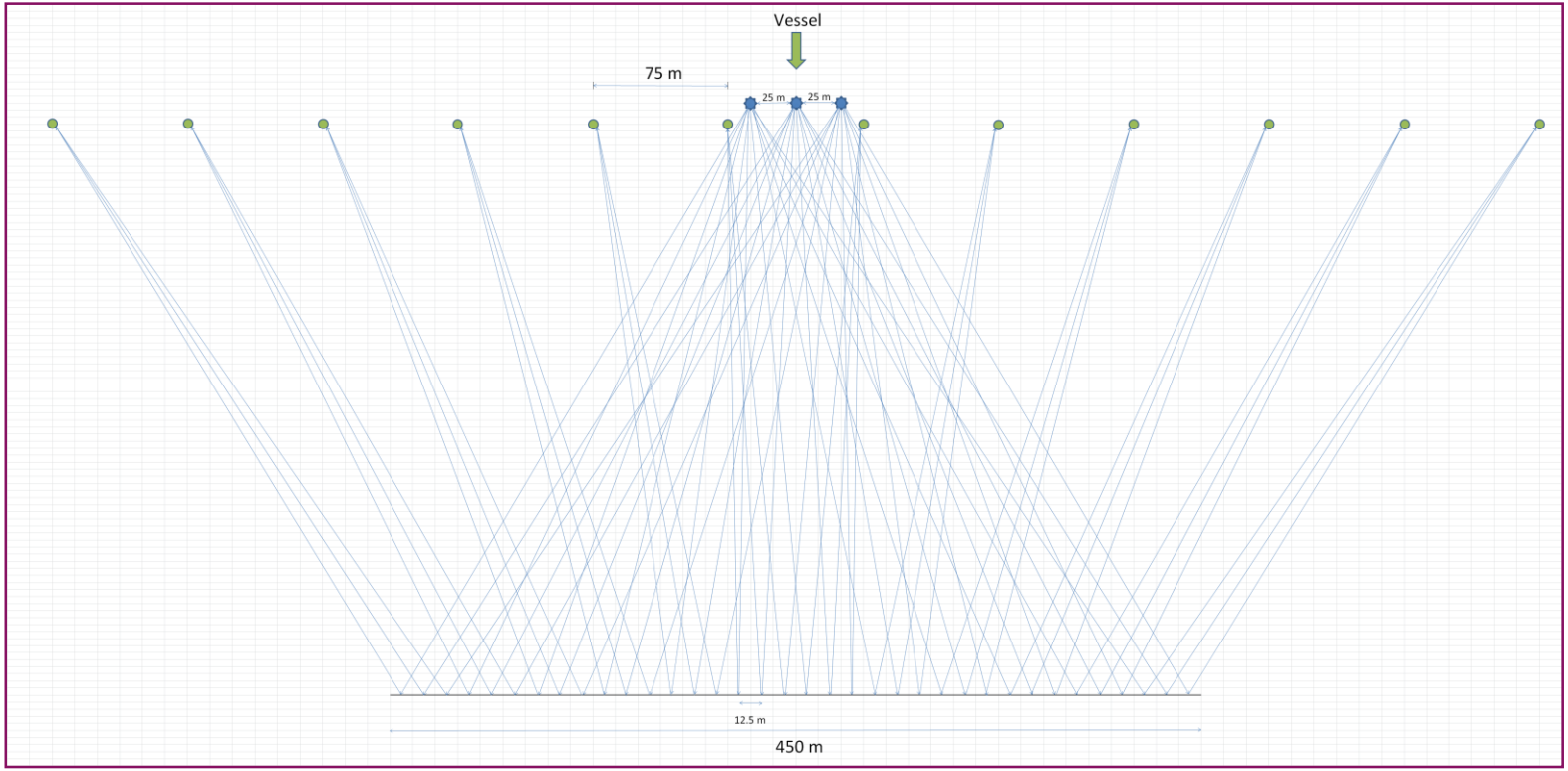
Crossline spacing 25m



Acquisition

Coverage and crossline spacing 12 x 75 x 3 sources

Crossline spacing 12.5 m

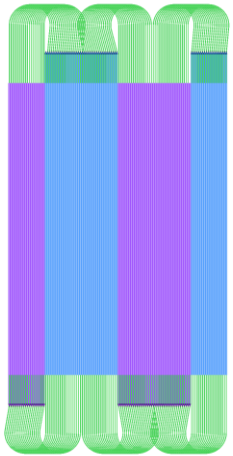


Acquisition

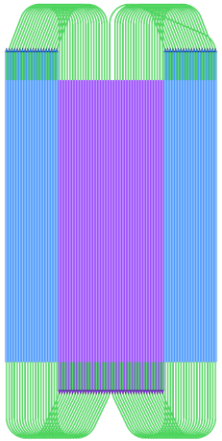
12.5m crossine sampling comparison

All surveys modelled with 10% standby – 5% TD – 12% infill

Dual source acquisition
Streamer spacing 50m
Total duration 46 days



Triple source acquisition
Streamer spacing 75m
Total duration 30 Days

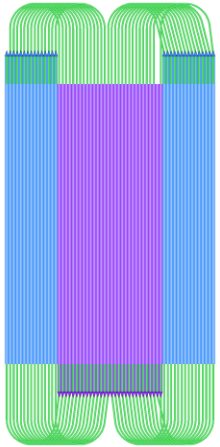


Acquisition

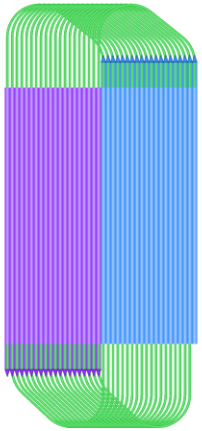
25m crossine sampling comparison

All surveys modelled with 10% standby – 5% TD – 12% infill

Dual source acquisition
Streamer spacing 100m
Total duration 24 days



Triple source acquisition
Streamer spacing 150m
Total duration 18 days

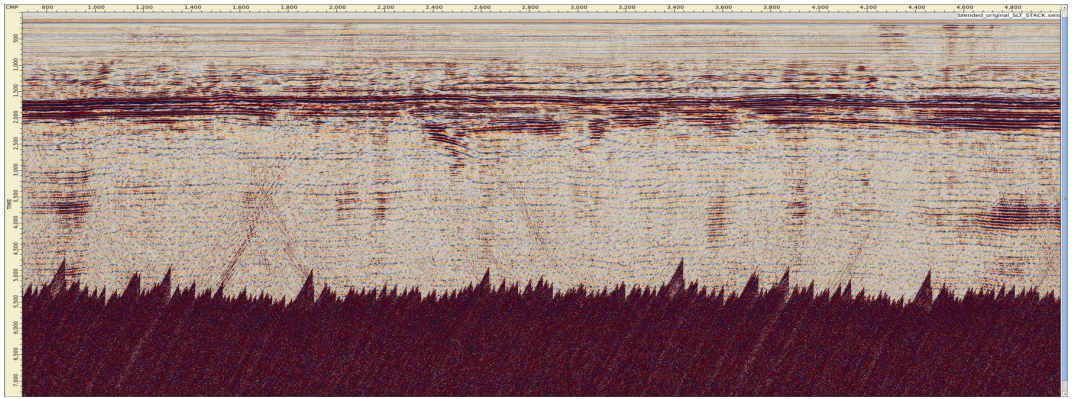


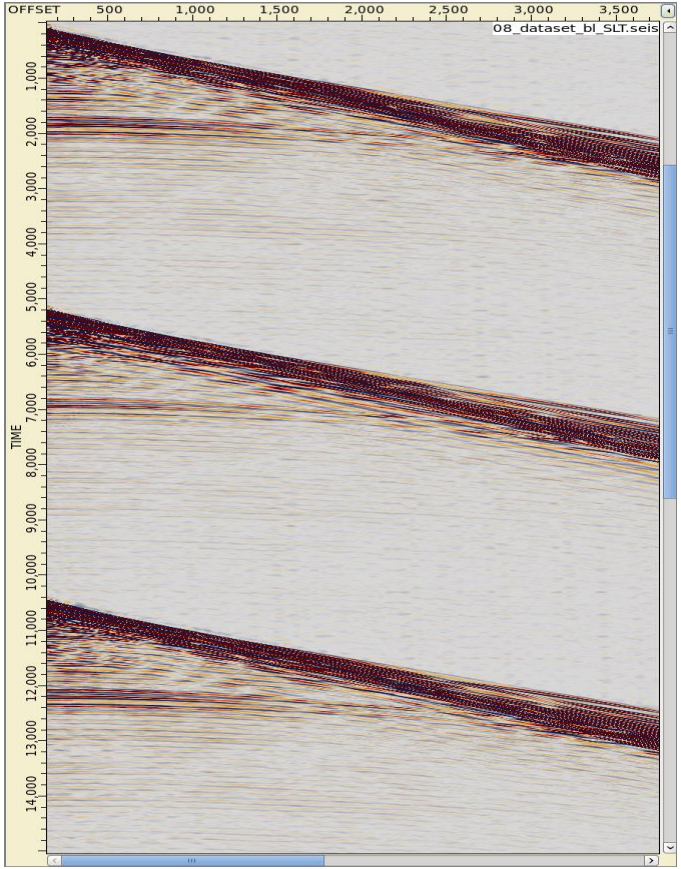
Content

- Shot Overlap Removal

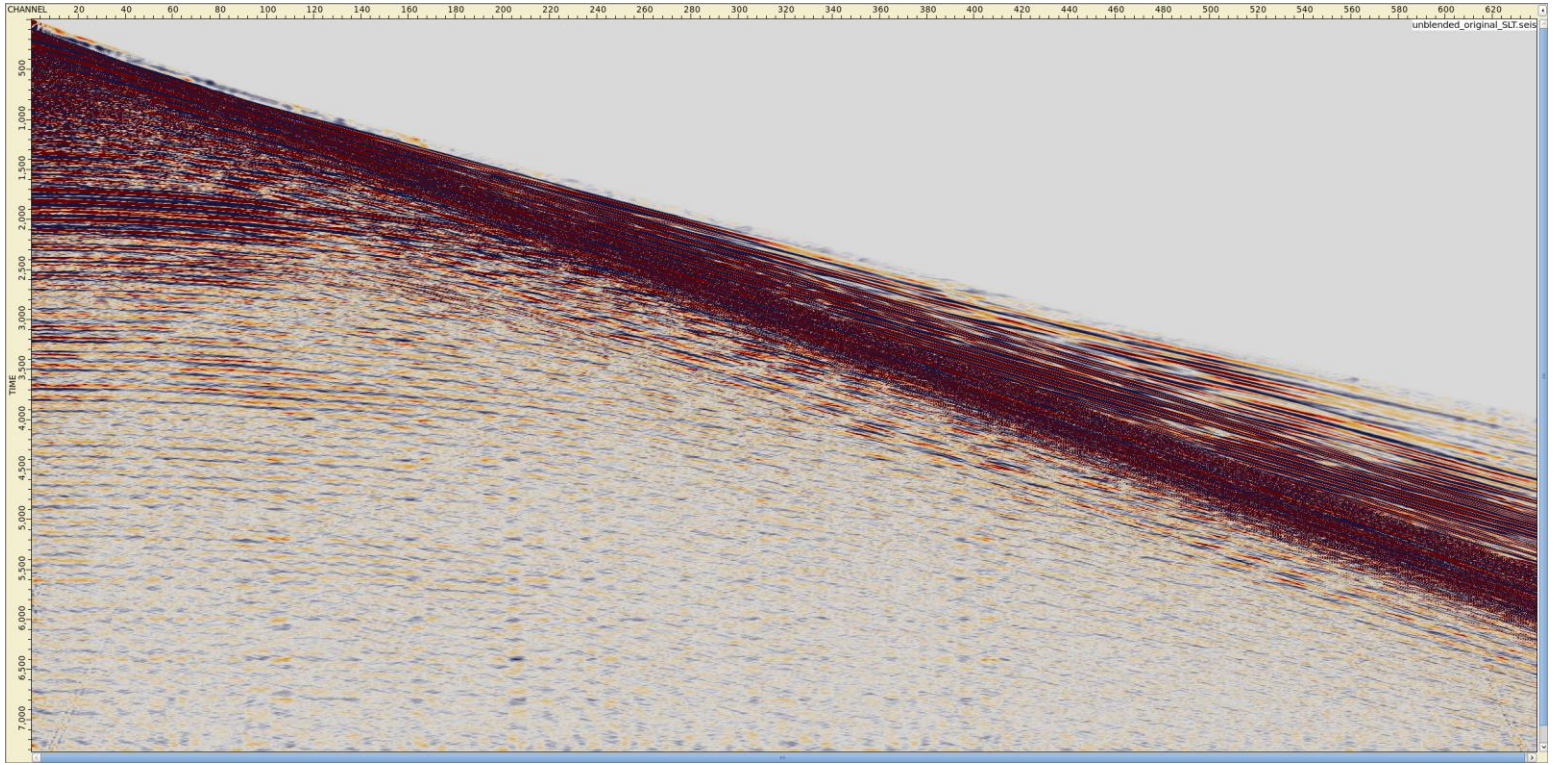
Triple source

- Triple source with approximately 5s spacing
- Natural dither due to vessel motion
- Some residual shot energy in the shallow

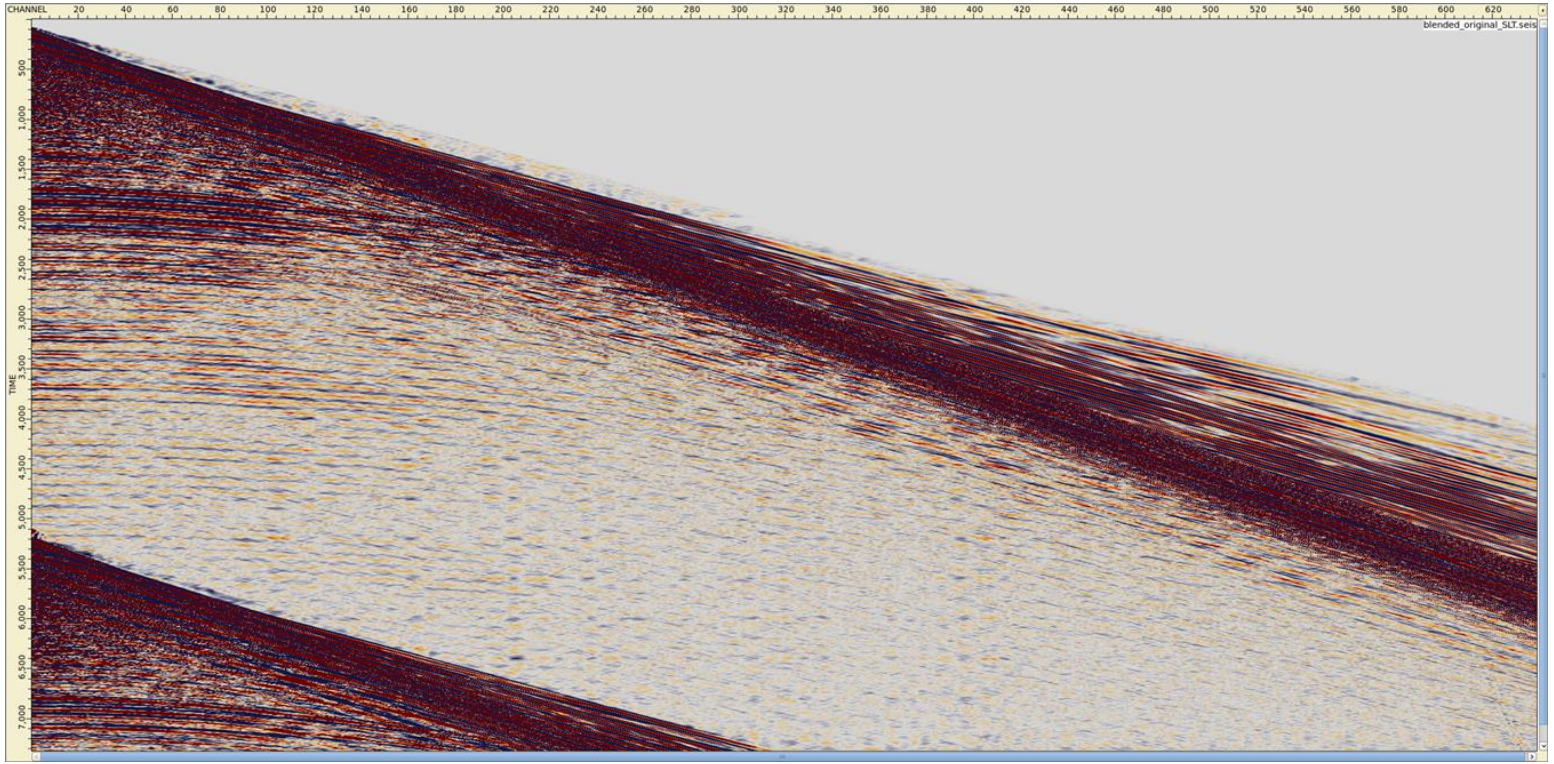




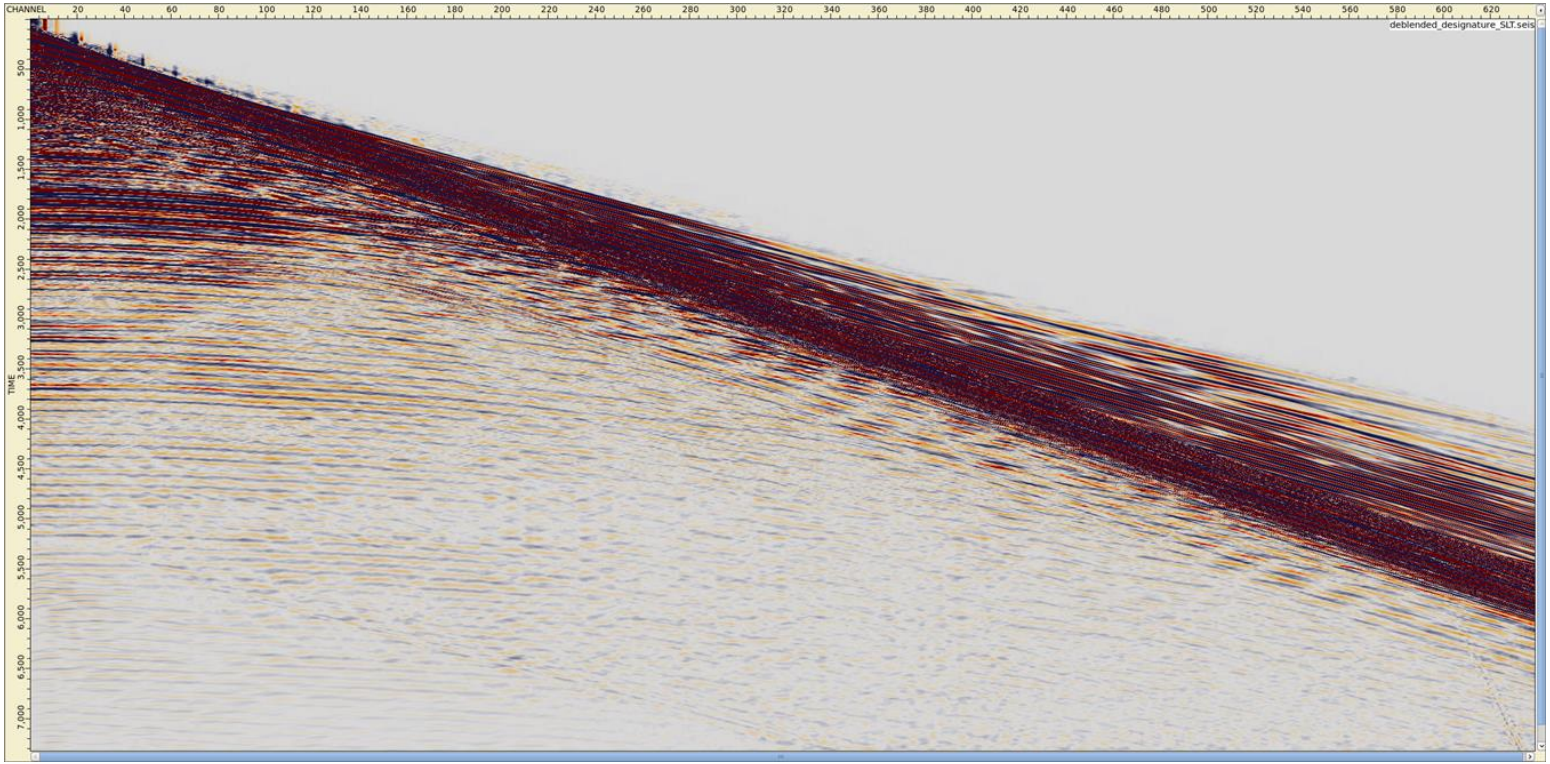
Original shot



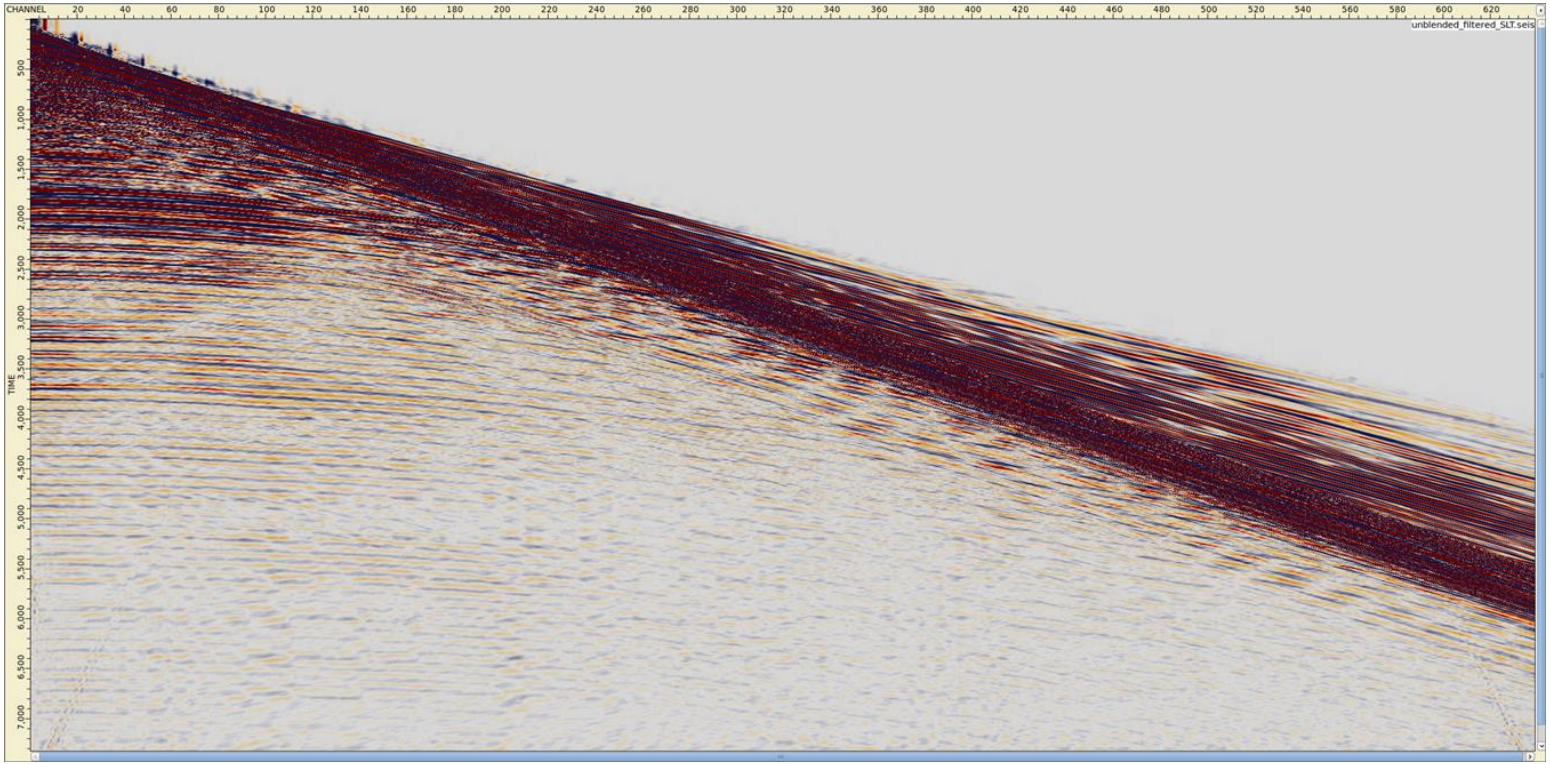
Overlapping shot



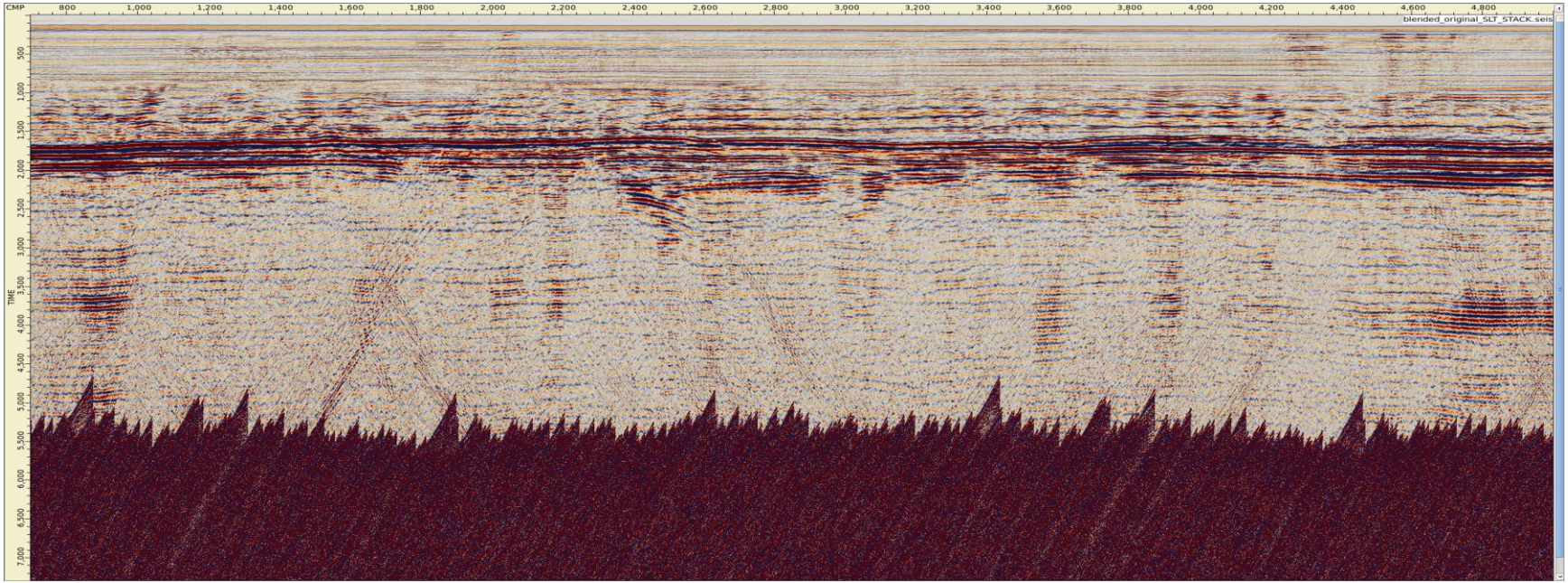
Deblended shot



Original shot



Raw Stack


CMP
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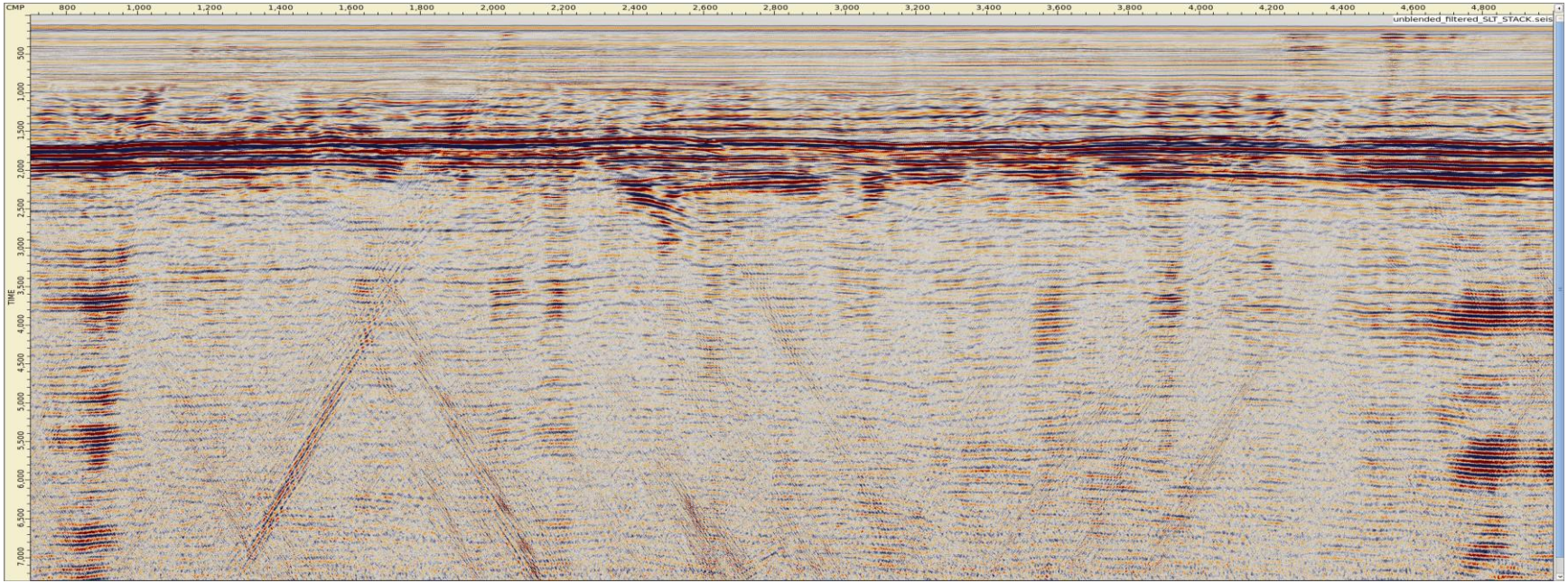
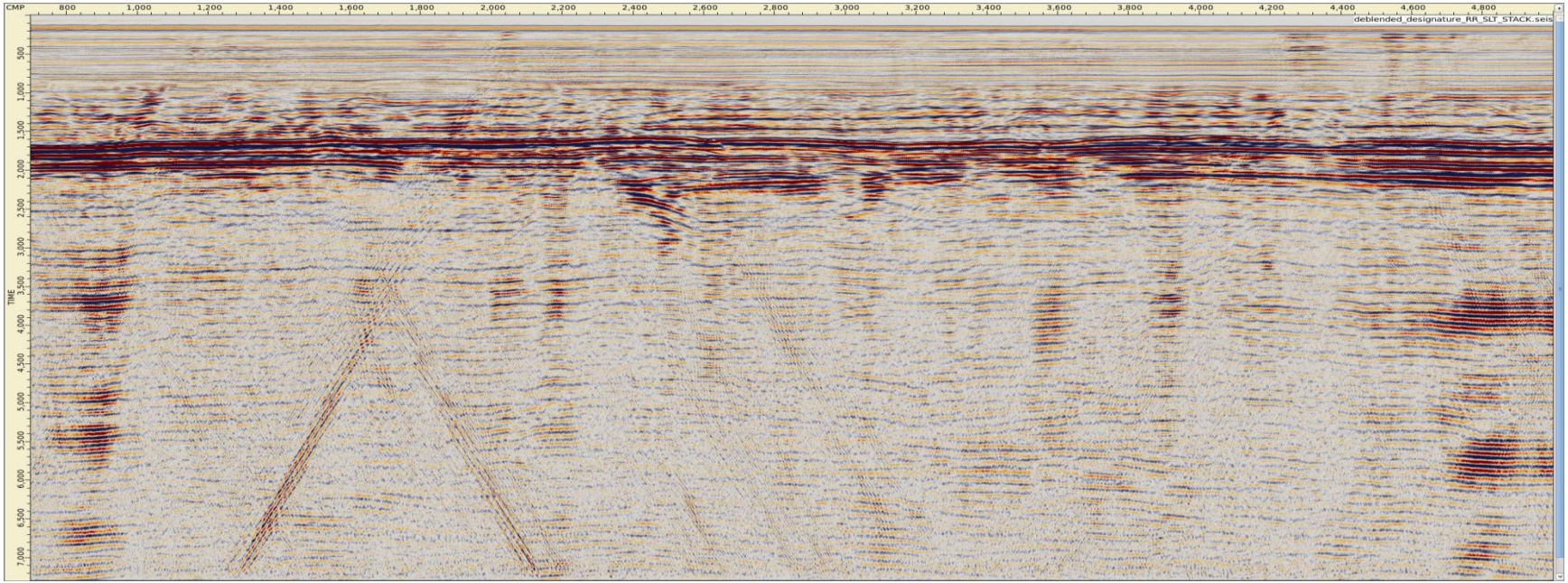
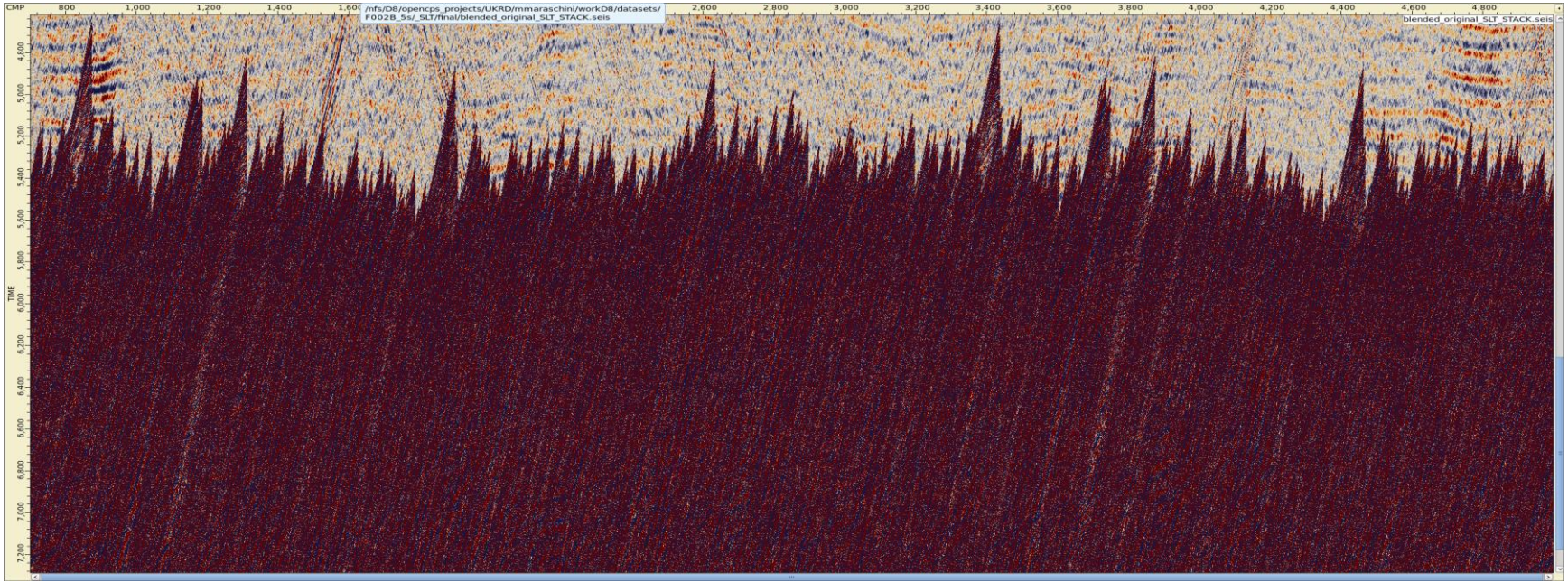
Original stack



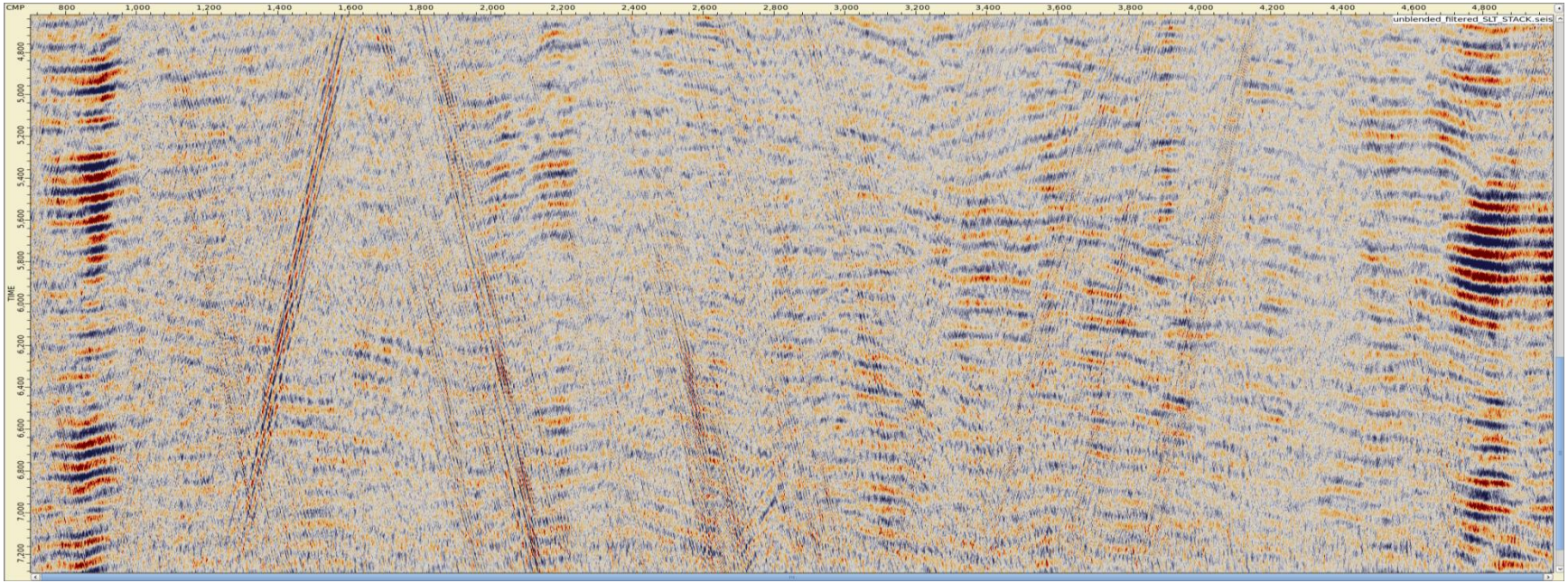
De-blended stack



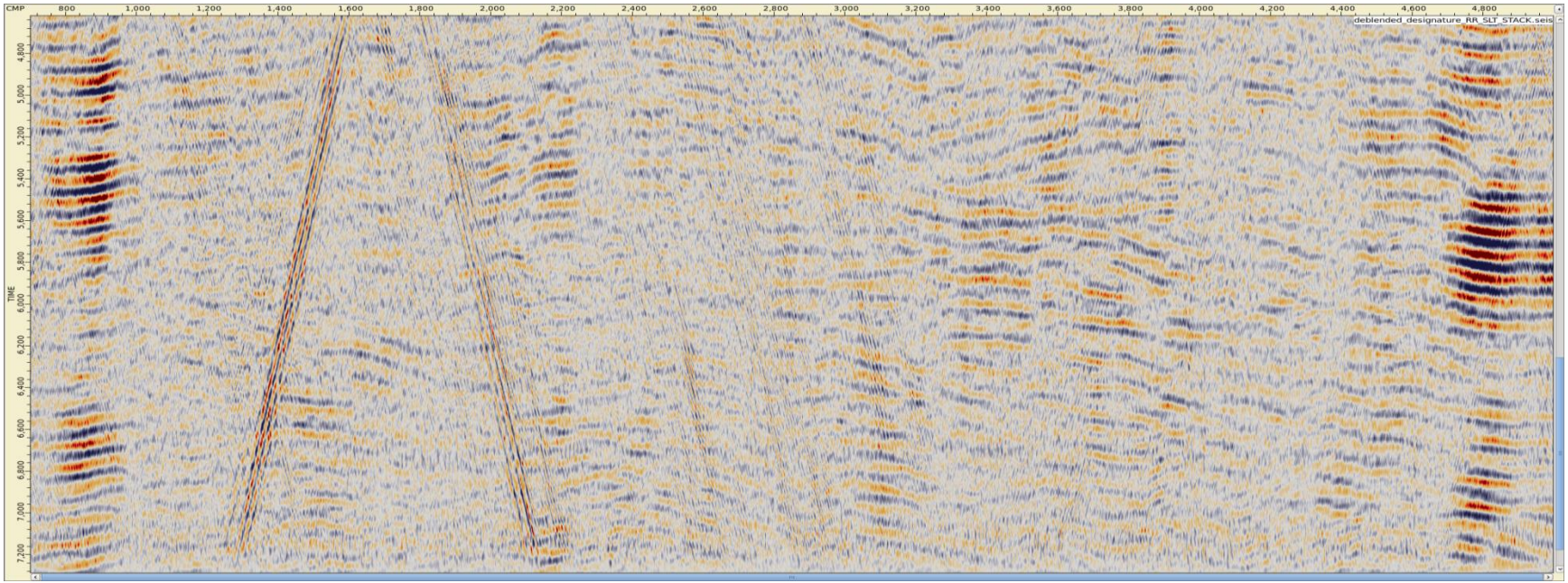
Deep zoom of blended stack



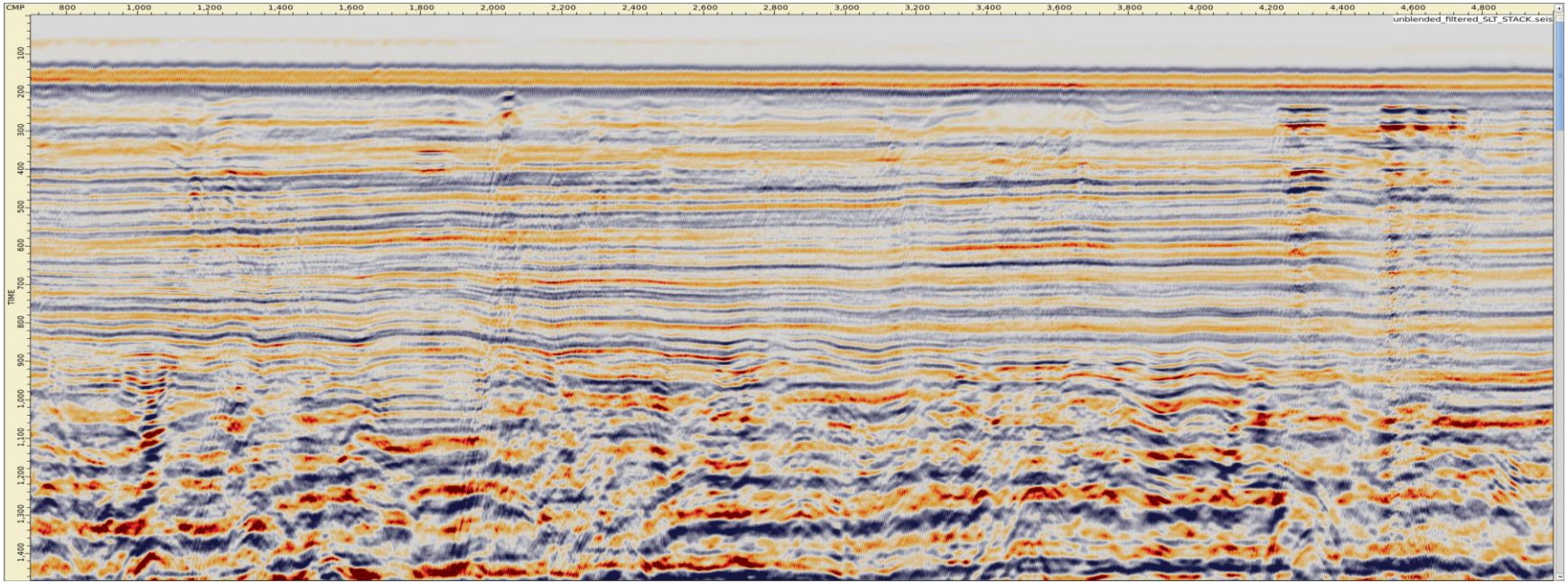
Deep zoom of original stack



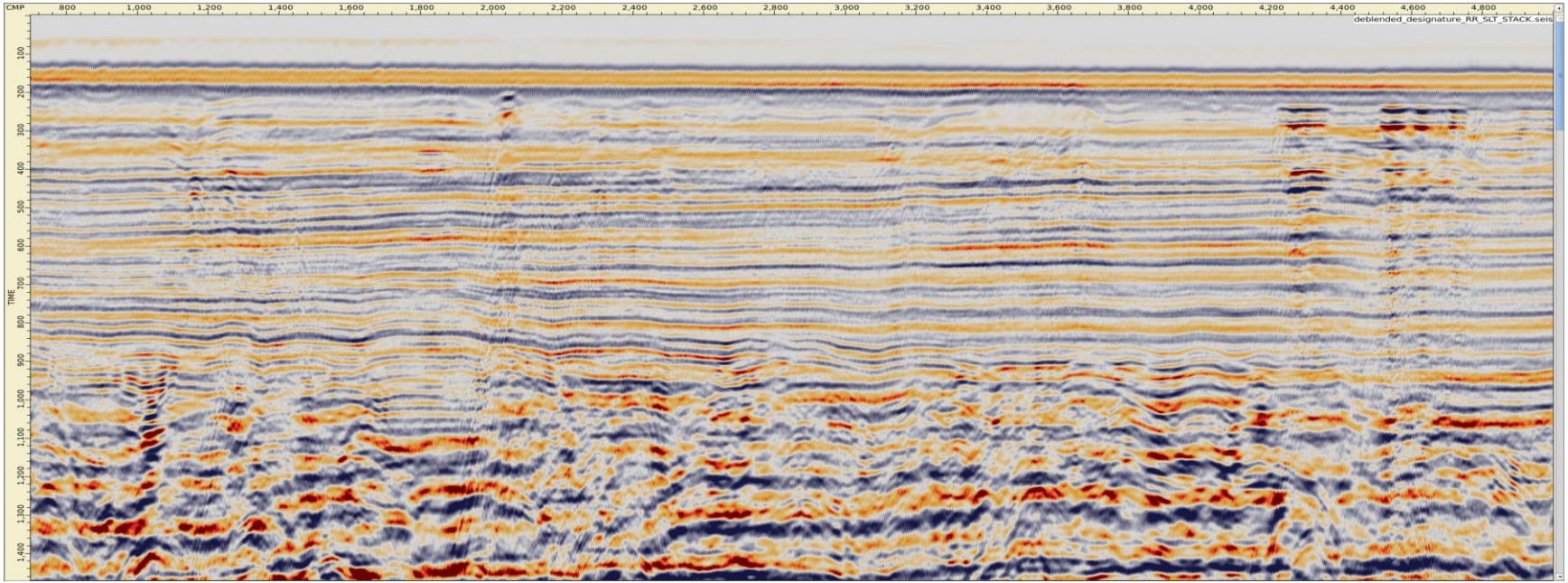
Deep zoom of de-blended stack



Shallow zoom of original stack



Shallow zoom of de-blended stack



Summary

- Triple source causes overlapping shots due to the reduced shot point interval
- De-blending is effective with natural dither
  - Shots are well separated by de-blending
  - Shallow stack not badly effected by residual shot energy from previous shot.
  - Deep stack well separated by de-blending to show underlying events

Content

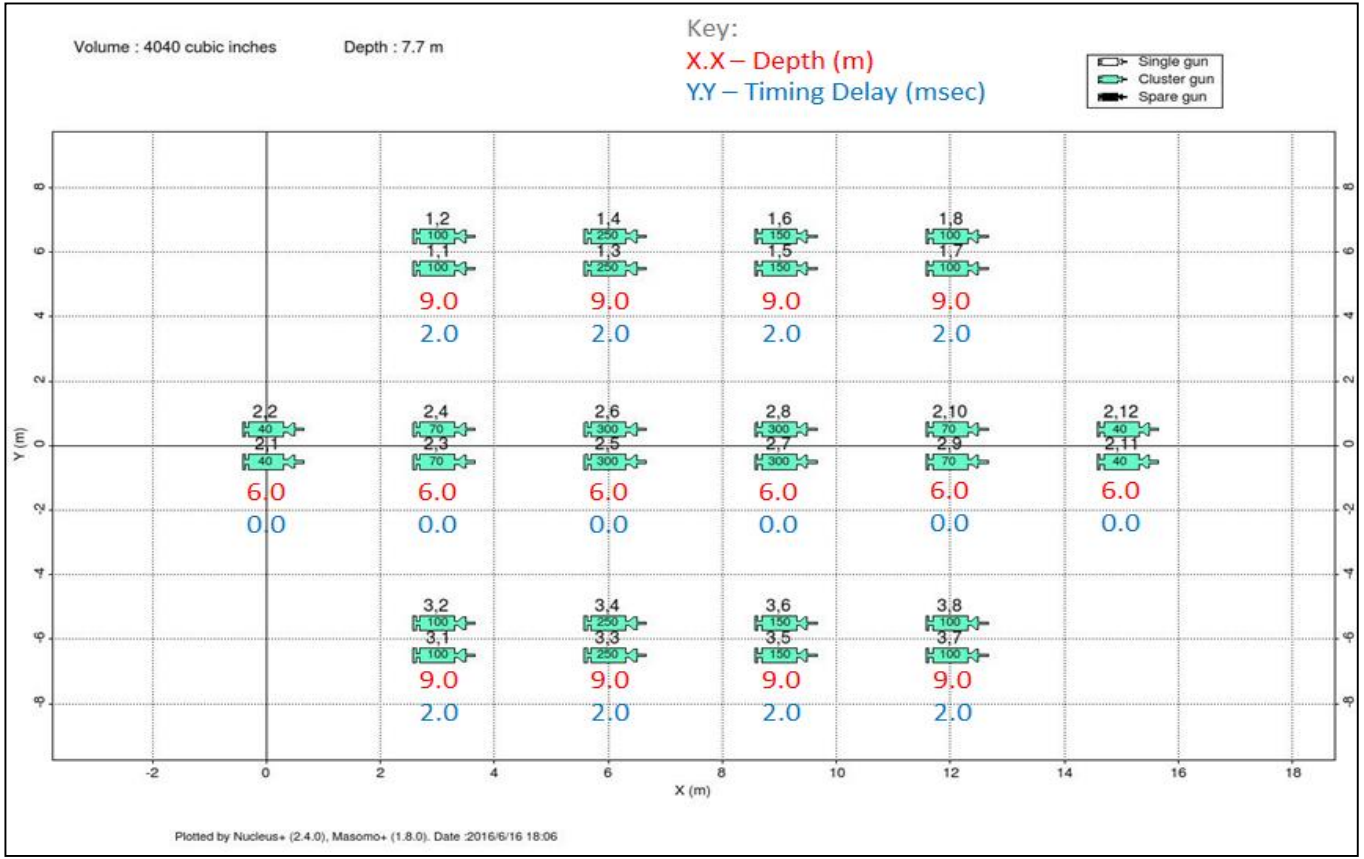
- Broadband Source

Modelling Parameters

- **4040 cubic-inch tuned Broadband Bolt gun Array**

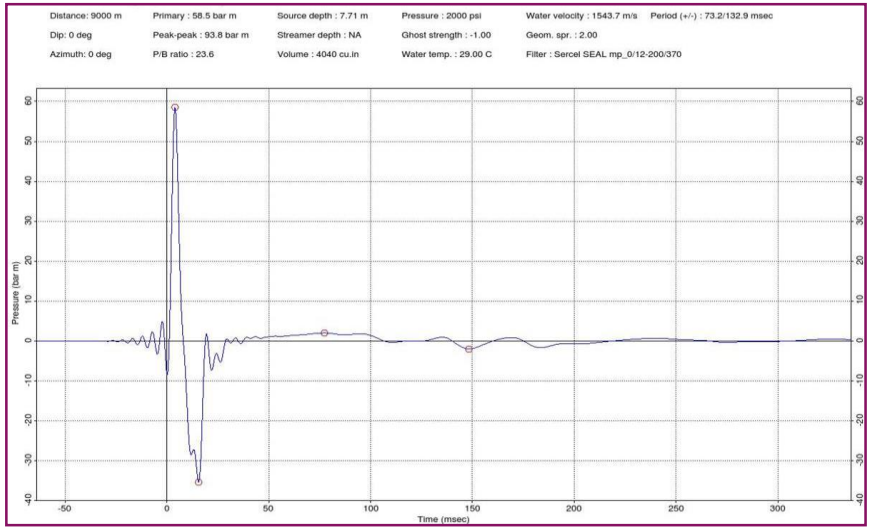
Source Depths (m)	**6m & 9 m (average 7.7 m)**
Firing Delays	**Yes (9 m strings fired with 2 msec delay)**
Number of Gun Strings	**3**
Total Number of Guns	**28**
Type of Guns	**Bolt 1900 LLXT (40 – 150 cu in)**
	Bolt 1500 LL (250 & 300 cu in)
String Length (m)	**15**
String Separation (m)	**6**
Temperature (°C)	**29**
Sound Velocity (m/sec)	**1543.7**
Nucleus Version	**2.4.0**
Marine Source Modelling Version	**1.8.0**

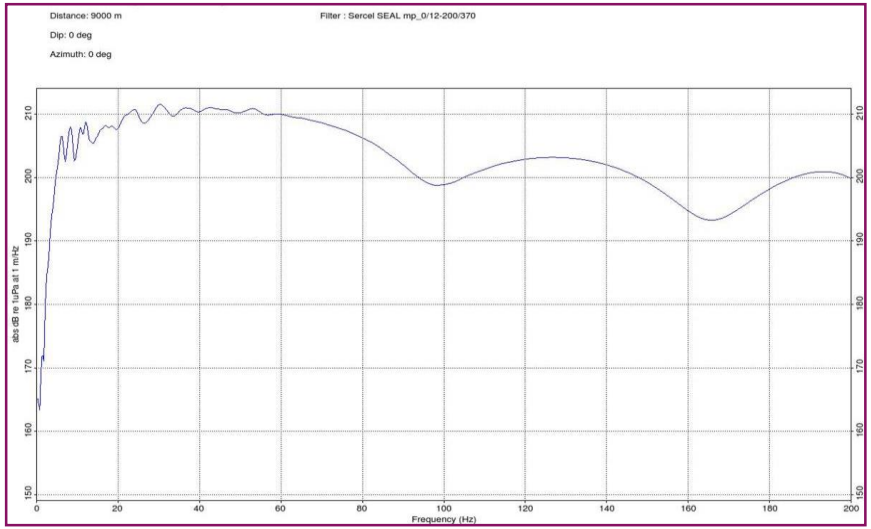
Array Diagram



Source Signatures –SEAL 0/12 – 200/370

Peak-Peak (bar-m)	93.8
P/B	23.6

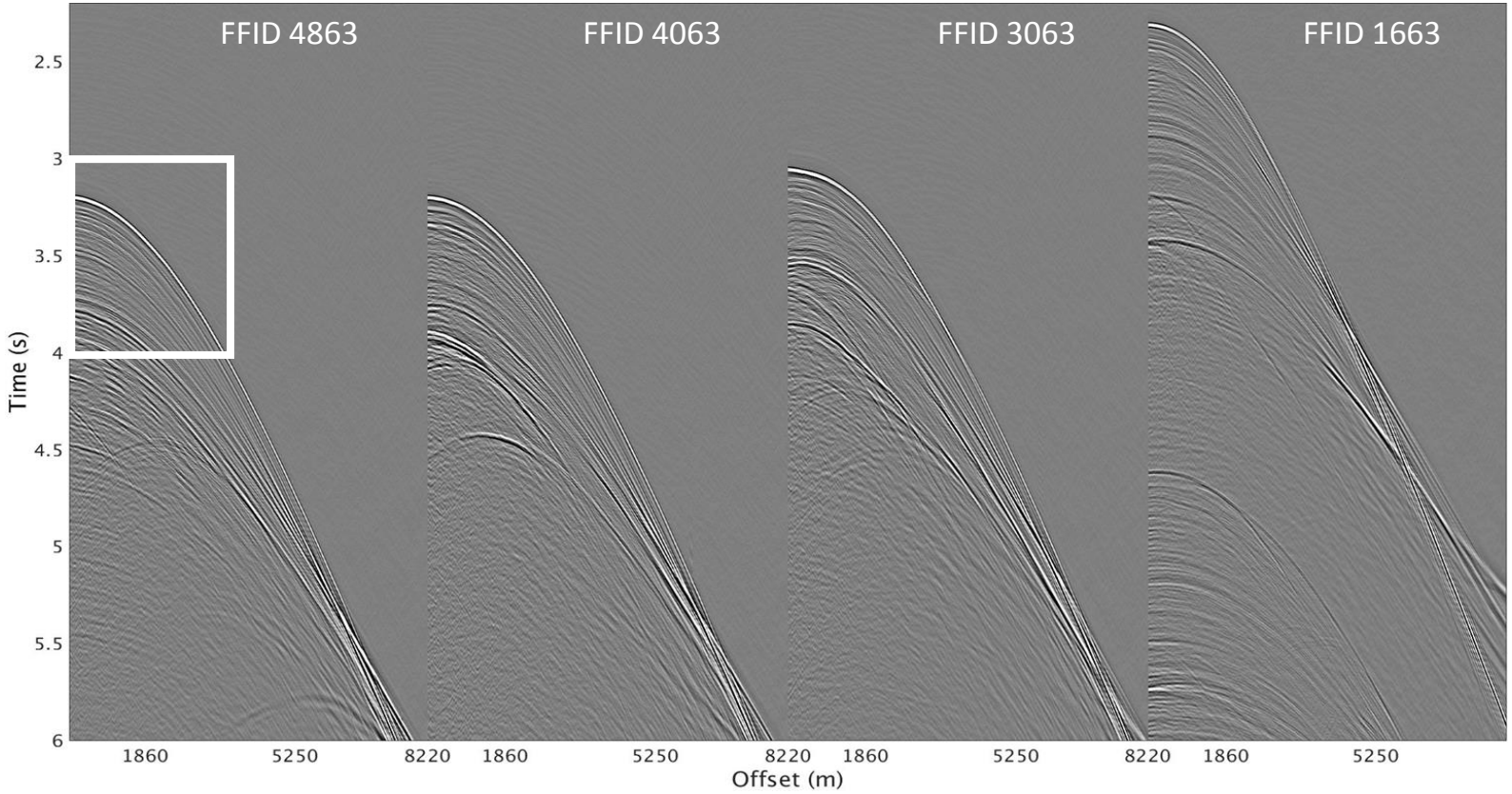




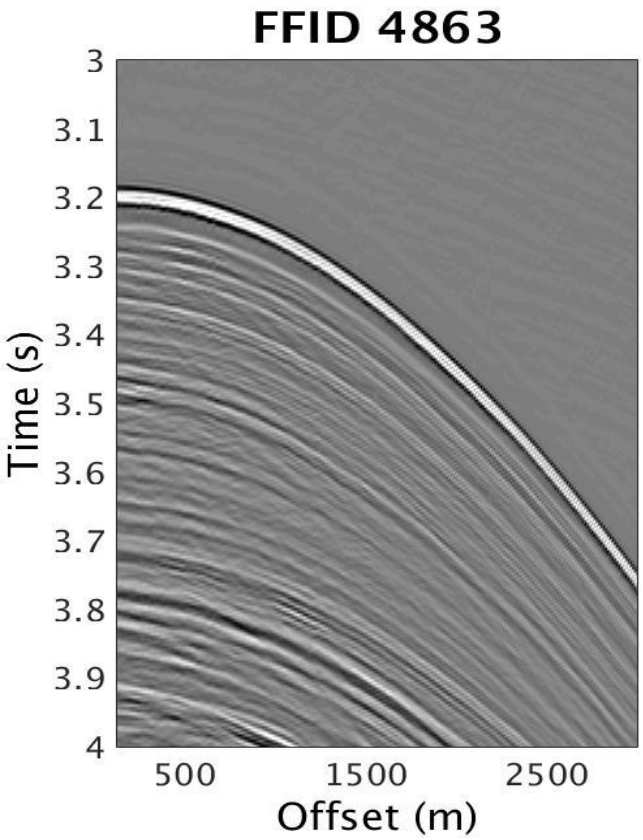
Content

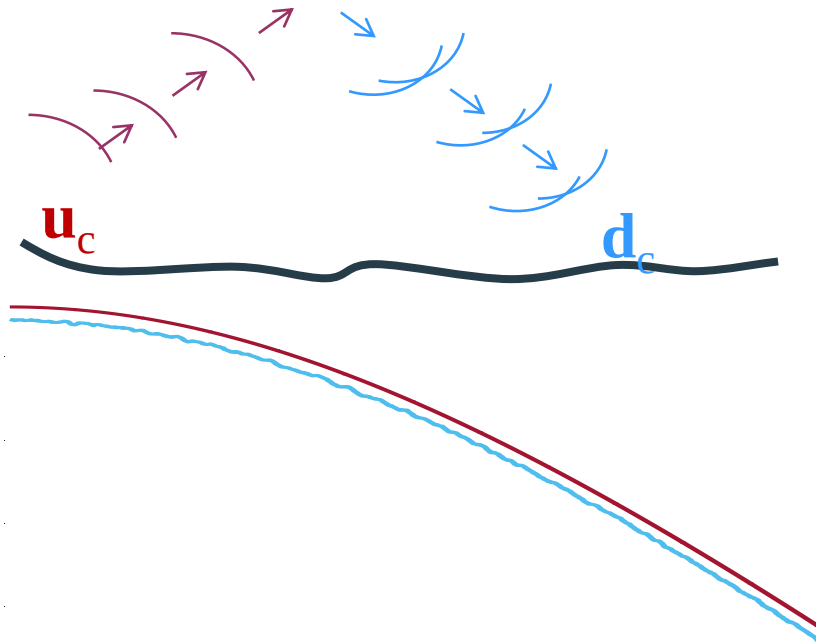
- Streamer phase shift De-ghosting using rough sea estimation.

Sample shot records – slanted 12-28m cable (2m/km)

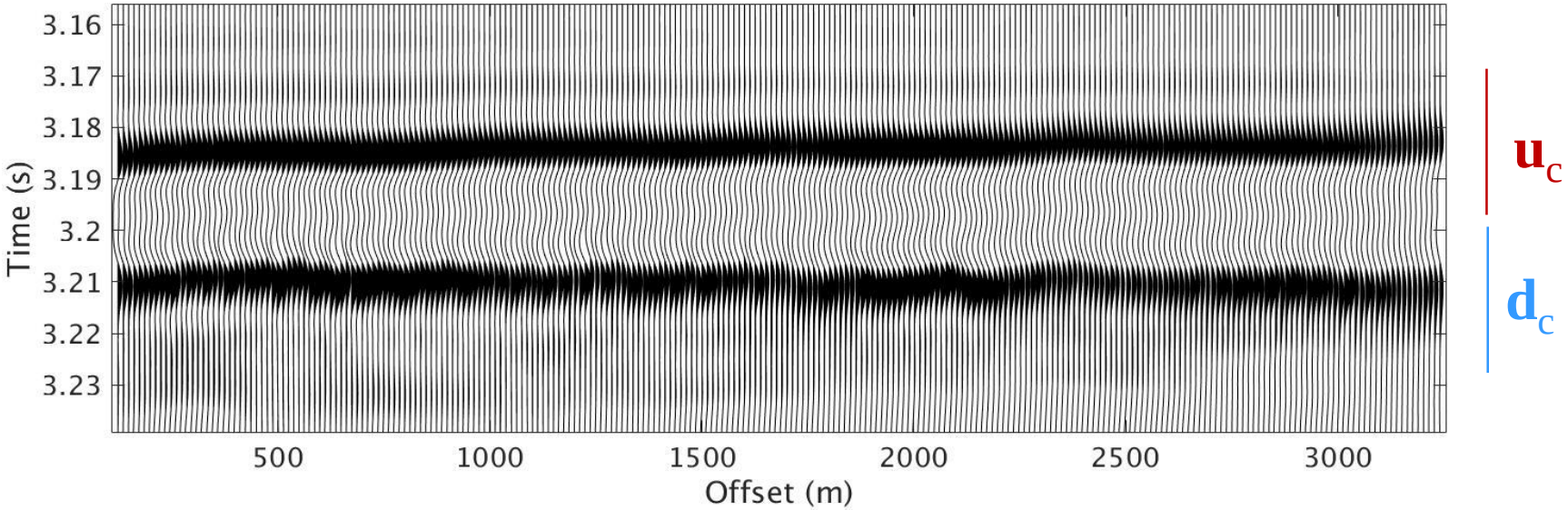


Sample shot record-close-up

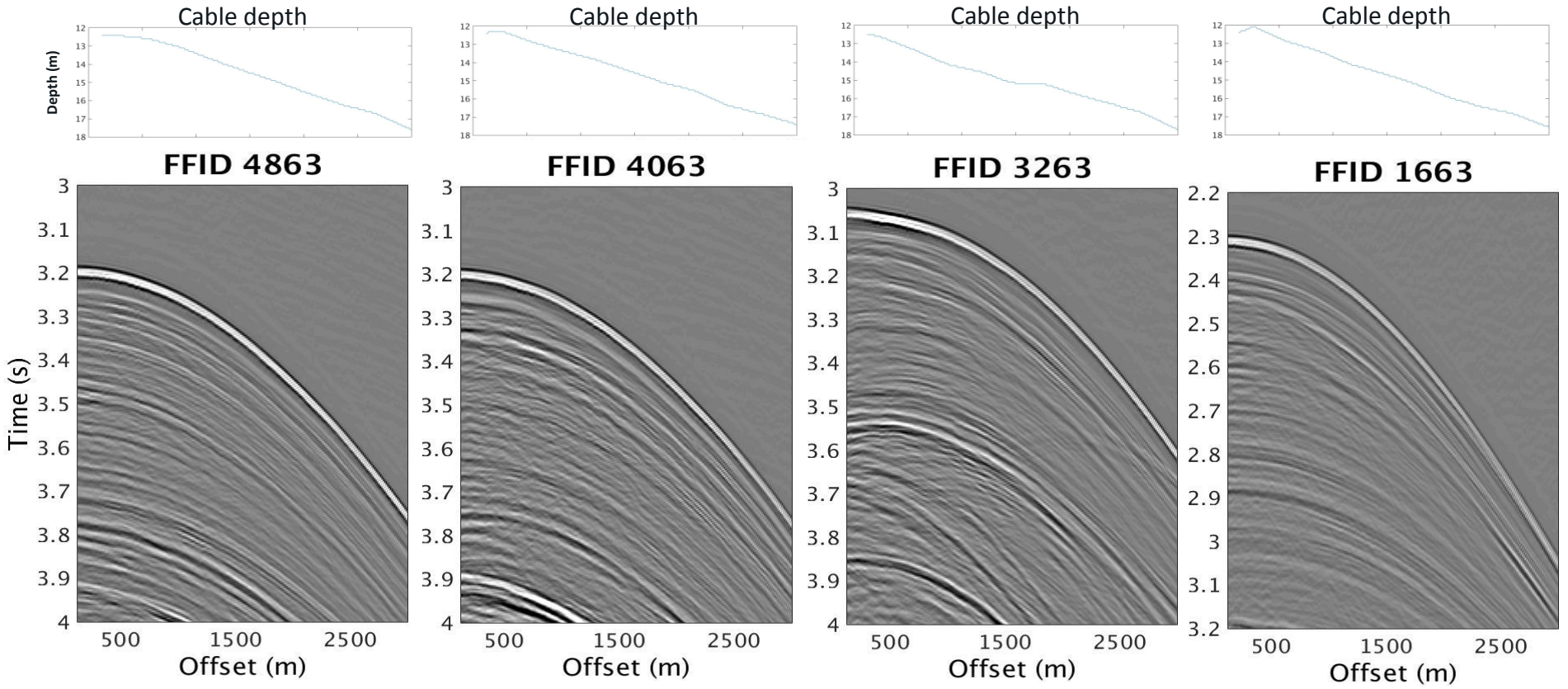




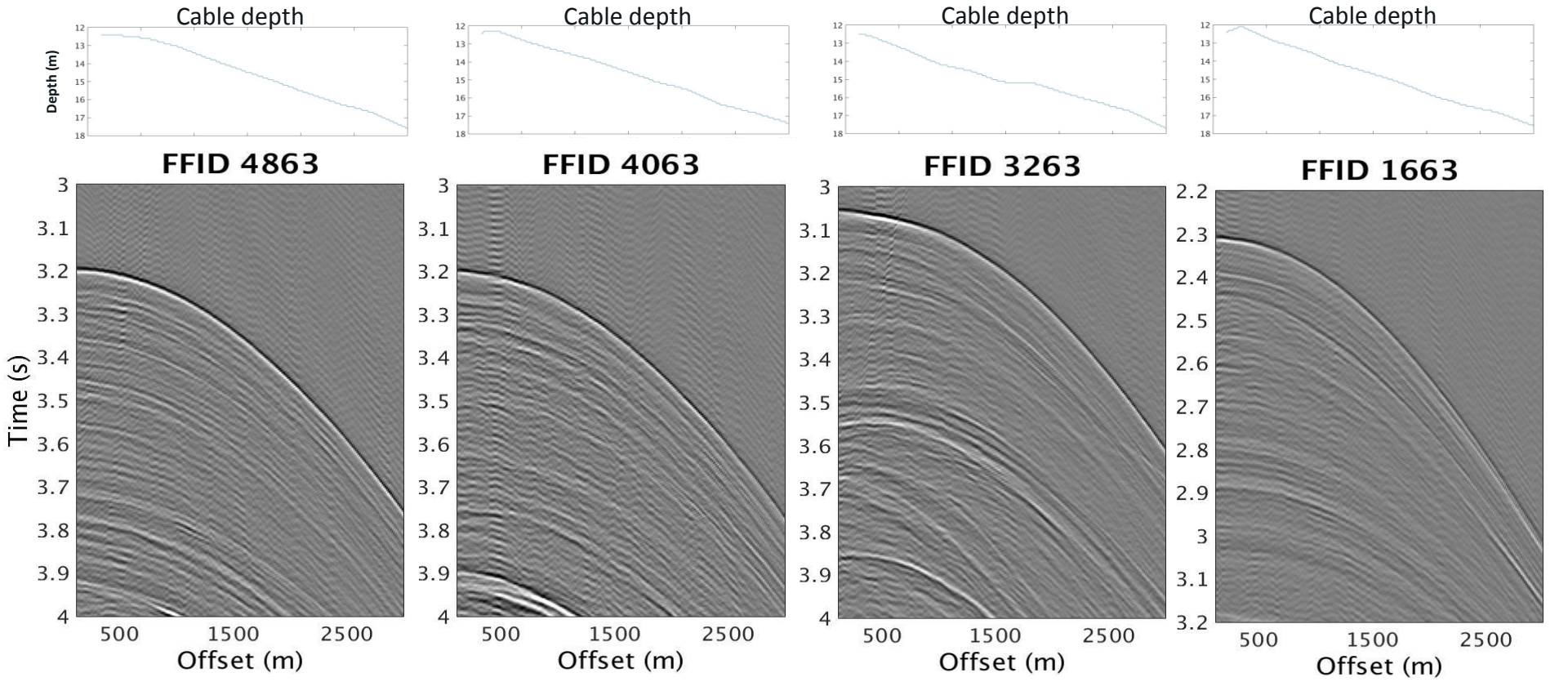
Sea-bottom reflection – static NMO



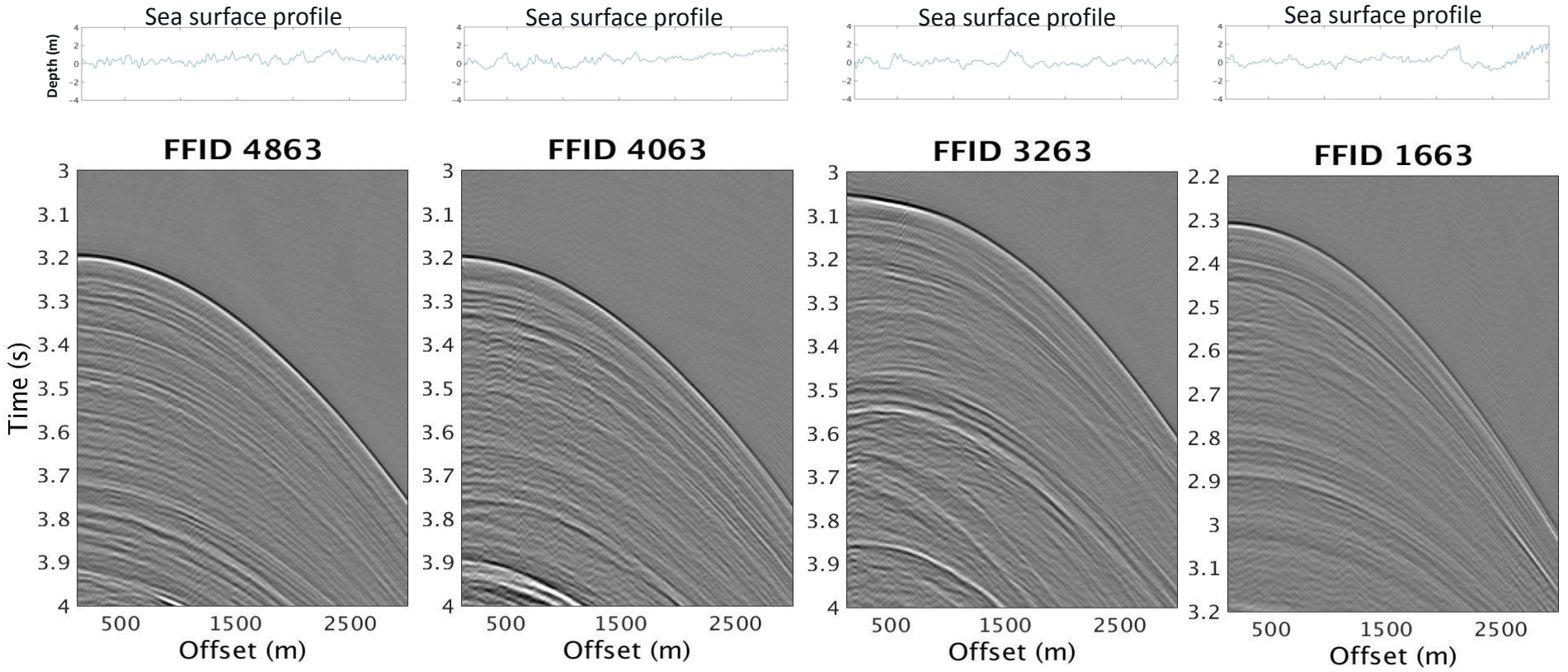
Sample shot records close-up



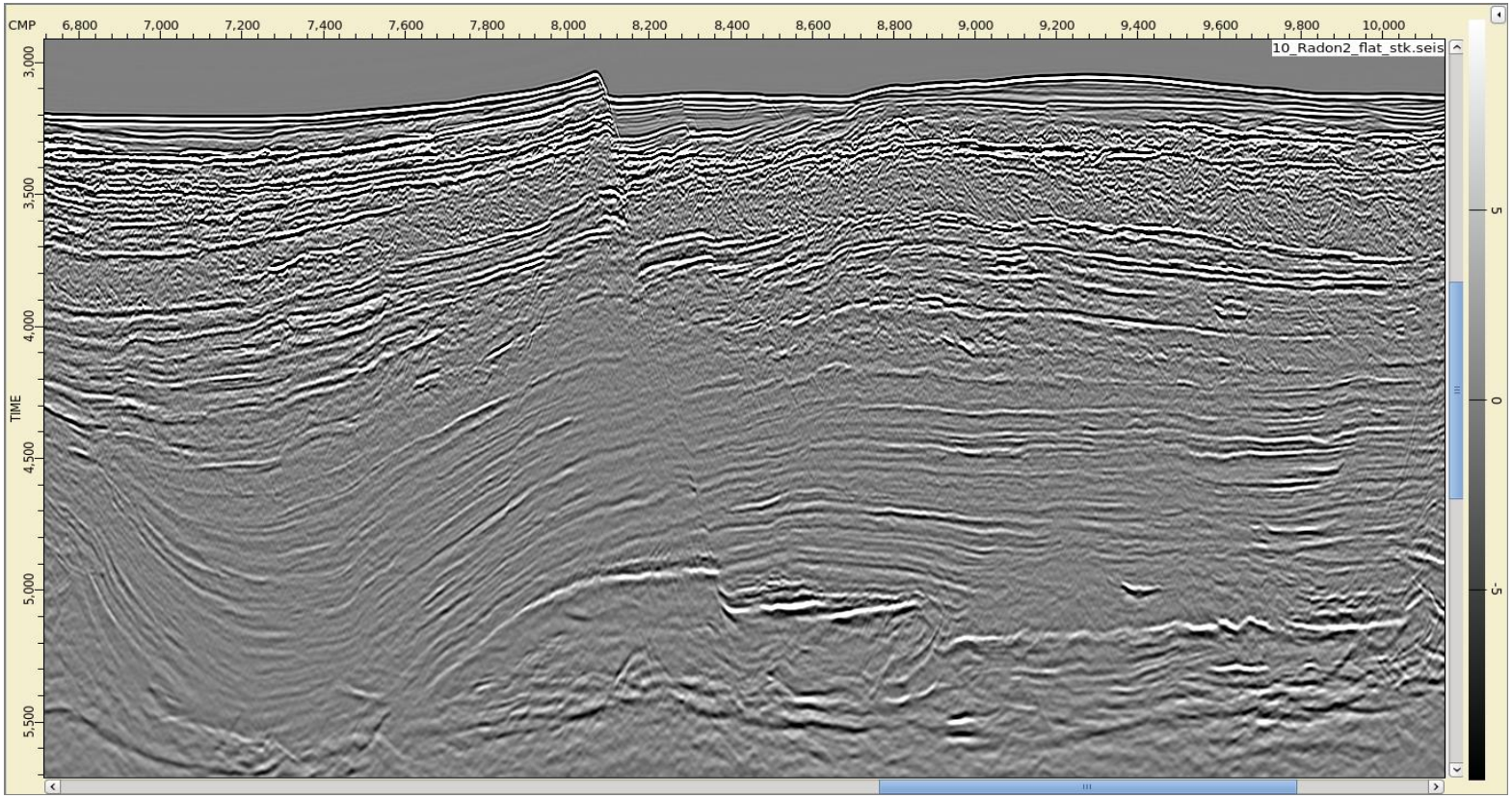
De-ghosting – calm sea



De-ghosting – rough sea

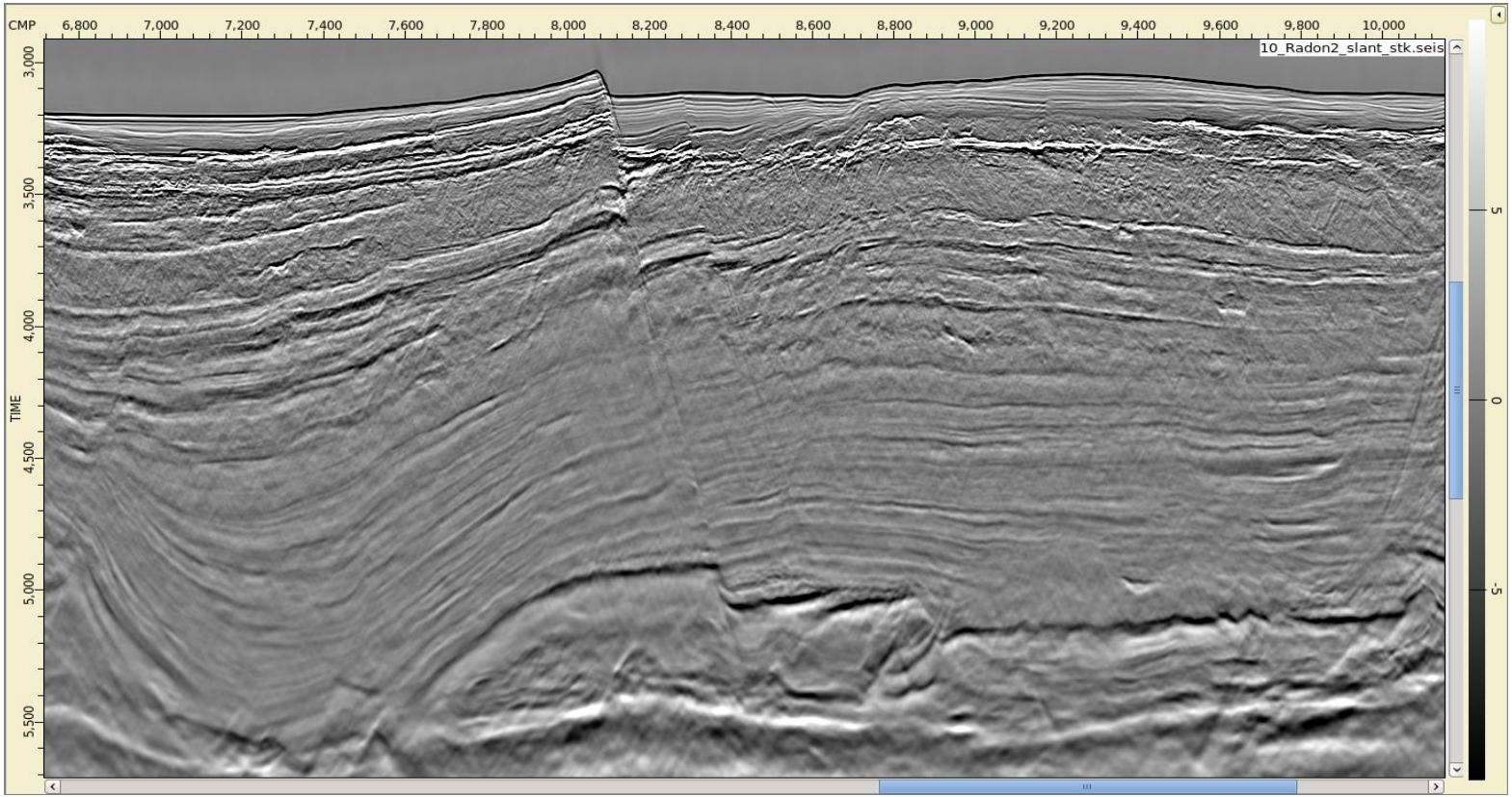


Conventional – 10m cable



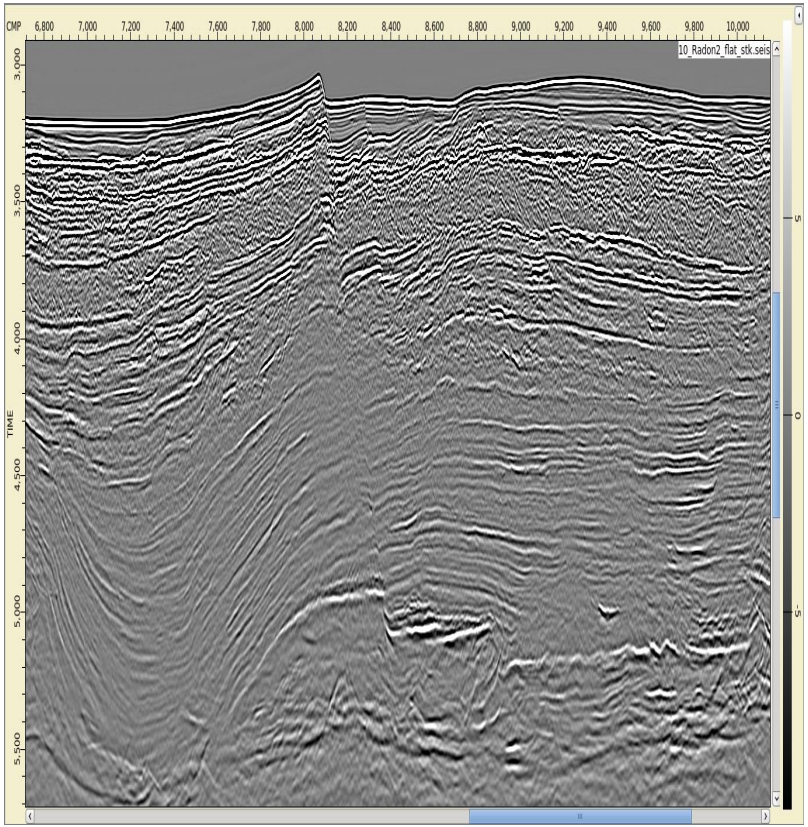
Courtesy of ENI

SHarp – slanted 10-20m cable (2m/km)

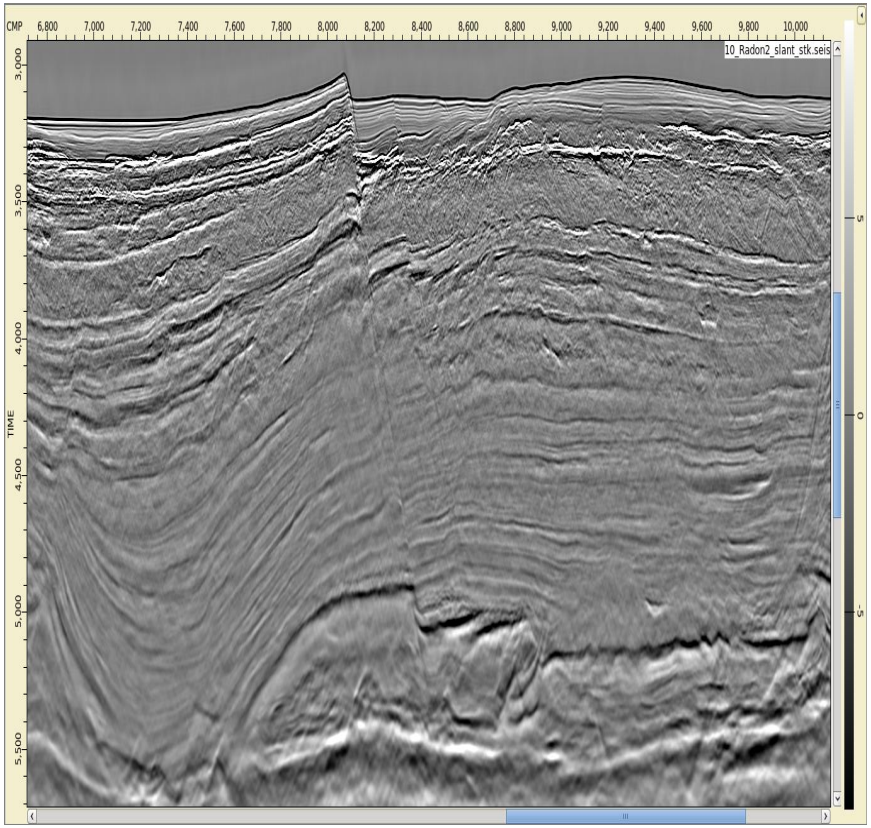


Courtesy of ENI

Conventional

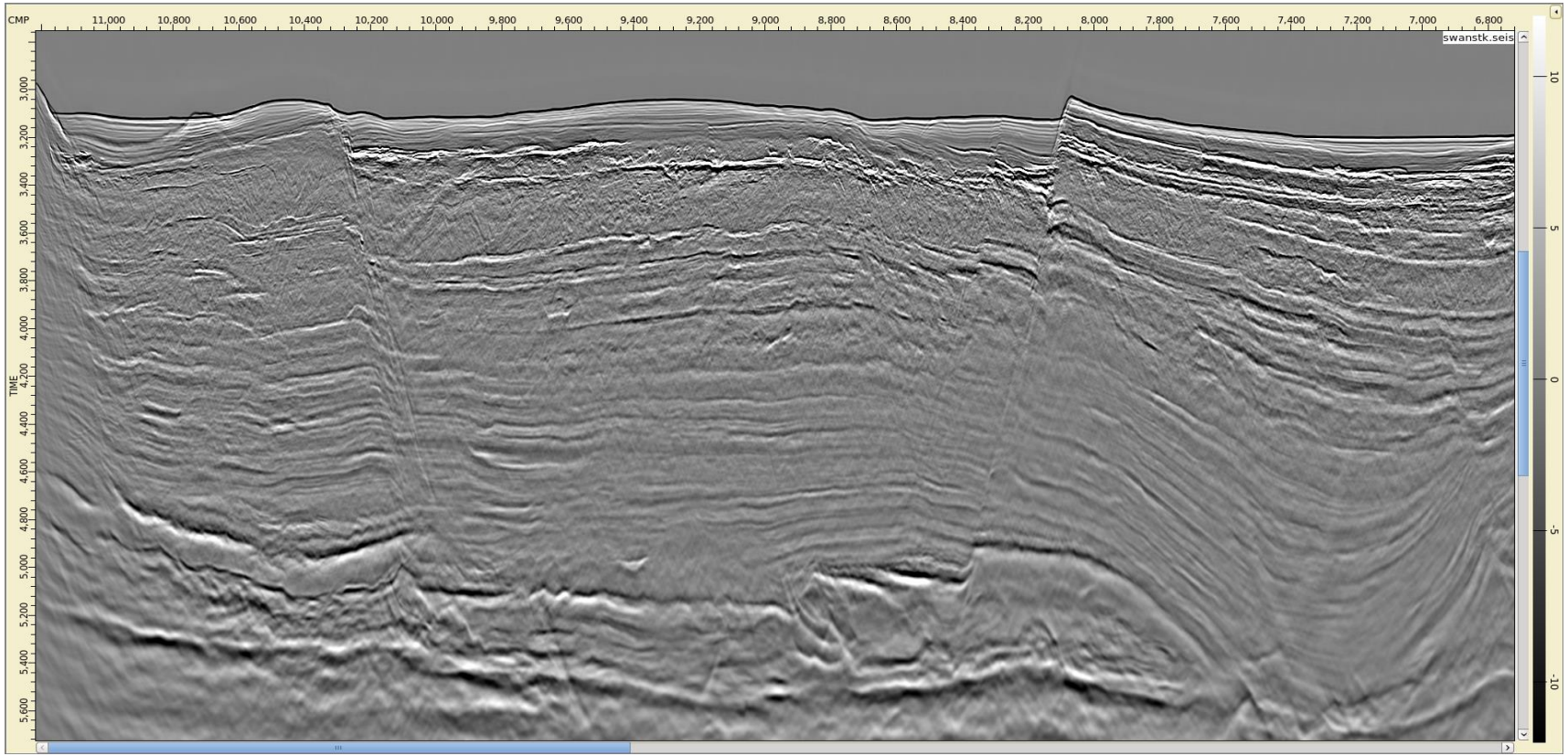


SHarp – phase-shift de-ghosting



Offshore Egypt, courtesy of ENI

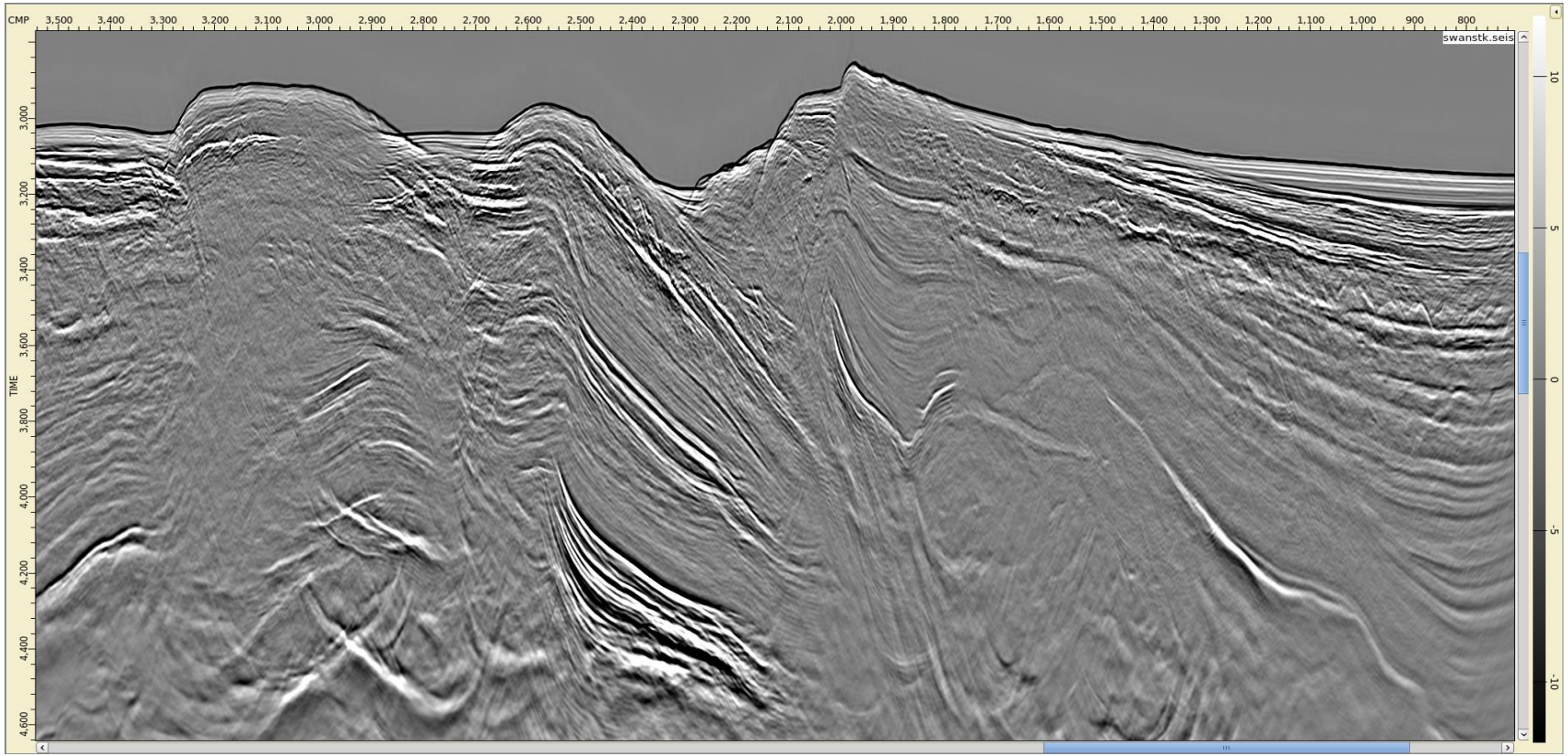
Southern End



SHEARWATER

Courtesy of ENI

Northern End



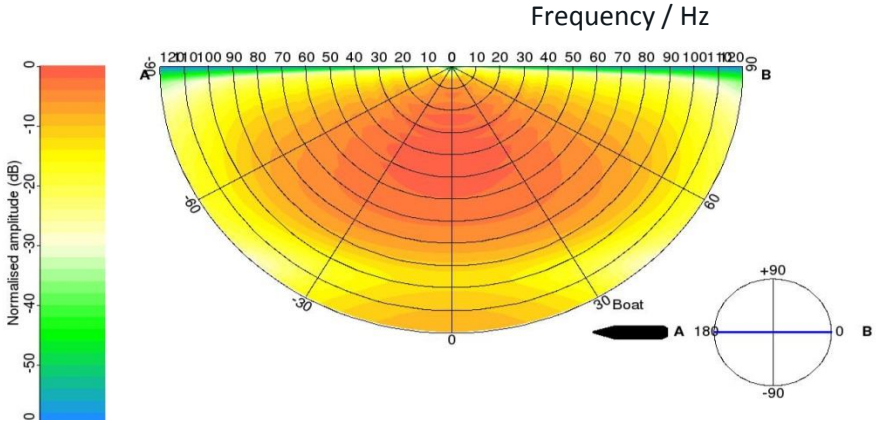
Courtesy of ENI

Content

- Near field hydrophones for directional de-signature and de-bubble

Introduction

- Accurate de-bubble is important for broadband results
- Directional de-signature compensates for the variation in signature with take-off angle

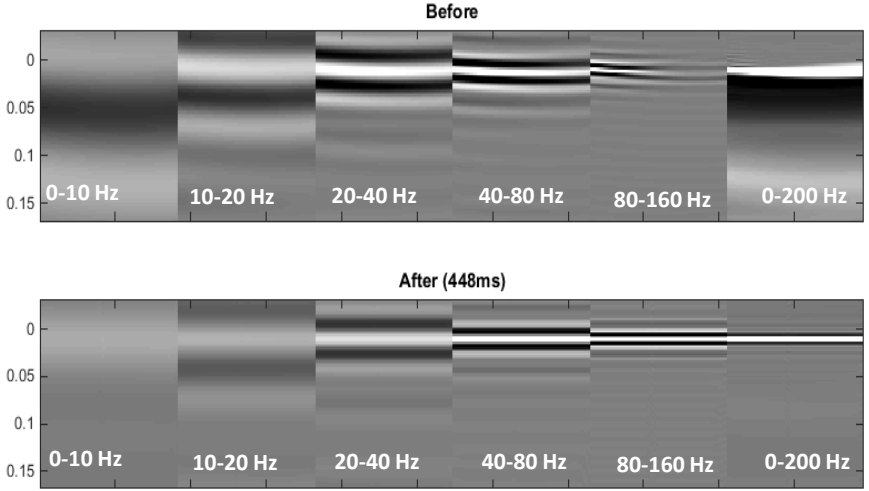


Example of variation of source amplitude as a function of in-line take-off angle and frequency

- Near field hydrophones can provide an improved solution
- Compute a set of ‘notional’ signatures from NFH – one for each element
  - Derived by LSQ taking into account bubble motion, ghosts and water-bottom reflections
- Compute far-field signature from notional signatures as a function of take-off angle
- Option available to do shot-by-shot de-signature on common receiver gathers

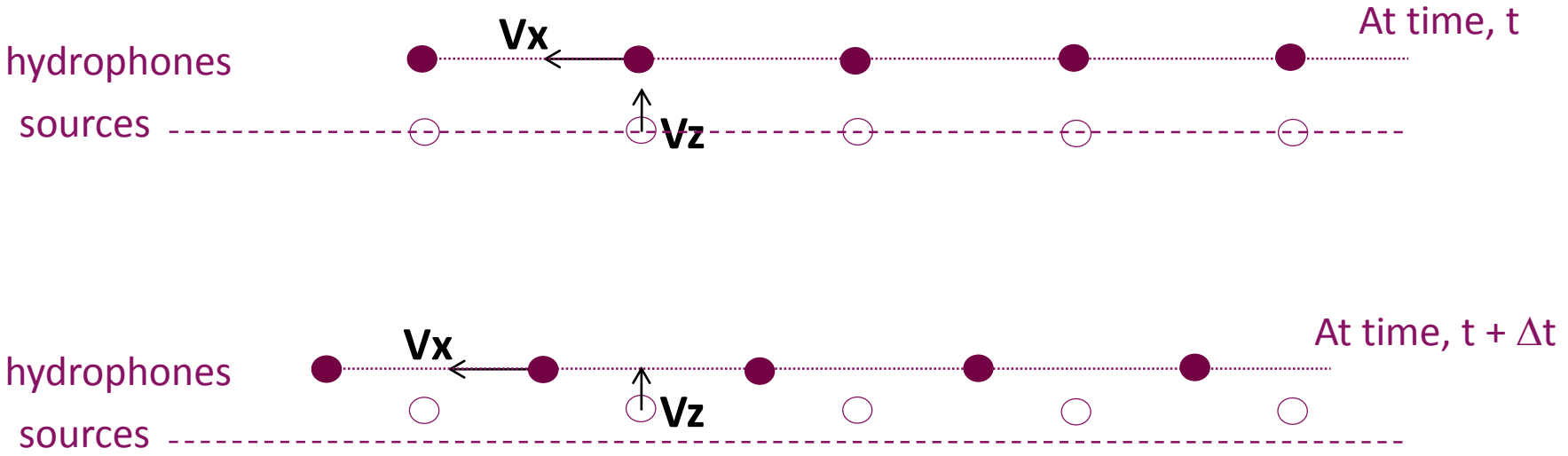
Effect of directional de-signature

- Benefits
  - All frequency components in phase across angles/offsets
    - increasingly important for broadband processing over 6 octaves
  - Improved accuracy of AVO / AVA effects
- Includes
  - Directional de-signature of the wavelet
  - De-bubble
  - Source-side de-ghosting
  - Zero-phasing/wavelet-matching
- Signature obtained from either
  - Seismic data – nr channel wavelet
  - Modelling e.g. *Nucleus*
  - The near-field hydrophone (NFH) records



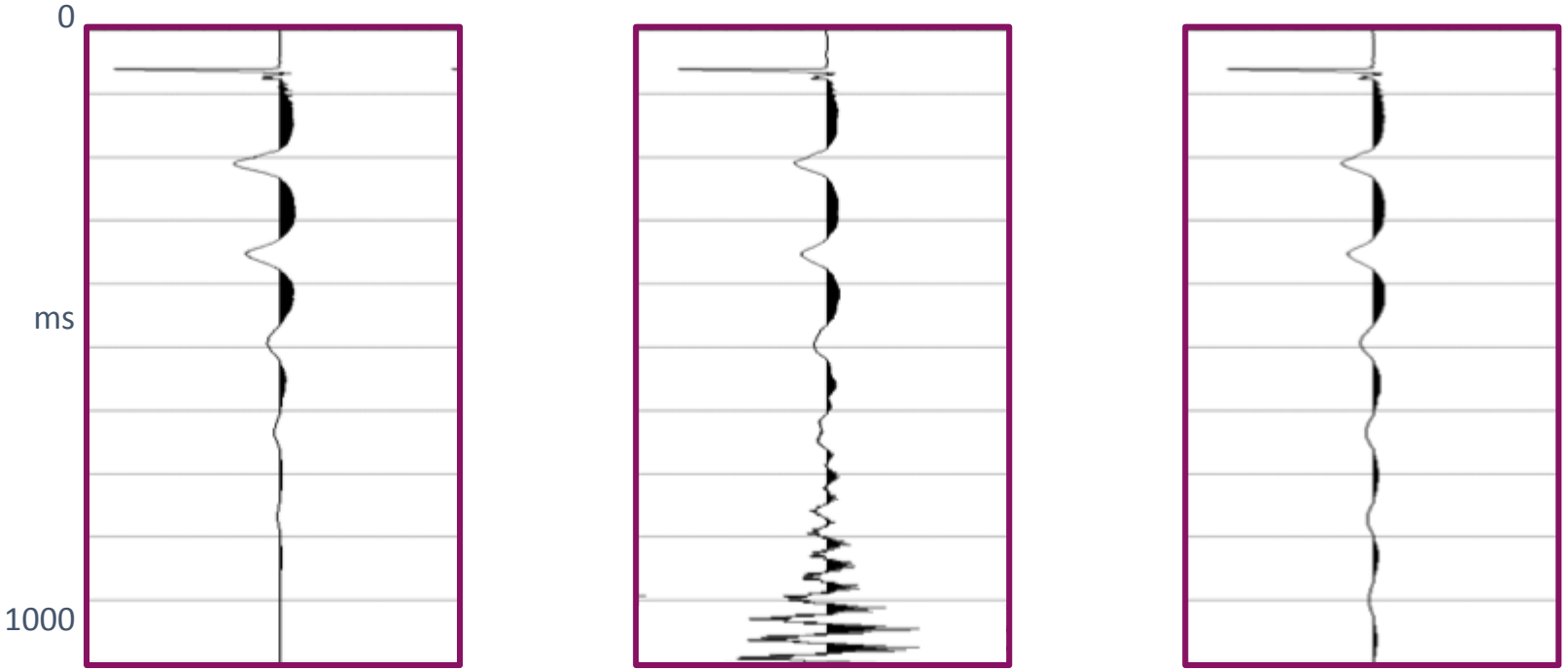
Synthetic example showing how de-signature aligns phase over all frequencies

Time dependent system



Significant change in path length from source to receiver on timescale of interest

Updating - nearest-neighbour vs. adjoint



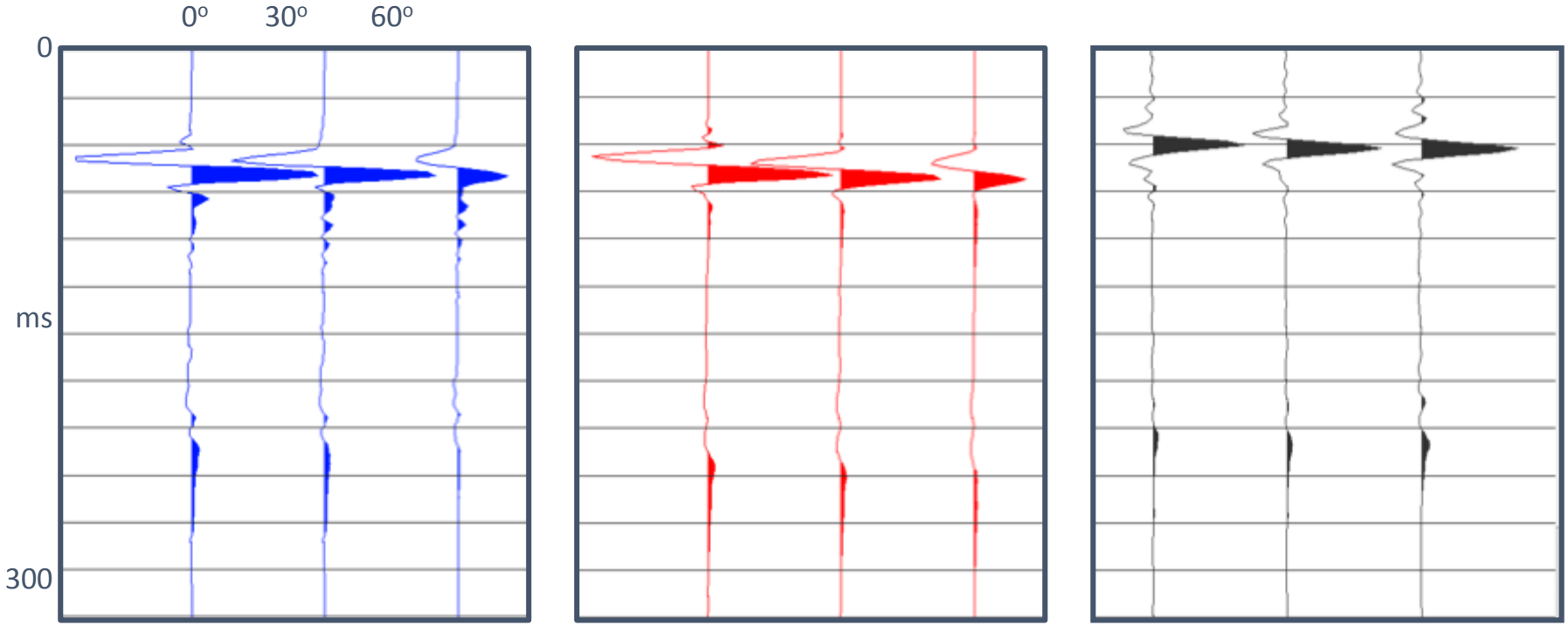
No bubble motion
iterative time domain

With bubble motion
iterative time domain

With bubble motion
adjoint - least-squares

Results - directional far-field signatures

All displays filtered 0-125 Hz



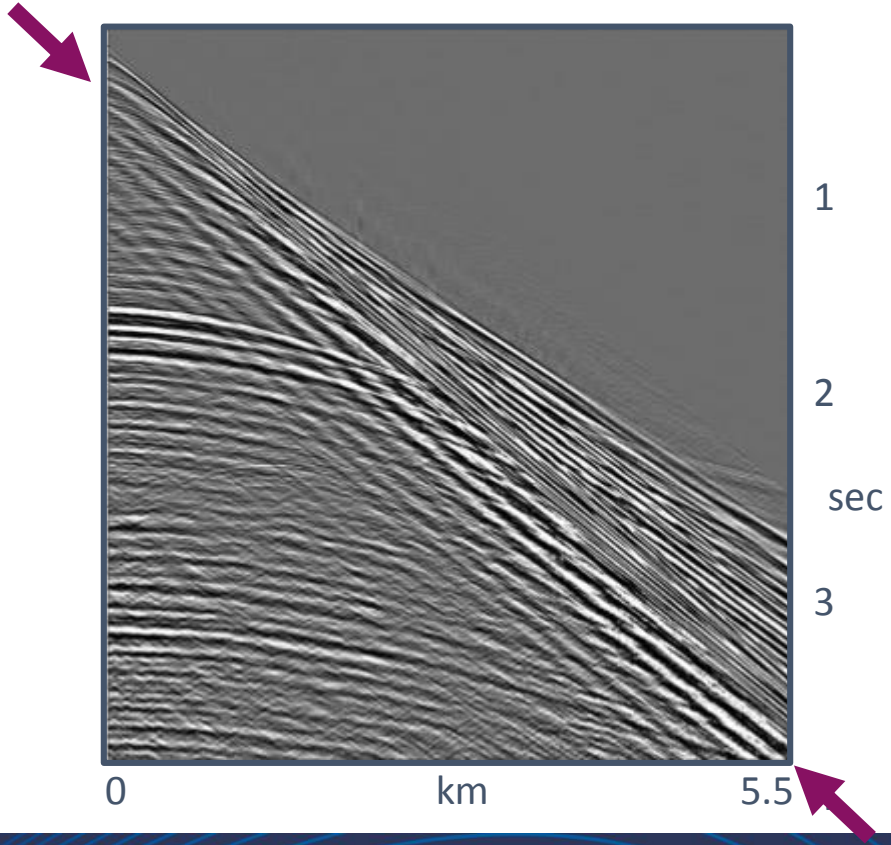
Estimated - least-squares algorithm with correction for bubble motion

Modelled (Nucleus™)

Shaping operator - estimated to modelled

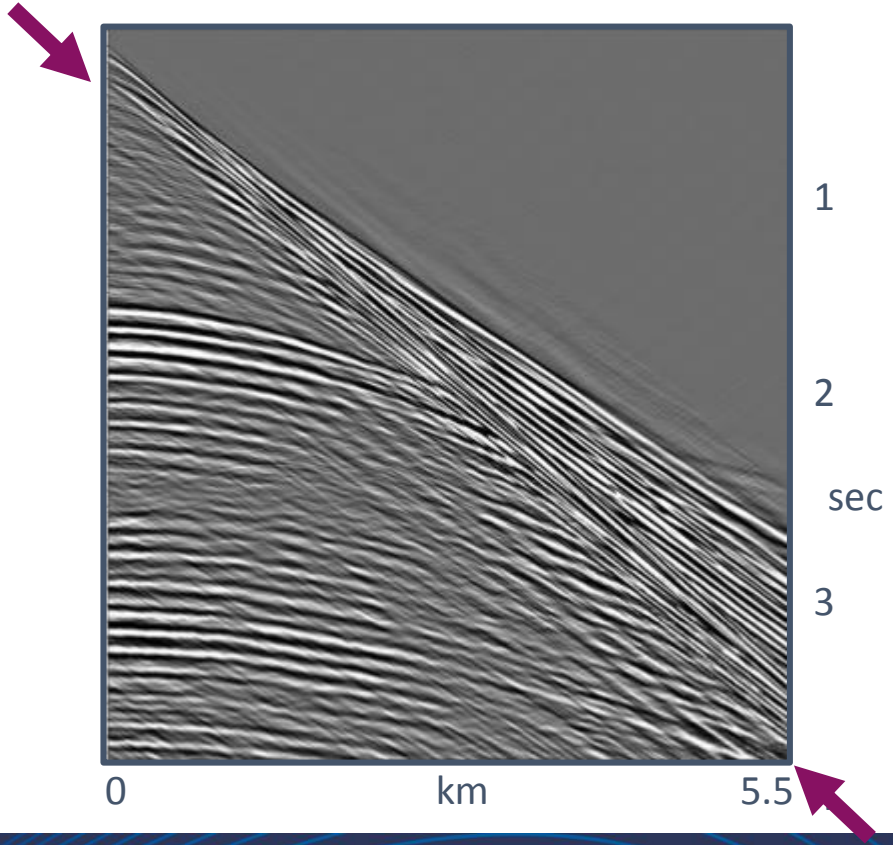
North Sea data - directional de-signature input gather

- Bubble oscillations



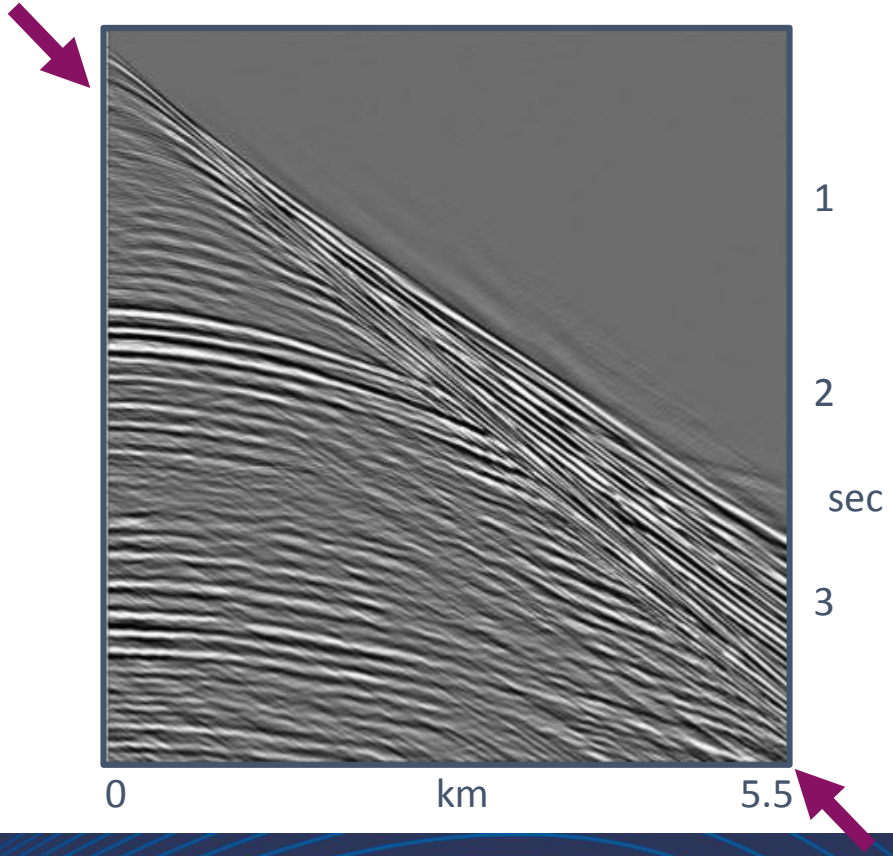
North Sea data - directional de-signature modelled signatures

- Residual is still present

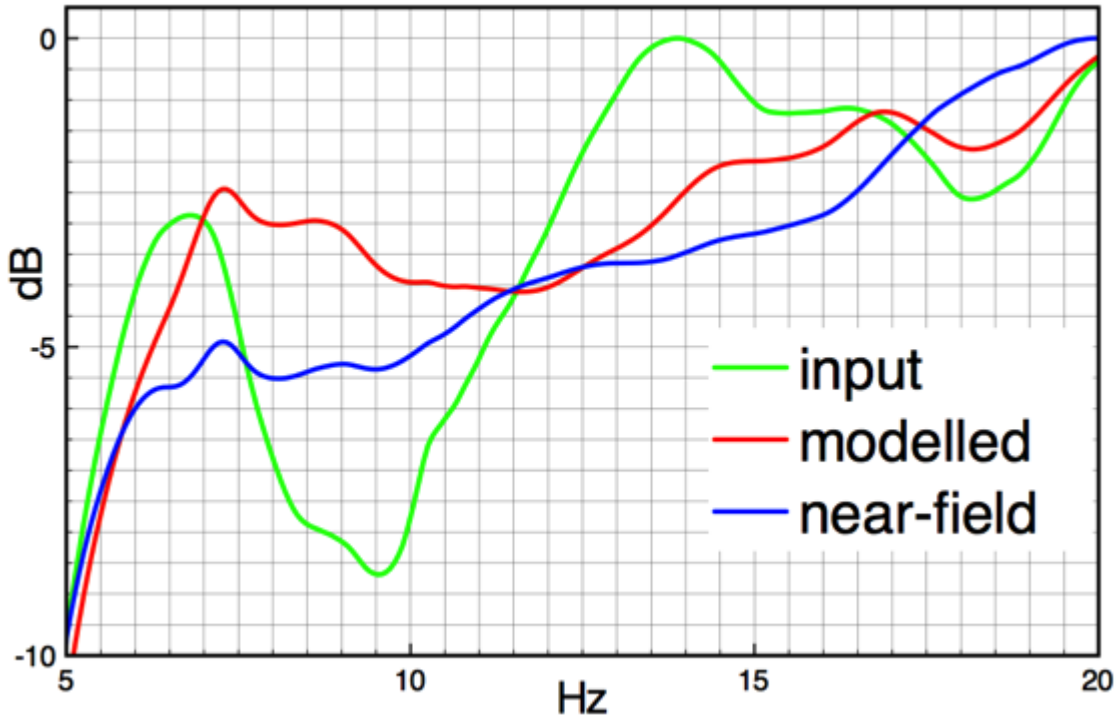


North Sea data - directional de-signature NFH signatures

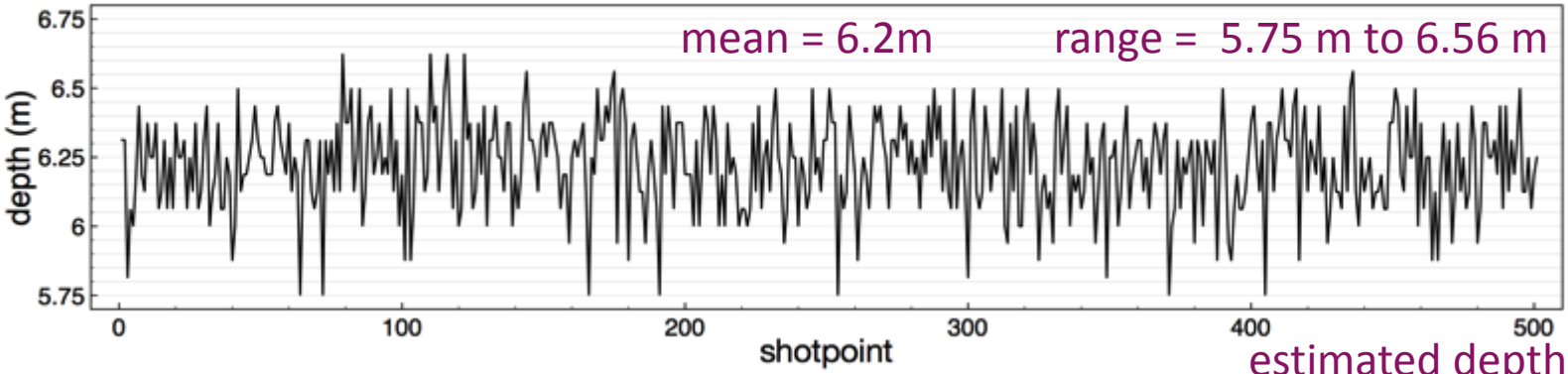
- Residual is reduced



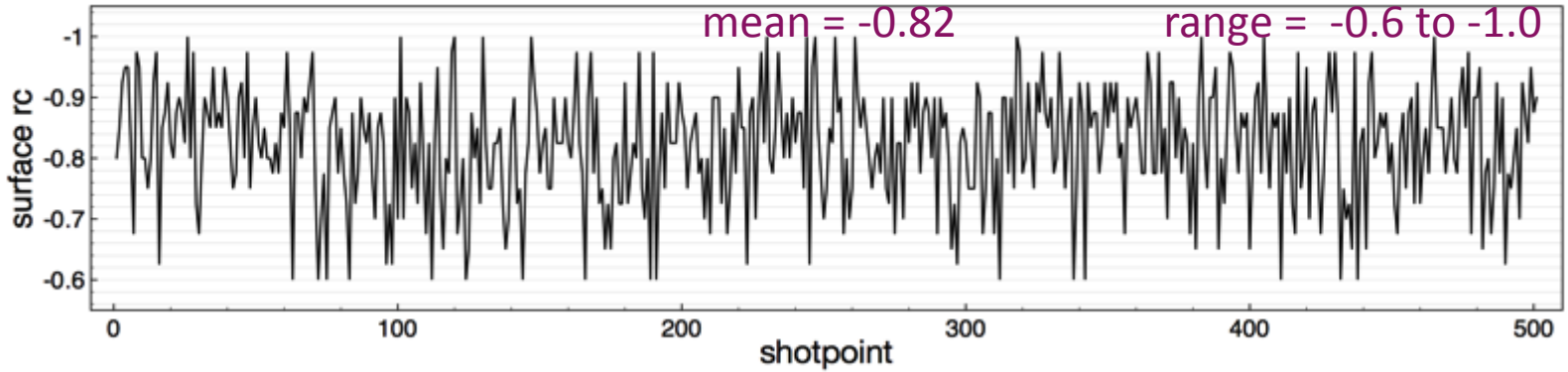
Directional designature - comparison of spectra



Results - shot-by-shot depths and reflection coefficients



estimated depth



estimated 120 Hz reflection coefficient

North Sea data - migrated section

directional, modelled signatures

directional, NFH-derived signatures