Optimizing quality and efficiency in shallow water acquisition environments

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Shallow water marine seismic acquisition

Narrow

Wider

Vessel Technology
Streamer Technology
Processing Technology

BUSINESS
DRIVERS

Next Big Thing Ahead
Outline

• Introduction
• Efficient acquisition – The vessel platform
  • The efficiency factor
  • The challenge
• The streamer platform
  • The efficiency factor
  • The quality factor
• Imaging with the dual wave-field
  • The principle
  • Mitigating the acquisition challenge in shallow water
• Summary and Conclusions
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Wide tow – The Efficiency Driver

Up to 18 Streamers @ 100m, Up to 24 @75m or less
Titan Back deck – 70m wide

- 24 x 12000m Streamers
- 16 x lead-in winches

Plenty of space for efficient and safe deployment and retrieval of multiple streamers
Increasing Productivity: Deflector Upgrades to Deliver Wider Spreads

Baro 412 – 12m x 5m; 4 foils
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Wide Tow in Shallow Water – Cross line – Illustrating the impact of Critical Angle
Footprint with Wide Tow in Shallow water

105m

125m

500m
Critical angle – Critical Offset

Critical angle

Critical offset for WD 50-300m
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OBC theory and experience suggest that we could de-ghost streamer data with the additional information from a particle velocity measurement.
Complementary ghost functions – receiver

Colocated pressure and motion sensors

Their ghost functions

Spectra of the ghost functions

Full 2D and 3D

\[ F(\omega, k_x, k_y) = \rho \omega \frac{k_x k_y}{k_z} , \text{ with } k_z = \sqrt{\left(\frac{\omega}{v_w}\right)^2 - k_x^2 - k_y^2} \]

\[ P_{\text{up}} = \frac{1}{2} (P - FV_z) \quad \text{and} \quad P_{\text{down}} = \frac{1}{2} (P + FV_z) \]
Complementary Ghost Responses

Hydrophone

Velocity Sensor

Receiver deghosted data
Source and receiver deghosting

Both ghosts included

Receiver ghost removed

Both ghosts removed and de-signature
Summary: GeoStreamer Wavefield Separation (= De-ghosting)

1. Method is very **robust**, **simple** and **accurate** (adding of different sensor recordings)
2. Only **measured** information is used (no model required)
3. Only **local** sensor information is used (no borrowing from neighboring sensors)
4. Process is **insensitive to sea-state** and **sensor depth** variations
5. Unique access to **wavefield estimates** (P-UP and P-DWN)
GeoStreamer benefits throughout the value chain

**Acquisition**
- Colocated pressure and velocity sensors
- Deep Tow

**Processing**
- Velocities
- Multiple attenuation
- Q estimation
- Imaging

**Interpretation**
- Wave-field separation
  - Up and downgoing P and V
- 4D
- Inversion
- Reservoir Characterization

A Broader Bandwidth without restricting assumptions
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Wave motion decreases exponentially away from the sea surface.

The above movie shows the wave form of a “perfect” surface wave in water. It also shows the associated water particle position as a dot and the velocity vector as a line.

- \( L \) is the wavelength
- \( u_{\text{max}} \) is the horizontal velocity
- \( v_{\text{max}} \) is the vertical velocity

(From Robert A. Dalrymple, Center for Applied Coastal Research, Univ. of Delaware)
Weather Related Noise – North Sea

Conventional streamer @ 8m depth

Dual sensor streamer @ 15m depth
North Sea - GeoStreamer vs Conventional

<table>
<thead>
<tr>
<th>(15\textsuperscript{th} April – 19\textsuperscript{th} June)</th>
<th>Ocean Explorer</th>
<th>Atlantic Explorer</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vessel</td>
<td>Ocean Explorer</td>
<td>Atlantic Explorer</td>
</tr>
<tr>
<td>Streamer type</td>
<td>Conventional</td>
<td>GeoStreamer (dual sensor)</td>
</tr>
<tr>
<td>Towing Depth</td>
<td>8m</td>
<td>15m</td>
</tr>
<tr>
<td>Weather standby</td>
<td>405hrs (24%)</td>
<td>62hrs (4%)</td>
</tr>
</tbody>
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Camamu Area - Brazil

Conventional

Dual sensor
Narrow bandwidth VS Broadband seismic – wavelet characteristic?

- Narrow bandwidth
  - More high octaves
    - Finer vertical resolution
  - Reduced side-lobes
  - Less artefacts

- Broadband
  - More low octaves
  - Less side-lobe artefacts
  - Cleaner boundaries

Octaves

<table>
<thead>
<tr>
<th>Frequency Range</th>
<th>Narrow Bandwidth</th>
<th>Broadband</th>
</tr>
</thead>
<tbody>
<tr>
<td>24-32 Hz</td>
<td>0.4 octave</td>
<td>1 octave</td>
</tr>
<tr>
<td>16-32 Hz</td>
<td>1 octave</td>
<td>1 octave</td>
</tr>
<tr>
<td>8-32 Hz</td>
<td>2 octaves</td>
<td>3 octaves</td>
</tr>
<tr>
<td>4-32 Hz</td>
<td>4 octaves</td>
<td>5 octaves</td>
</tr>
<tr>
<td>2-32 Hz</td>
<td>5 octaves</td>
<td>7 octaves</td>
</tr>
</tbody>
</table>

Peak/Trough ratio (log)

- Narrow Bandwidth: $A_p/A_t = 2.08$
- Broadband: $A_p/A_t = 4.1$
- Broadband: $A_p/A_t = 5.55$
- Broadband: $A_p/A_t = 5.88$
1D Modelling Schematic – the fundamentals

SAND

NO SIGNAL IN UNIFORM LITHOLOGY

FALSE REFLECTIONS FROM SIDELOSES

VIRTUALLY NO SIGNAL

Wavelet spectrum
Barents Sea – High Res
Frigg field area, NVG: GeoStreamer seismic bandwidth enables better lithology discrimination and fluid prediction.

Conventional:
- No separation of clusters for gas sands from wet sands.
- Clusters for gas and wet sands overlap completely.
- Diffuse distribution of points.

GeoStreamer:
- Clearer separation of clusters for gas sands from wet sands.
- Tighter distribution of points.

**KEY:**
- YELLOW = SAND
- BROWN = SHALE
- RED = GAS (residual)
- GREEN = BRINE (residual)

*Residual gas visible (red) in Top of structure of Odin and Frigg Northeast fields.*

*Window attribute of P-impedance below Top Frigg TWT.*

*Frigg residual GWC (red).*

*Residual gas visible in Top of structural culminations along sand channels at Frigg East (red bodies).*

*Lower Eocene Frigg formation sand channels Extracted from impedance ranges from cross-plot (yellow).*

*Frigg Field*

*Frigg Northeast*

*Frigg East*
Let’s not forget the spatial version of Nyquist in this Broadband Age.
## High Res Acquisition

<table>
<thead>
<tr>
<th>Acquisition Parameters</th>
<th>Dual Source</th>
<th>High Density Dual Source</th>
<th>Triple Source</th>
<th>High Density Triple Source</th>
<th>P-Cable Single Source</th>
<th>High Density Triple Source</th>
</tr>
</thead>
<tbody>
<tr>
<td>Streamer Spread</td>
<td>12x75m</td>
<td>18x50m</td>
<td>12x75m</td>
<td>18x50m</td>
<td>16x12.5m</td>
<td>16x37.5m</td>
</tr>
<tr>
<td>Crossline Bin Size</td>
<td>18.75m</td>
<td>12.5m</td>
<td>12.5m</td>
<td>8.33m</td>
<td>6.25m</td>
<td>6.25m</td>
</tr>
<tr>
<td>Sail Line Separation</td>
<td>450m</td>
<td>450m</td>
<td>450m</td>
<td>450m</td>
<td>100m</td>
<td>300m</td>
</tr>
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Imaging the Seabed
Imaging the subsurface
We normally throw away ray-paths like these
Principles of SWIM

- SWIM (Separated Wavefield Imaging) utilises the up- and down-going wavefields and free-surface related multiples in order to provide improved imaging of the subsurface in shallow water areas. This method can provide superior illumination and angular diversity compared to imaging techniques which use primary energy.

By separating the wavefields each receiver can be treated as a new ‘virtual source’ (VS).

Sub-surface illumination (EI) is extended by using the wavefield separated data as a new VS.

Angular diversity (DS) is improved by increasing the density of source points.
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SWIM illumination overburden Image Malaysia
Edward Grieg: SWIM vs Kirchhoff PSDM

Kirchhoff PSDM stack

SWIM stack

Shallow hazards

High fold
SWIM 3D view, Z=250 m
SWIM 3D view with FWI model overlay
Kirchhoff PSDM stack – model from wavelet shift tomography
Kirchhoff PSDM stack – FWI velocity model

CWI
- Complete
- Wavefield
- Imaging

Using
- Reflected
- Refracted
- Multiples

Build
- Velocity Model
- IMAGE
Angle stacks and gather comparisons

PSTM 10°-20°

SWIM 10°-20°

30°-40°

30°-40°
Amplitude vs Angle

Roden et al. 2012

SWIM Angle Gathers

10° - 20°

30° - 40°
Complete Wavefield Imaging (CWI)

Dual-Sensor Acquisition

Wavefield separation

FWI
- Exploits GeoStreamer low frequencies
  - REFRACTIONS
- High resolution shallow velocity model

SWIM
- Exploits near surface illumination
  - MULTIPLES
- High resolution refinements to velocities

Reflection Tomography
- Exploits GeoStreamer S/N
  - PRIMARIES
- High resolution velocity model at depth

Beam Q Kirchhoff Q WEM Q RTM SWIM
Vintage data
2014 GeoStreamer – 3D Broadband CWI Q-PSDM
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Conclusions

• Ramform Titan Class takes operational efficiency to yet another level in terms of deployment, production and retrieval efficiency.

• GeoStreamer is a proven broadband marine seismic solution with a 10 year track record with respect to experience, efficiency, data quality and 4D compatibility.

• GeoStreamer offers great flexibility in towing configurations in order to optimize speed and efficiency without compromising quality.

• Imaging with separated wavefields – SWIM – has the potential to become a game changer in both acquisition and imaging.

• Ramform, GeoStreamer and SWIM is a perfect fit.
Thank You