High Resolution Marine Seismic: A Short Webinar Series

A four-part series of short webinars that addresses fundamental issues necessary to achieve high resolution seismic imaging with towed streamer acquisition and imaging is available at the PGS Webinar Library. Suitable for anyone with a basic knowledge of reflection seismic principles, the series begins by establishing the key factors during towed streamer acquisition that influence the temporal frequency content available for seismic imaging. After identifying the best-practice spatial sampling limits of wide tow multi-source shooting with long GeoStreamer spreads I then highlight how even shorter spatial sampling intervals (i.e., high spatial frequencies) are required to exploit kilohertz frequencies produced by Boomer and Sparker source concepts used for 3D UHR (ultra-high-resolution) towed streamer surveys. After identifying key acquisition and imaging considerations necessary to optimize 3D UHR seismic projects I conclude with several use cases and example survey designs.

Webinar One: Modern Multisensor Streamer Benchmarks

I recorded a short four-part webinar series that discusses the key issues relevant to ultra-high subsurface resolution using marine seismic data:

- Resolution Limits of Conventional Towed Streamer Acquisition (12 mins).
- Temporal and Spatial Sampling Considerations (10 mins).
- The 1-meter Resolution Challenge (12 mins:secs).
- UHR Multi-Source Configurations (14:25 mins:secs).

In the first webinar I begin with short list of many factors relevant to a discussion on seismic resolution before summarizing the fundamentals of towed streamer acquisition geometry.

Thanks to the towing and handling innovations pioneered by PGS, up to 18 long multisensor GeoStreamers can be towed with close separation, and for a vessel towing both sources and streamers, the four Titan-class vessels can tow up to six sources with maximum lateral distribution of about 350 meters. The smallest inline shot interval used in practice is about 6 meters, and overall, the best practice spatial sampling interval is about 5 meters in the crossline direction and 6.25 meters in the inline direction. When using air gun arrays and time sample rates of two milliseconds, we are recording temporal frequencies between 0 and 250 Hertz.

For targets within a couple of km of the seafloor, this means small geobodies with dimensions of 2 or 3 m may be resolvable. The use of wide tow multi source shooting decreases the spatial sampling interval in the crossline direction and improve the near offset coverage beneficial to higher quality and higher resolution near surface imaging whilst maintaining high overall survey efficiency (measured as square kilometers of 3D seismic acquired per day).

Figure 1 schematically illustrates how the temporal frequency range emitted by a seismic source is successfully modified by a series of wavefield propagation effects, interaction with the free surface of the ocean, the acquisition geometry deployment, the characteristics of the recording system, our ability to minimize or attenuate any artifacts recorded and introduced into the data, and the accumulated effects of a multi-stage processing and imaging workflow.

After the application of wavefield separation and source deghosting in the initial processing of GeoStreamer data, the resulting ghost-free data is the best possible representation of the temporal frequencies recorded in the seismic data.

To further improve the resolution of seismic images in a substantial manner, the seismic acquisition effort must use source concepts that can emit much higher frequencies, use much shorter time sample rates to record these higher temporal frequencies, and correspondingly, use higher spatial frequencies to be able to exploit these higher temporal frequencies.

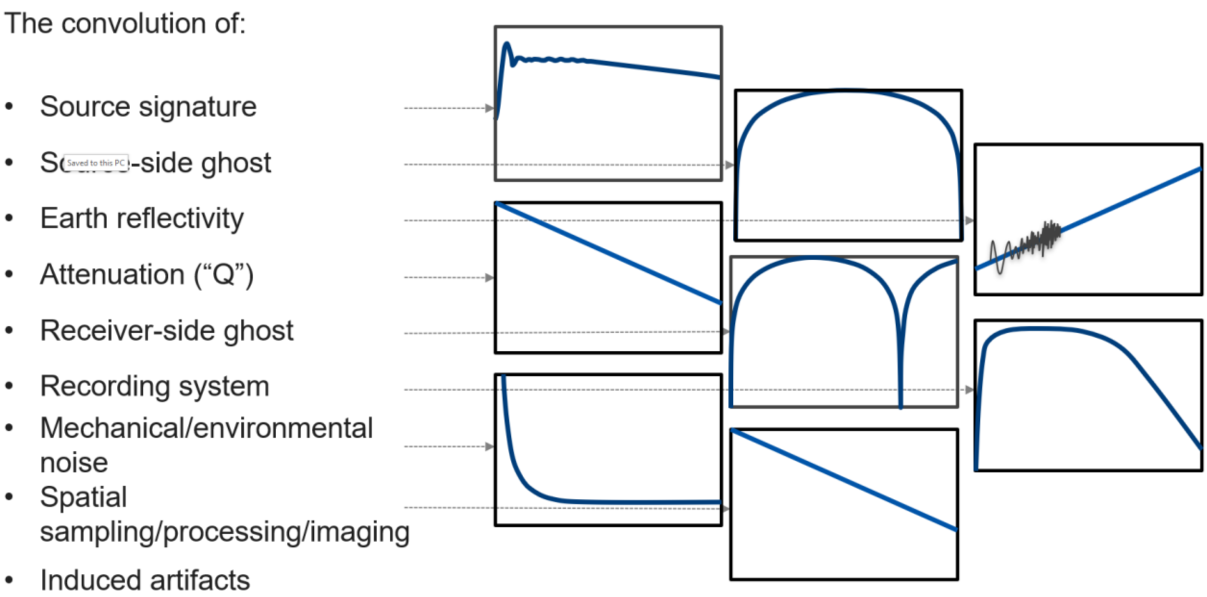

Figure 1: Schematic illustration of acquisition and processing / imaging factors that affect the temporal frequency content in final seismic images.

Webinar Two: High Temporal and Spatial Frequencies are Critical!

This sets the stage for the second webinar, which moves focus to the relevance of having an increased range of both temporal frequencies and spatial frequencies, beginning with the highest temporal frequencies available.

For traditional target depths 1 or 2 kilometers or more below sea floor, the peak amplitudes from air guns typically occur at frequencies of about 30 to 50 Hertz or even lower, and we are working with frequencies less than 250 hertz. When using ultra high resolution or ‘UHR’ source concepts such as Boomer or Sparker, frequencies in excess of 2000 Hertz may be emitted, which necessitates time sample rates of 0.25 milliseconds or even lower. Note that due to natural anelastic absorption and dispersion effects in the earth, high temporal frequencies of hundreds of hertz are only recorded from near-surface geology with a useful signal-to-noise ratio (SNR). UHR seismic investigations are therefore typically limited to depths of tens to hundreds of meters.

To exploit available higher temporal frequencies in seismic imaging, higher spatial frequencies must also be used during data acquisition. This principle is firmly established in classic seismic imaging literature. Furthermore, specific processing and imaging workflows are necessary to exploit the rich temporal and spatial frequency content of UHR data.

As elaborated within the second webinar, a focus upon fine scale regularization and spectral enhancement is critical, as is a focus on seismic information that may traditionally be regarded as ‘noise’. For example, shallow multiples can be used to create remarkable shallow seismic images (PGS SWIM), and the use of diffraction information can be very informative. We also combine FWI (Full Waveform Inversion), Least Squares Migration, and QI tools to improve image resolution and detectability of tiny geobodies and subtle geomechanical features present in near-surface images.

Figure 2 introduces the technology required to go to UHR seismic. The horizontal axis is both vertical and horizontal resolution and the vertical axis is the target depth below seafloor. As noted, modern high-resolution GeoStreamer data generally works for frequency less than 250 Hz (assuming 2 ms sample rate) and is applicable to all depths for hydrocarbon exploration. To go to kilohertz frequencies, extremely high-resolution (XHR) imaging, hull-mounted systems or AUVs (autonomous underwater vehicles) are used to map seafloor bathymetry. UHR seismic fits into the middle range of temporal frequencies.

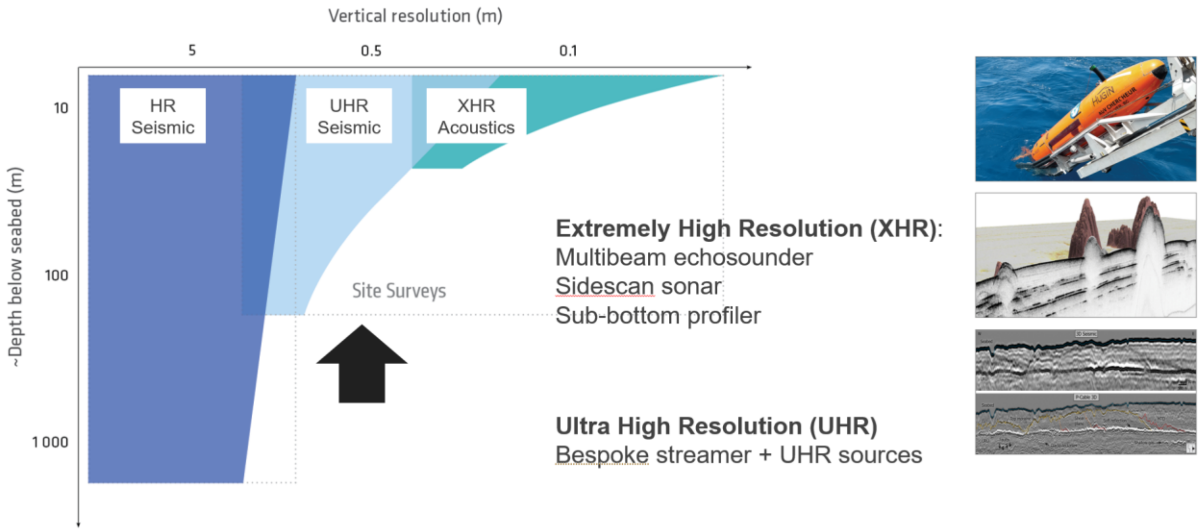

Figure 2: Schematic illustration of the depth of investigation versus resolution capabilities of HR, UHR and XHR seismic, respectively.

Webinar Three: Parameters Necessary to Achieve 1-m Subsurface Resolution

The third webinar begins with a brief review of some publications by Dan Davies and others (then) from BP who were working in the North Sea on the positioning of a platform over the Clair South field. They pursued a series of 2D and 3D UHR seismic tests to determine whether they could image boulders in the near surface with diameter of only 20 to 30 centimeters. Although they did not quite manage to achieve all their objectives, they did achieve outstanding results, and were nevertheless able to successfully reposition the platform without incurring problems when drilling the pilings.

I use this introduction to then consider the survey design parameters necessary to achieve submeter resolution.

The best-known 3D UHR 3D streamer solution in recent years has been the P-Cable platform, now generically referred to UHR streamer as PGS have improved the spatial sampling possible with this methodology since buying the original P-Cable platform from NCS Subsea and continue to work on improved engineering for the system too. In addition to the deployment of sources that can emit useful frequencies more than 2000 Hertz, 3D UHR streamer acquisition uses very short time sampling rates, tows high resolution streamers at very small separation (typically 6.25 or 12.5 m) and deploys wide-tow multi-source shooting to provide extremely high temporal and spatial frequencies in the recorded data. Remarkably high resolution is feasible for shallow depths below sea floor.

The most common applications are to assist and augment geotechnical studies, focusing on the reduction of risk with drilling operations and planning to install sea floor pilings and sea floor anchors, the management of CCS projects, and sea floor mining.

Cone Penetration Testing (CPT) is the main geotechnical measurement historically used to establish the Stiffness and Shear Strength of cohesive soils, but it is unable to reliably identify small-scale hazards such as shallow boulders, channels, gas pockets, and so on. Many of these hazards may also be below the resolution limits of UHR seismic imaging and cannot be resolved as discrete geobodies. Consequently, complementary solutions such as ‘diffraction imaging’ are often used to help detect and characterize all the shallow hazards relevant to the long-term stability of wind turbine foundations or anchoring.

Webinar Four: 3D UHR in Practice with Wide-Tow Multi-Source Shooting

My fourth webinar in this series elaborates on the UHR towed streamer technology that can be deployed to yield both spatial resolution and detectability for geological features with dimensions less than one meter.

PGS typically tows the streamers at 6.25 or 12.5 m separation, and as illustrated in **Figure 3**, the streamers are all connected to the cross-cable between the paravanes. Each streamer section is 50 m long, and one or two sections are most common for each streamer. Note that these are hydrophone-only streamers towed close to the surface, so a ghost removal solution is applied in processing to enhance the recoverable (low and high) frequency range.

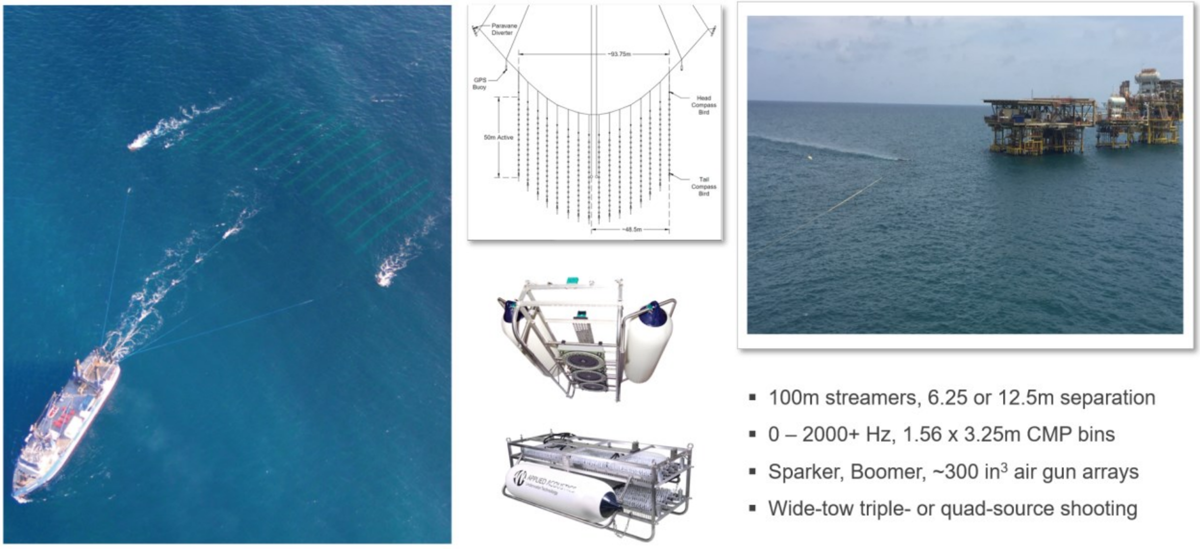

Figure 3: Components of the P-Cable system, now generically referred to as 3D UHR streamer seismic. Although small air gun arrays have been used in the past, modern wide tow multi-source shooting more commonly uses Boomer or Sparker sources. The compact streamer spread dimensions means that close pass acquisition is feasible to installations.

The actual UHR streamer configuration chosen will depend upon the particular survey challenge. **Figure 4** shows the offset distribution versus crossline location for 10 streamers towed with 6.25 m streamer separation and wide-tow triple source shooting, such as could be used to prepare for an offshore wind farm. Note the remarkably small near offset distribution because of the wide tow multi-source shooting and the small streamer spacing—most sublines would have near offsets less than 10 m!

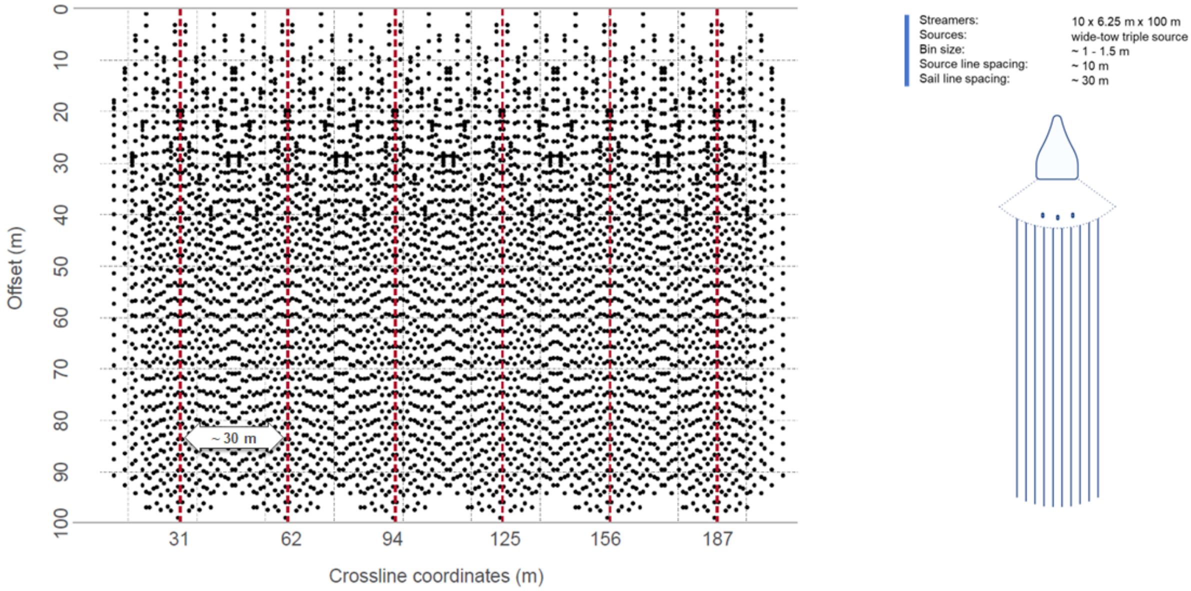

Figure 4: Example of modelled offset coverage for six adjacent sail lines with the 10-streamer, wide tow triple-source configuration shown on the right. The vertical axis represents inline source-receiver offset increasing downwards from 0 m at the top, and the horizontal axis represents the crossline location of each subline (30 sublines per sail line). Courtesy of Martin Widmaier (PGS). A relevant reference can also be accessed here on the survey design relationships between exploration 3D and UHR 3D configurations.

Because of the compact physical dimensions of a typical streamer spread, PGS 3D UHR streamer configurations may be considered for a variety of applications in congested survey areas where obstructions such as platforms are situated, or where water depths are too shallow for large exploration streamer spreads. Past surveys have been able to safely operate the UHR streamers within only 25 m of the platform!

Figure 5 is a compilation set of examples that collectively highlight fantastic seafloor bathymetry mapping, the delineation of localized gas pockets on the lower-right, and on the left, ultra-high-resolution of the most complex stratigraphy for at least 1 km below seafloor.

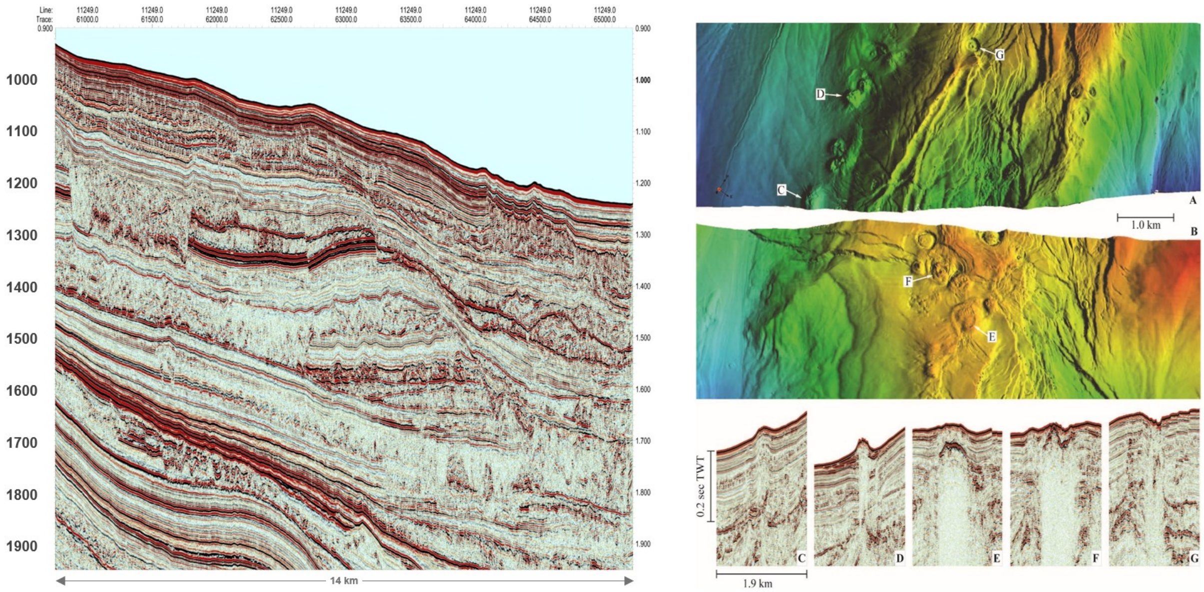

Figure 5: Compilation of 3D UHR seismic images of complex stratigraphy and seafloor morphology.

The remarkable shallow UHR image resolution capabilities are similarly applicable to the evaluation of legacy well integrity when repurposing depleted reservoirs for CCS projects, planning seafloor infrastructure and drilling programs, characterizing geomechanical features relevant to the 'containment' aspect of CCS, and to long-term monitoring of CO2 plume movements.

In principle, 3D UHR seismic data can be inverted to yield shallow soil properties at a dense spatial sampling rate for windfarm planning: as dense as 1.56 x 3.25 m! Although none of the 3D UHR examples shown in the third and fourth webinars explore emerging opportunities to invert for soil properties or present ongoing windfarm projects, the principles discussed are intended to reinforce the collective value of high temporal and spatial frequency content when optimizing the seismic description of the near surface.

Summary

The progression in marine seismic image resolution has been enabled by an evolution in towed streamer acquisition technology that enables higher temporal and spatial frequencies to be exploited during imaging and subsurface characterization. Four short webinars describe the relevant principles behind multisensor GeoStreamer and UHR streamer surveys.

Further Reading

- PGS Live | Wind | Webinar.
  - → Learn how PGS can help assess hazards and optimize the design of wind farm developments with new ultra-high resolution 3D seismic acquisition and existing data library products.
- Shallow Resolution | Achieved in Many Ways | Webinar.
  - → Learn how seismic imaging innovations including Full Waveform Inversion (FWI), Full Wavefield Migration (FWM), and Least-Squares Migration (LSM) can enhance shallow image resolution.