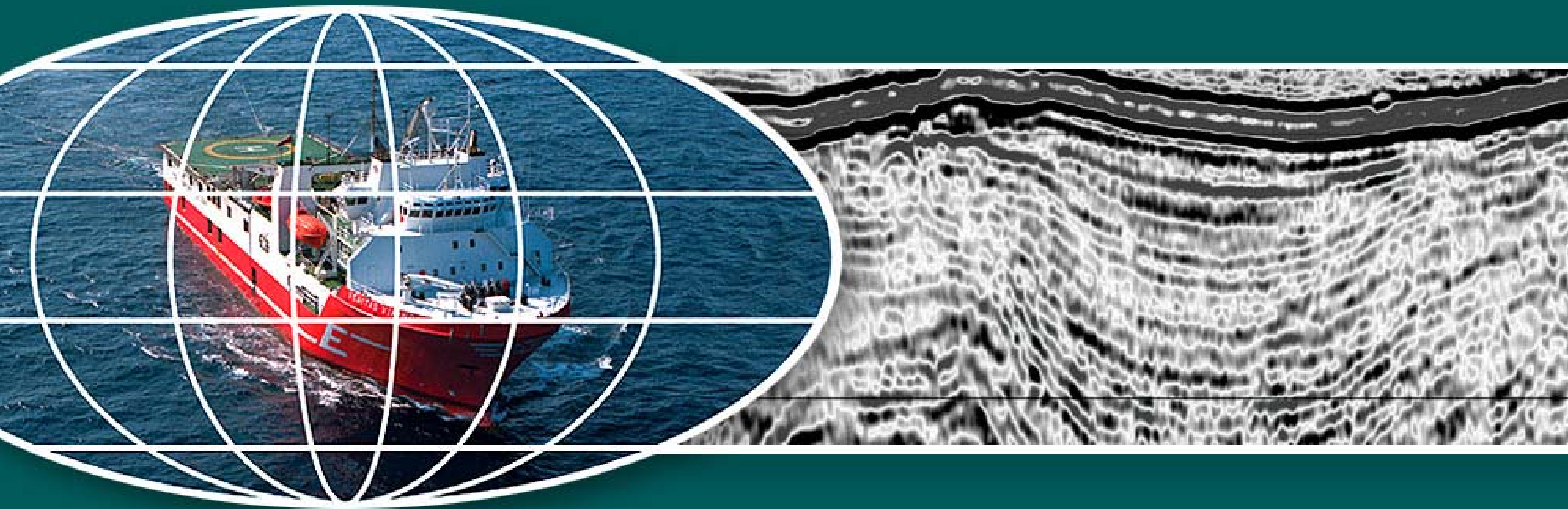
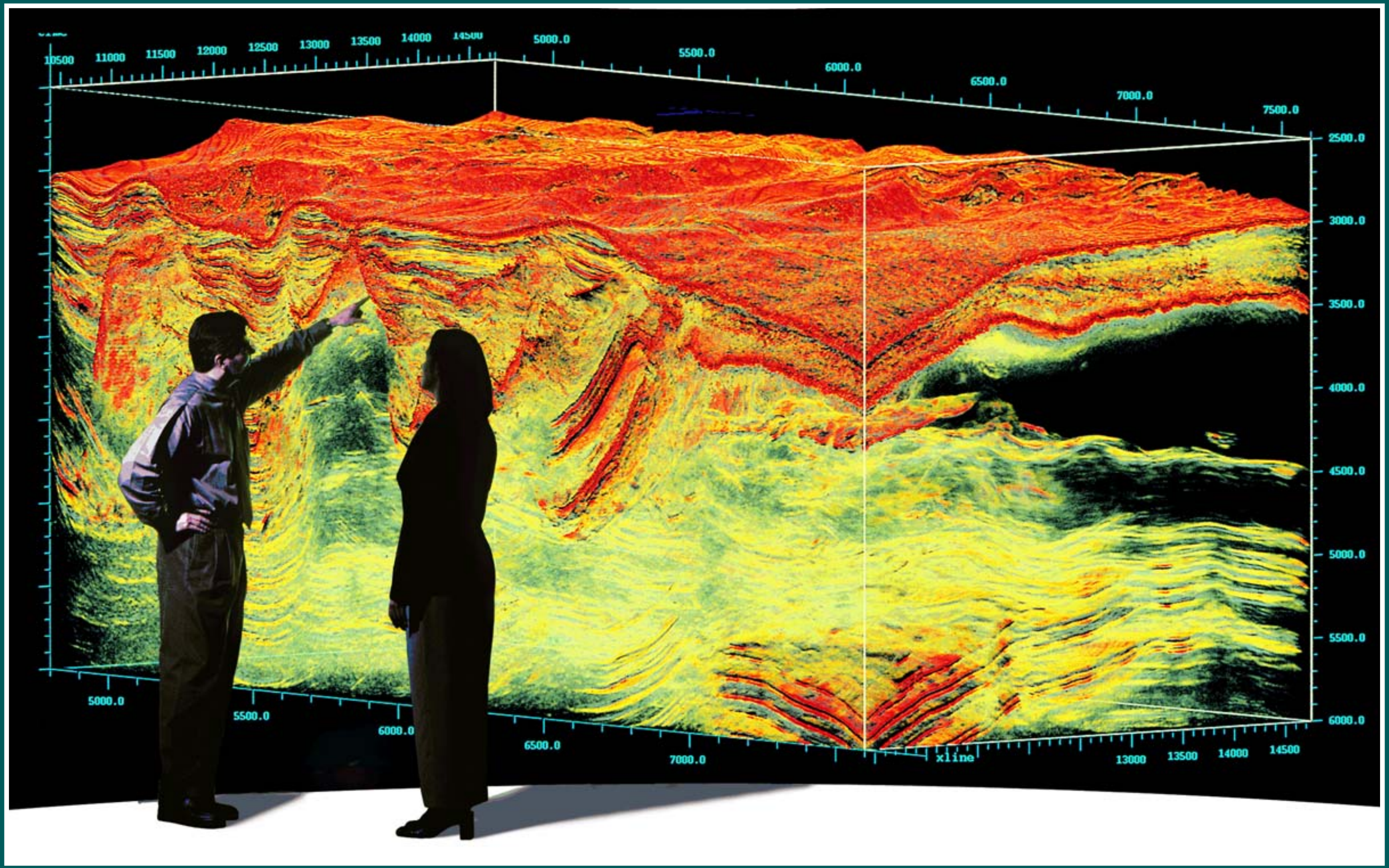


Marine 3D Survey Design

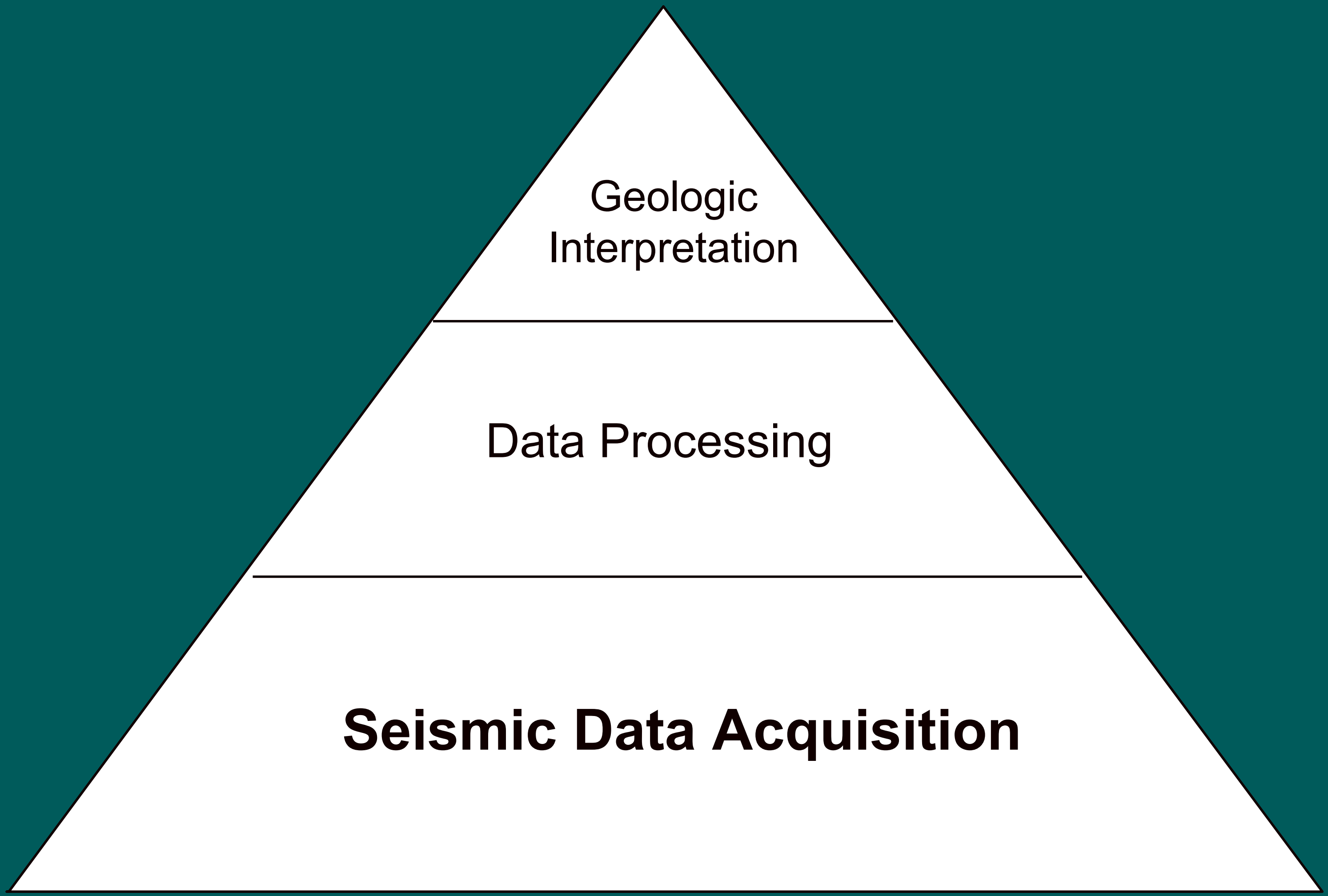
LDEO 3D Seismic Workshop : September 10, 2005

Phil Fontana - Veritas DGC, Inc.

Geologic Interpretation



Survey Design



3D Survey Process Flow

Pre-Survey	Startups	Daily / Weekly	End of Survey
Survey Design	Job start meeting	Confirm data on tape	Confirm coverage
Technical Proposal	Navigation Calibrations	Review 3D coverage	Post survey navigation calibrations
Permitting	QC INS Set-up	Review QC summary	Generate Nav Deliverables
Define geodetics	QC Nav Processing Set-up	Review Production	Final post plots
Mapping	3D Binner Set-up	Review seismic data	Archive Nav Data
Pre-plots	QC set-up of Seismic Systems	Monitor In-water Network	Archive QC Databases
Positioning requirements	QC setup of seismic processing system	Monitor compass bias	Archive 3D binner database
Source modelling		Monitor of GPS	Close Survey Document
Define deliverables		Pre vs. post plot	Post project analysis
Survey Parameter Document		Update preplots	
Client meeting(s)		Bathymetry	
		QC nav deliverables	
		Problem solving	

(cyan)	Geophysical
(orange)	Navigation
(green)	Geodetics and Mapping

Agenda

- Spatial Sampling
  - Velocity and Dip >>> Spatial Nyquist
  - 3D bin dimensions >>>> Source and Streamer Geometry
  - Bin Fold >>>> Shot Point Interval and Streamer Length
  - Imaging apertures >>>>> Size of Survey Area
  - Shooting Direction (Strike or Dip) >> Sail Line Length vs Number of Sail Lines

- Temporal Sampling
  - Record Length >>>>> Shooting Speed
  - Data Bandwidth >>>> Source and Receiver Depth

- Positioning Networks
  - Network design considerations
  - Onboard navigation data processing

- Survey QC
  - Seismic data quality >>>>> Signal and Noise
  - Positioning Networks >>>>> Precision of positions
  - 3D Coverage >>>>> Steering the spread and Infill
  - QC processing >>>> brute stacks, low fold cubes

- Computing Survey Duration >>> Costs

Survey Design

Geologic Objectives > Geophysical Parameters > Operational Considerations

Geologic Objectives

- Target Type : Structural and/or Stratagraphic >>> Imaging
- Target Depth >>>> Imaging
- Lithology and Fluids >>>> Seismic Attribute Analysis

Geophysical Parameters

- Spatial Sampling >>> Velocity, Frequency, and Dip
  - 3D bin dimensions >>>> Source and Streamer Geometry
  - Imaging apertures >>>>> Survey Area
  - Shooting Direction (Strike or Dip) >>>>> Sail Line Length vs Number of Sail Lines
- Temporal Sampling
  - Bin Fold >>>> Shot Point Interval and Streamer Length (i.e Number of Channels)
  - Record Length >>>>> Shooting Speed and Water Depth
  - Data Bandwidth >>>> Source Design and Source and Receiver Depth

3D Survey Design Process

- Obtain hazard map and previous seismic data
- Outline 3D image area and use seismic data to calculate image aperture and spatial sampling requirements
- Add aperture to 3D image area to obtain full-fold coverage area; use maximum offset to determine full operational area
- Examine full operational area for the presence of
  - Surface obstructions
  - Bathymetric hazards (shoals, reefs, shallow water)
  - Shipping lanes, regional currents
- Select shooting direction(s) and estimate survey timing and costs based on proposed acquisition configuration
  - Plan undershoots and directional seams

Spatial Sampling = 3D Image Resolution

Spatial sampling requirements are a function of apparent velocity, dip, and maximum recoverable frequency.

Frequency-wavenumber (F-K) Domain
Summary of Terminology

F-K domain is directly invertable to/from T-X domain

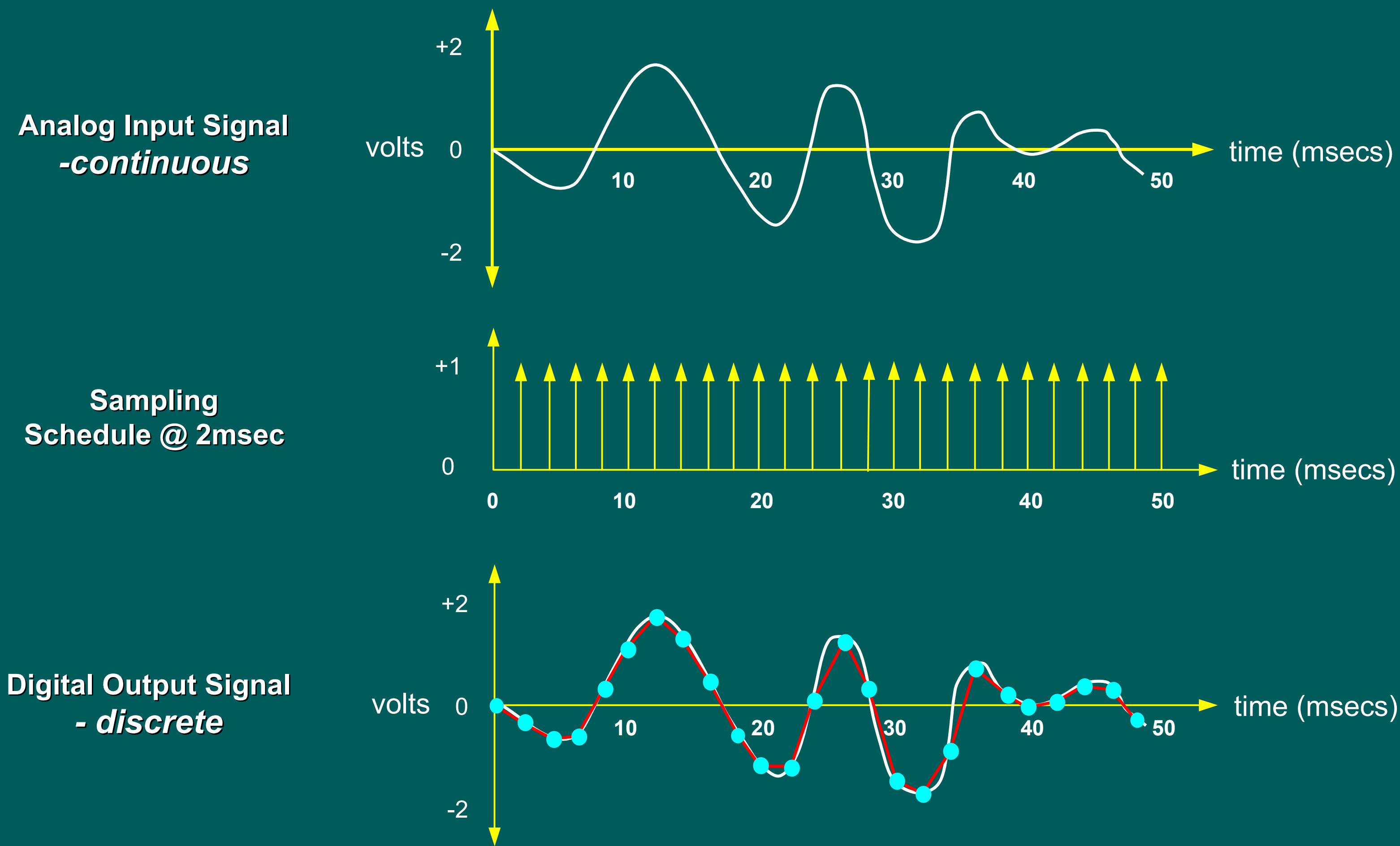
T-X domain		F-K domain	
T	time (in seconds)	F	frequency (in Hertz)
X	distance	K	wavenumber
t	period of wavelet	$f = 1/t$	frequency of wavelet
λ	spatial wavelength	$k = 1/\lambda$	wavenumber of wavelet
δT	time sample interval	$F_n = 1/(2\delta T)$	Temporal Nyquist
δX	spatial sample interval	$K_n = 1/(2\delta X)$	Spatial Nyquist

V phase velocity of signal or noise

$=X / T$ $= f\lambda$ $=f / k$

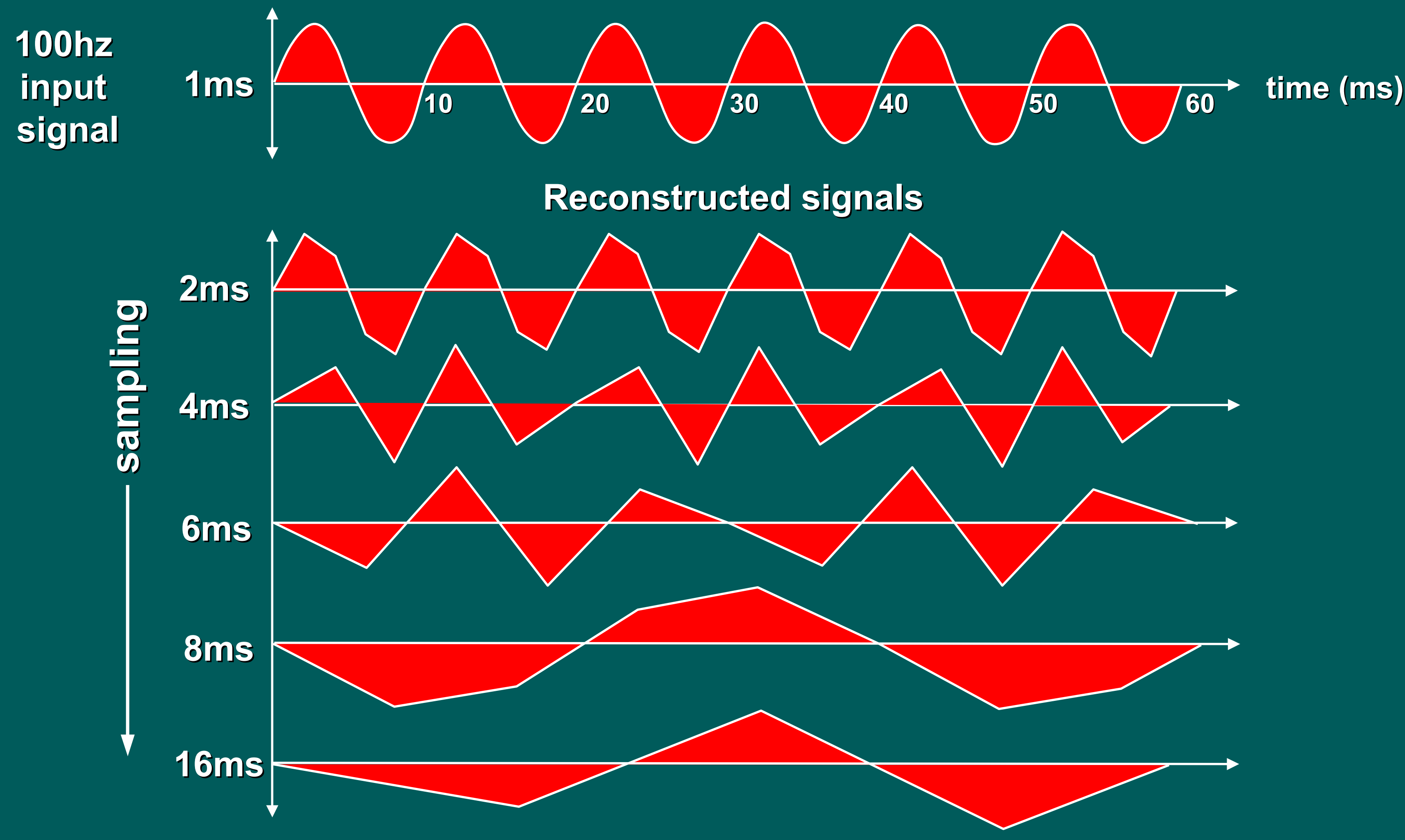
Events in T-X domain with given dip, transform to straight line through origin in F-K domain. Steeper dips in T-X transform to flatter lines in F-K

Temporal Aliasing



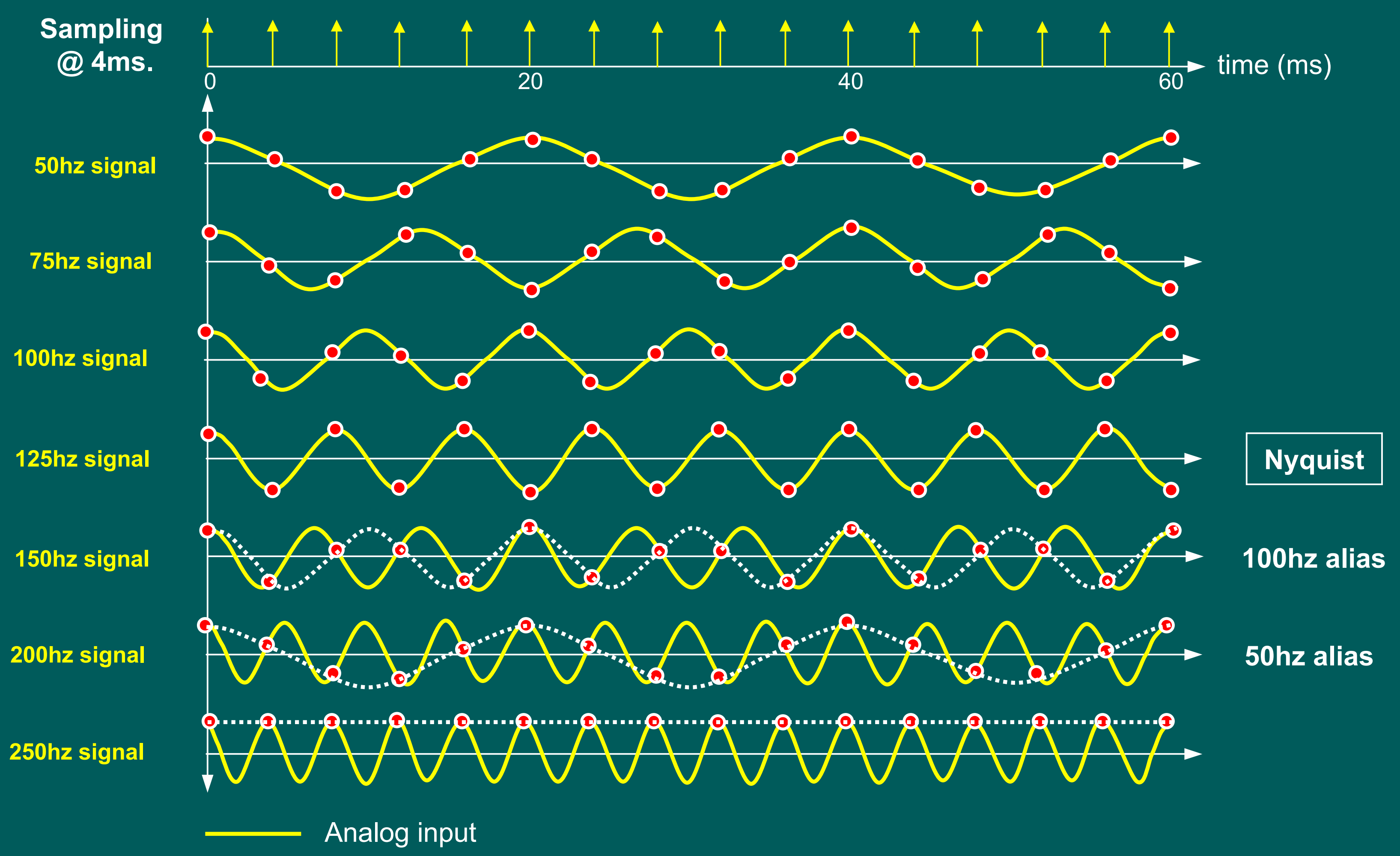
Digital Sampling

Temporal Aliasing



Data aliasing - 1: constant frequency

Temporal Aliasing

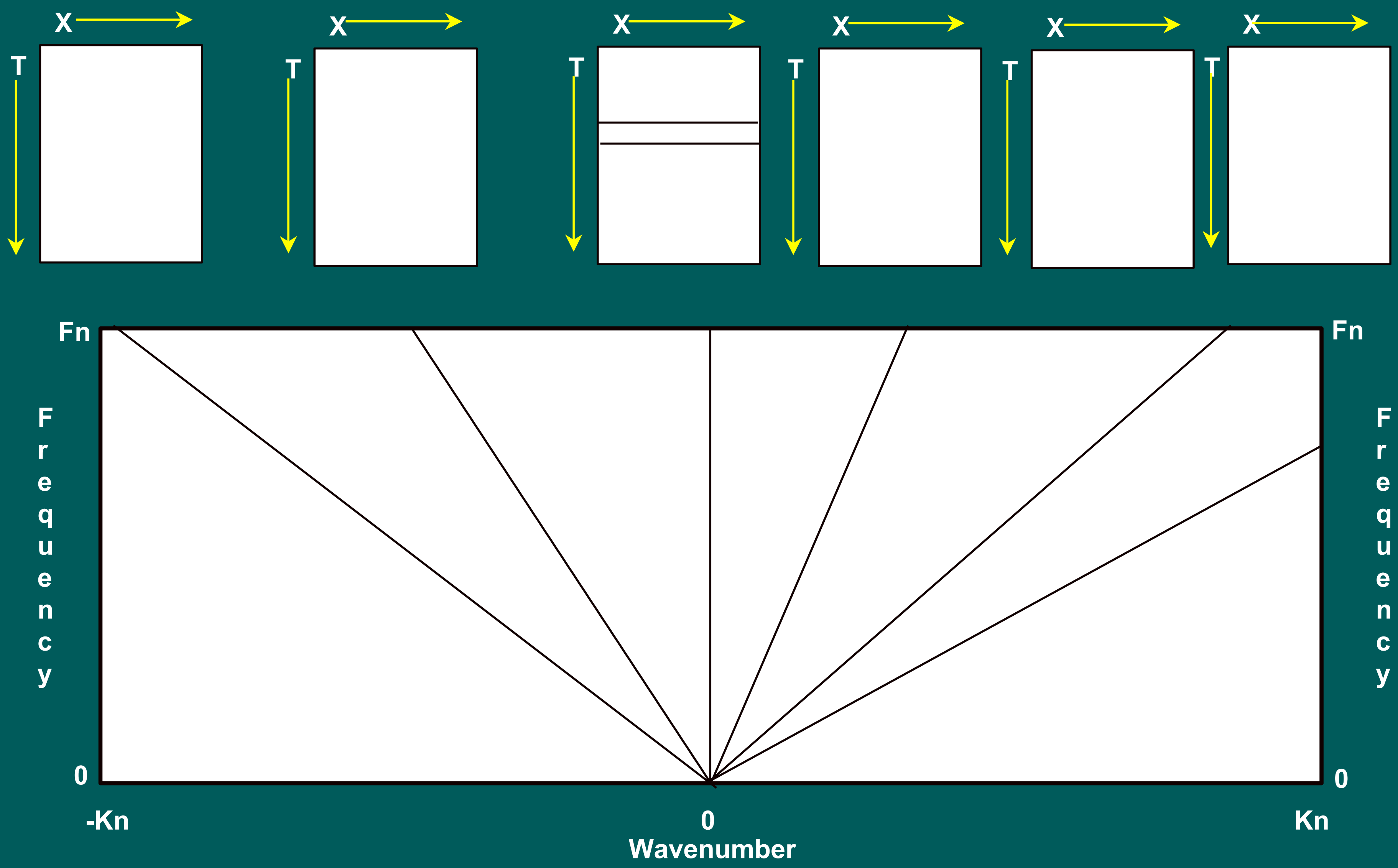


Data aliasing - 2: constant sampling

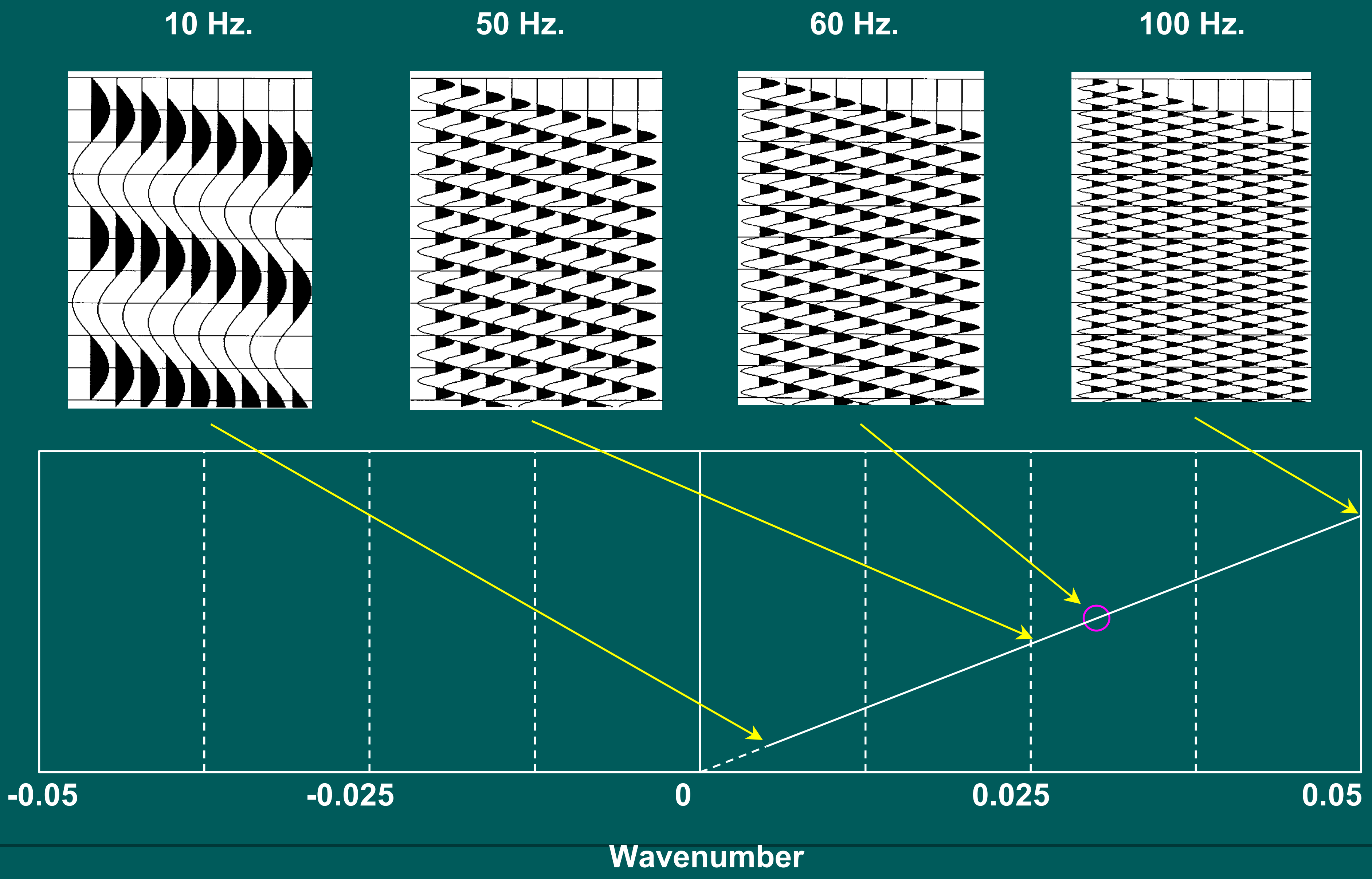
Spatial Aliasing

- **Until sampled, the seismic wavefield is not aliased**
  - noise
  - signal
- **Spatial aliasing occurs when wavefield is sampled with fewer than 2 samples per wavelength**
  - frequency dependant
  - dip dependant
- **Spatial aliasing causes apparent dips which are incorrect**
  - may be incorrect sign (ie. appear to dip in opposite direction)
  - frequency dependant
  - dip dependant
- **The steeper the dip, the lower the frequency at which aliasing occurs for a given spatial sampling interval**

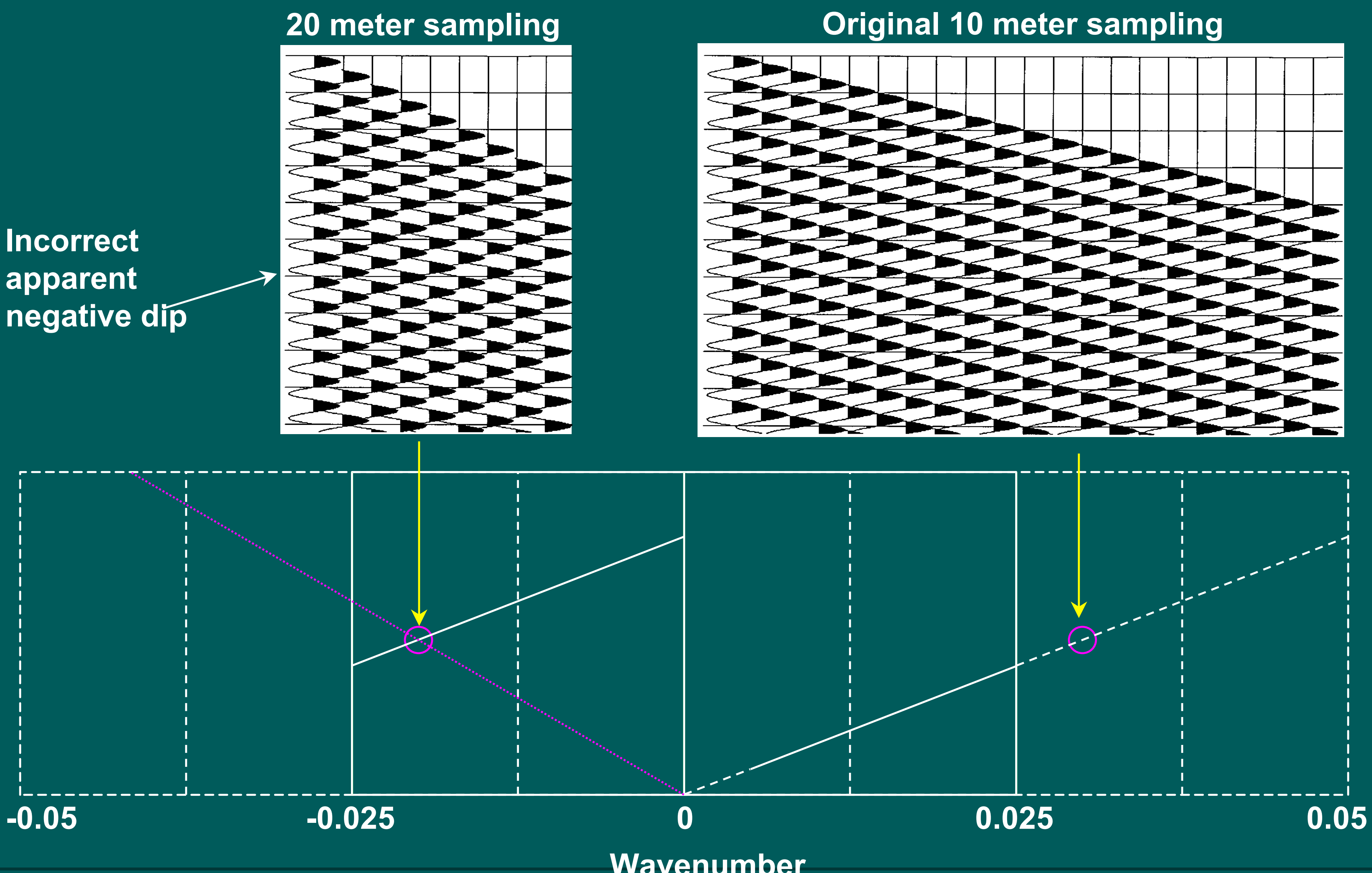
F-K domain vs T-X domain



Spatial Aliasing - 10 meter Sampling

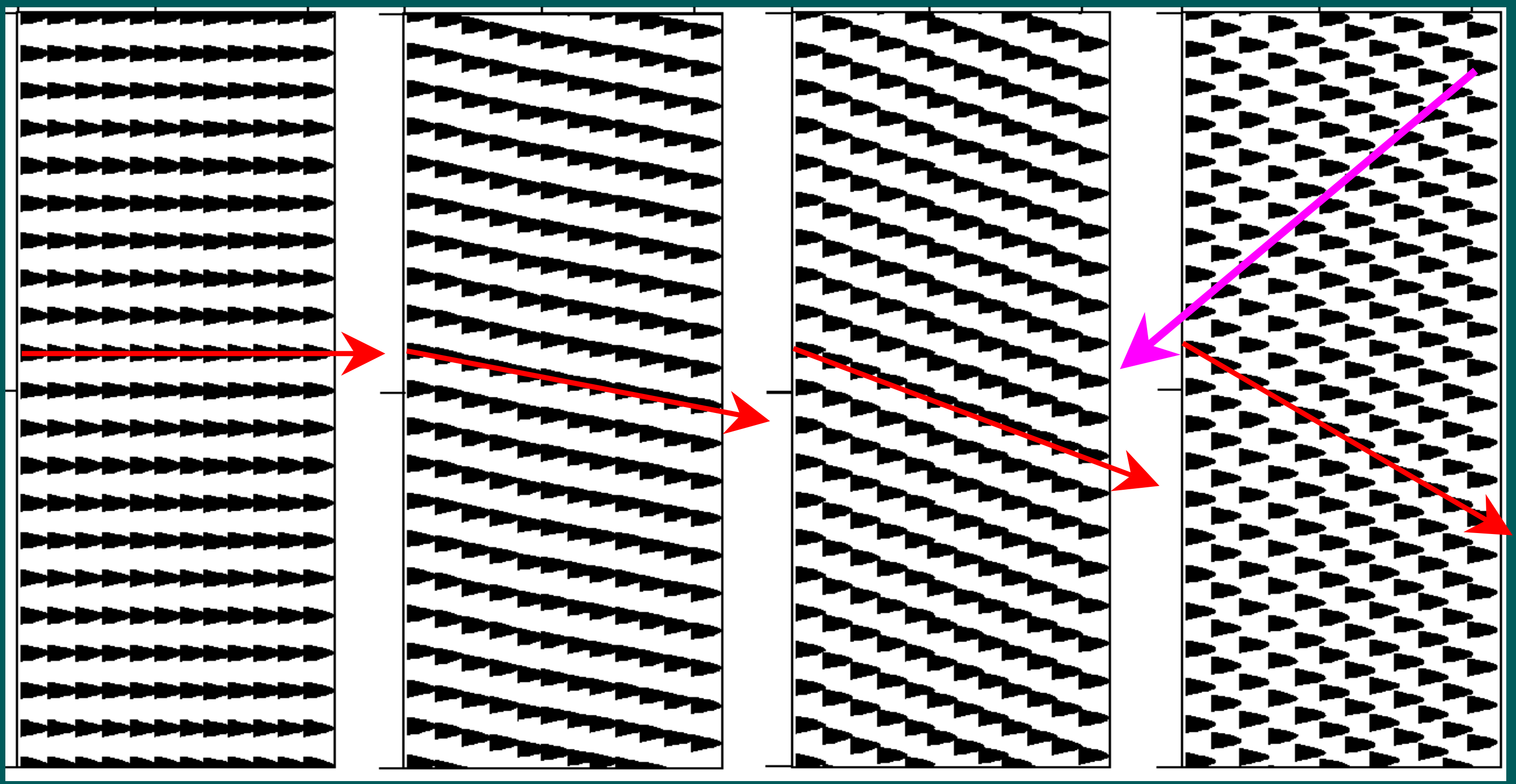


Spatial Aliasing - 20 meter Sampling at 60 Hz



Spatial Aliasing

50 m. trace separation   1500m/s. velocity

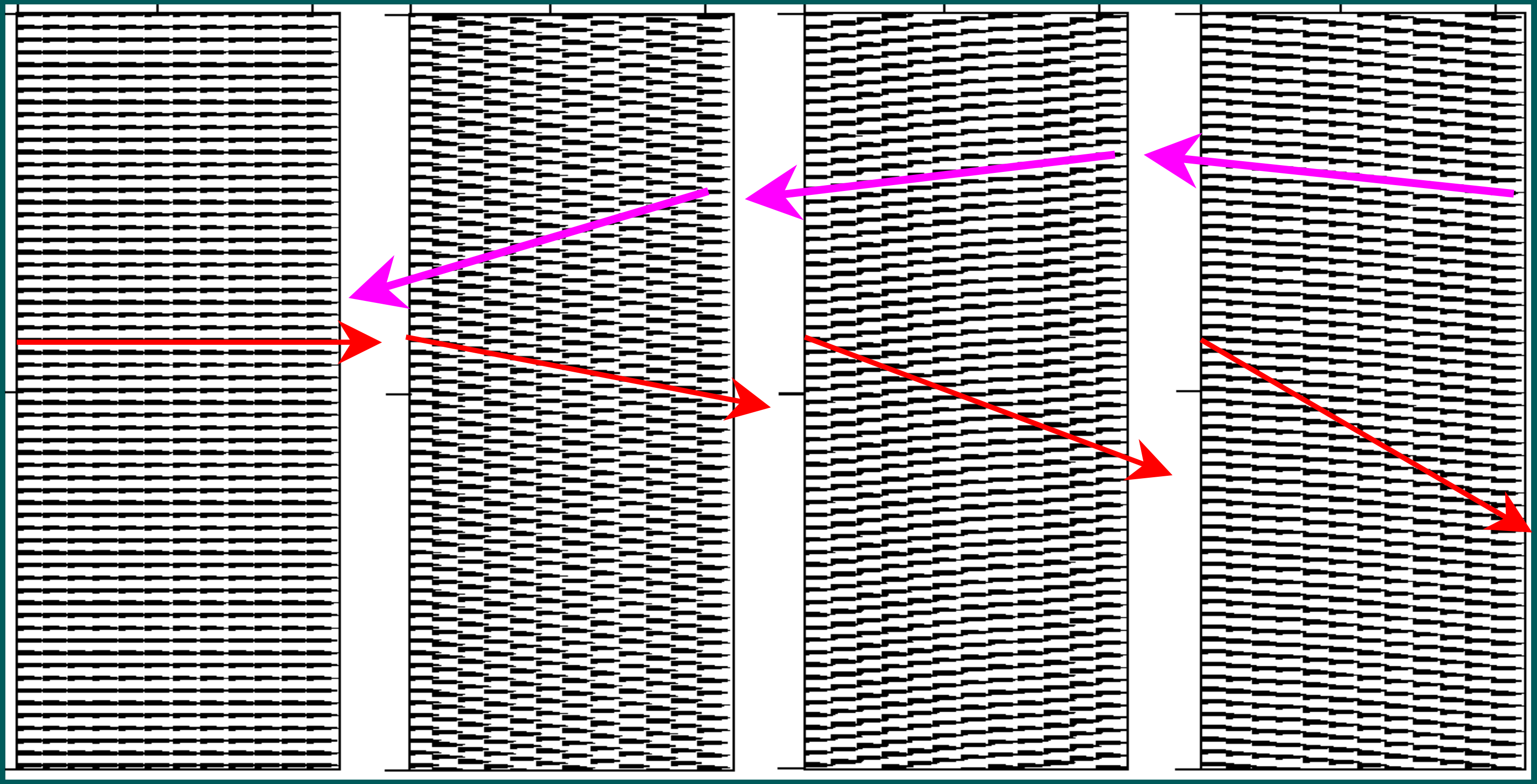


0^0 dip 10^0 dip 20^0 dip 30^0 dip

Constant frequency = 20hz.

Spatial Aliasing

50 m. trace separation   1500m/s. velocity



0⁰ dip **10⁰ dip** **20⁰ dip** **30⁰ dip**

Constant frequency = 60hz.

Spatial Sampling from Straight Ray Calculations

❖ Spatial Sampling Calculations

- Subsurface spatial sampling interval as a function of dip and required high frequency

$$dX = \frac{V}{4 * F_m * \sin\phi} \quad \text{for Nyquist sampling}$$

$$dX = \frac{V}{2 * m * F_m * \sin\phi} \quad \text{for m samples per wavelength}$$

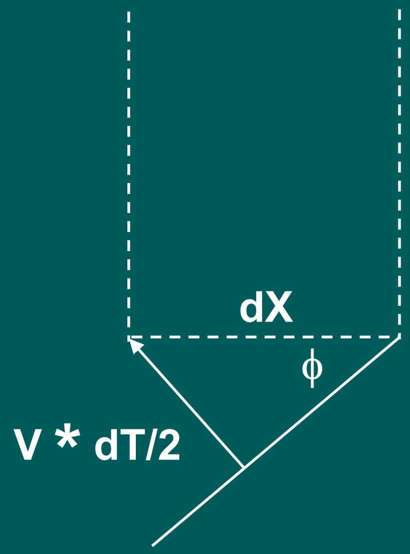
❖ If unmigrated data are used for measuring dips

- No need to calculate dip angle

New sampling interval $dX_{new} = \frac{(dX/dT)_{old}}{m * F_m}$

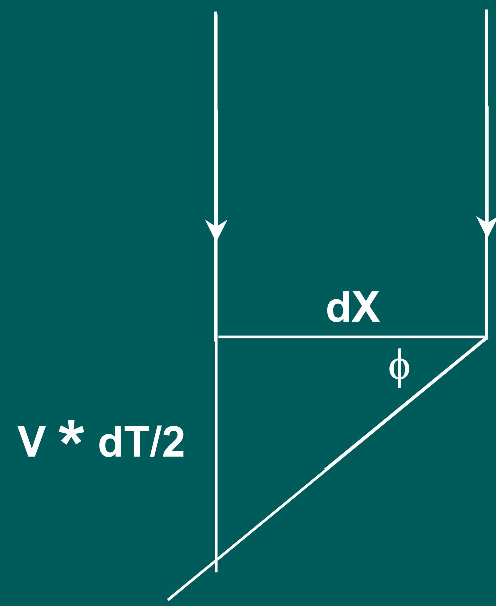
Straight Raypath Dip Equations

Unmigrated data



$$\sin \phi = \frac{V * dT}{2 * dX}$$

Migrated data



$$\tan \phi = \frac{V * dT}{2 * dX}$$

where V = Vrms at target (metres / second)
dT = 2-way time dip (seconds / trace)
dX = subsurface trace sampling interval (metres)

Spatial Sampling – Unmigrated 2D Data

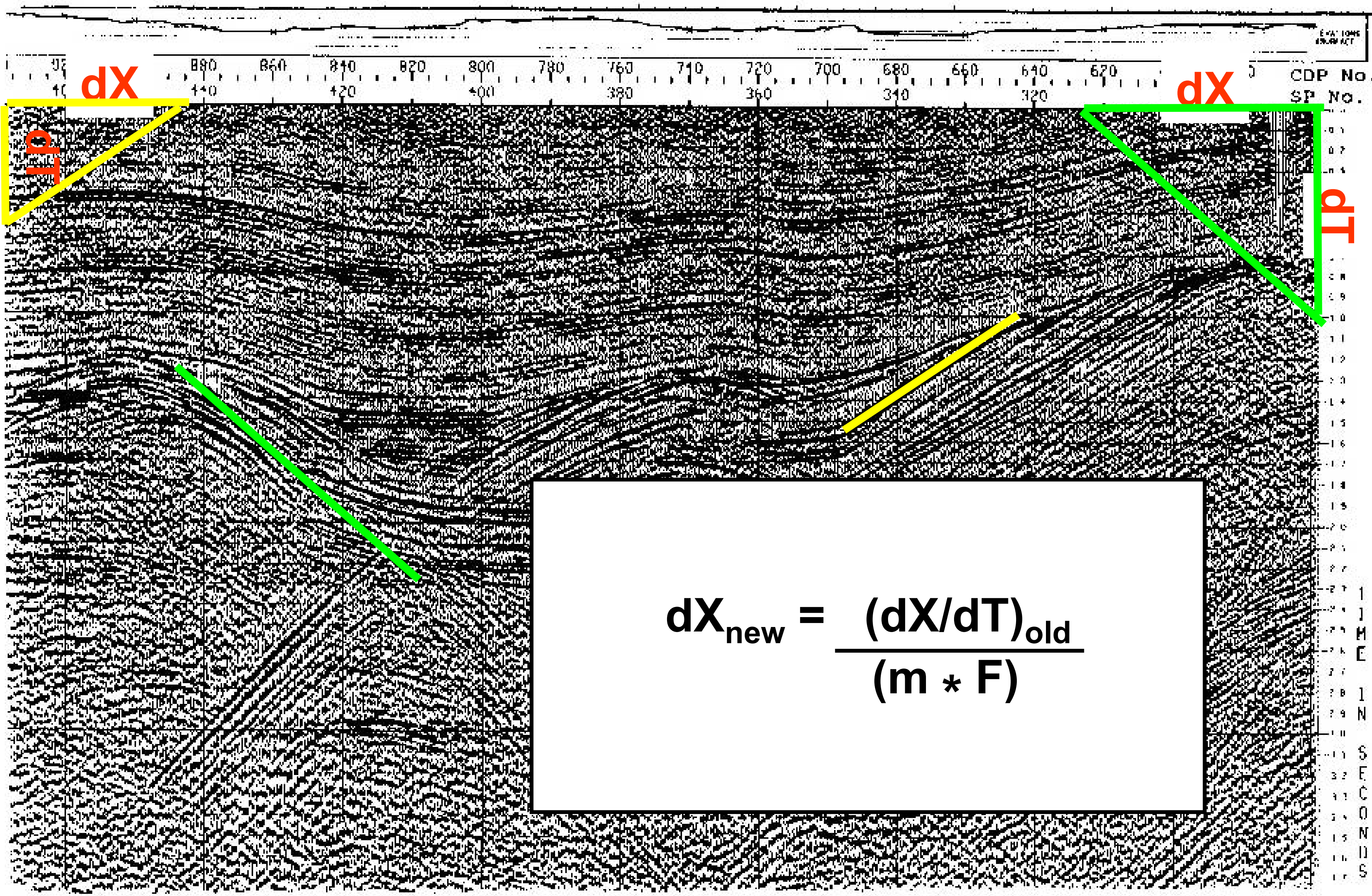
$$dX = \frac{V}{2 * m * F_m * \sin\phi}$$

$$\sin\phi = \frac{V * dT}{2 * dX}$$

Using unmigrated data

$$dX_{new} = \frac{(dX/dT)_{old}}{(m * F_m)}$$

Unmigrated Section



$$dX_{new} = \frac{(dX/dT)_{old}}{(m * F)}$$

Sample spreadsheet for aliasing frequency dX vs Frequency

3D Survey Parameterisation

RMS velocity (ft/sec or m/sec)=	2500	No. of samples per wavelength=	2
2-way time (in msecs)=	2700		
Minimum dip (in degrees)=	20	Dip increment=	5
Minimum subsurface interval=	5	Sample interval increment=	2.5

Dip----->	20	25	30	35	40	45	50
Sample. Interval	<--------------Frequency supported at			2 samples per wavelength------------->			
5	365	296	250	218	194	177	163
7.5	244	197	167	145	130	118	109
10	183	148	125	109	97	88	82
12.5	146	118	100	87	78	71	65
15	122	99	83	73	65	59	54
17.5	104	85	71	62	56	51	47
20	91	74	63	54	49	44	41
22.5	81	66	56	48	43	39	36
25	73	59	50	44	39	35	33
27.5	66	54	45	40	35	32	30
30	61	49	42	36	32	29	27
32.5	56	46	38	34	30	27	25

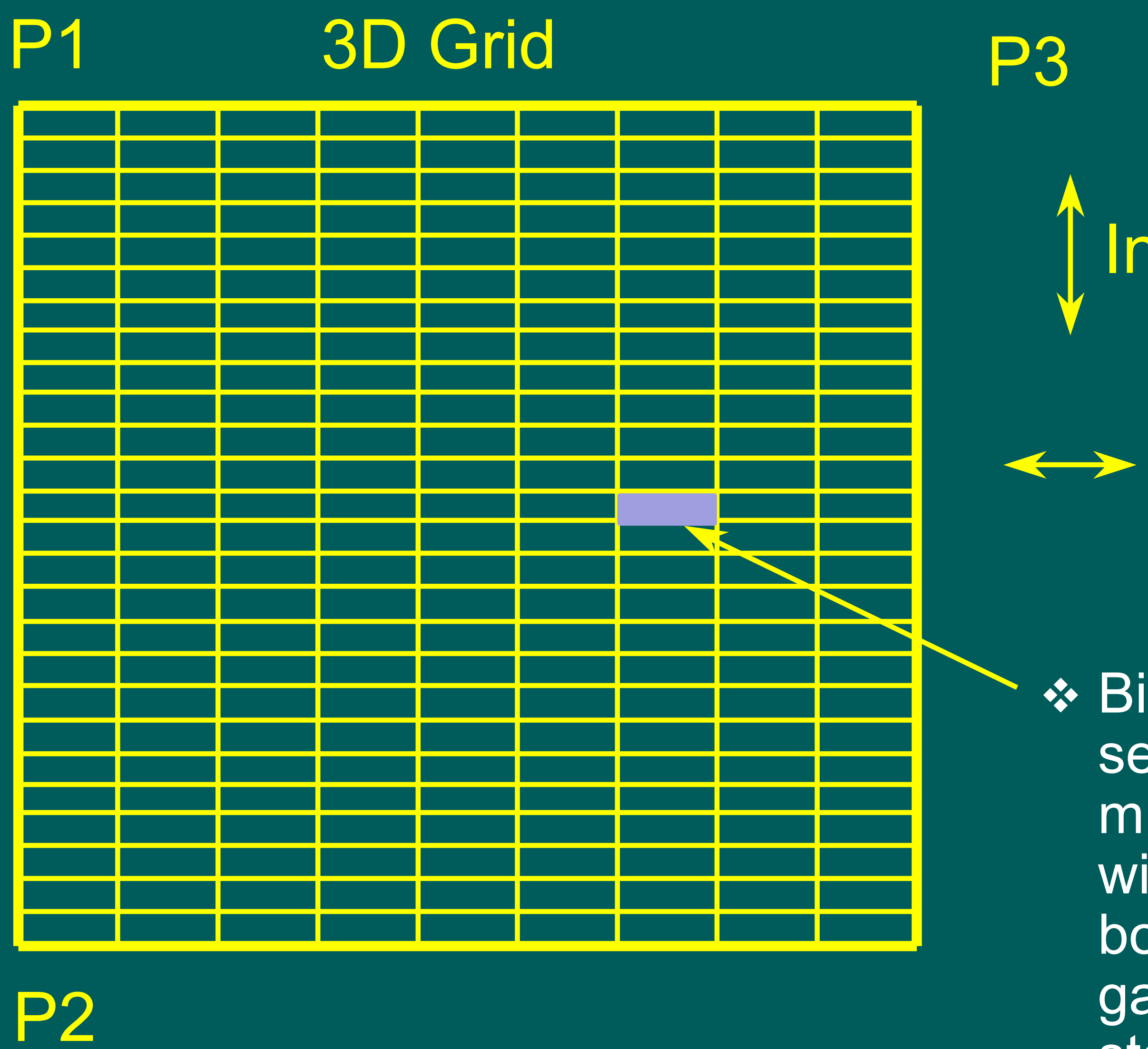
Sample spreadsheet for spatial sampling Frequency vs dX

3D Survey Parameterisation

RMS velocity (ft/sec or m/sec)= 2500 No. of samples per wavelength= 2
2-way time (in msecs)= 2700
Minimum dip (in degrees)= 20 Dip increment= 5
Minimum frequency= 30 Frequency increment= 5

Dip----->	20	25	30	35	40	45	50
Frequency	<-----------------Sampling required at			2 samples per wavelength------------->			
30	61	49	42	36	32	29	27
35	52	42	36	31	28	25	23
40	46	37	31	27	24	22	20
45	41	33	28	24	22	20	18
50	37	30	25	22	19	18	16
55	33	27	23	20	18	16	15
60	30	25	21	18	16	15	14
65	28	23	19	17	15	14	13
70	26	21	18	16	14	13	12
75	24	20	17	15	13	12	11
80	23	18	16	14	12	11	10
85	21	17	15	13	11	10	10

Spatial Sampling - 3D Grid Definition



- Bin or grid cell: seismic traces with midpoints that fall within the bin boundaries are gathered for CMP stacking

Spatial Sampling – Source / Streamer Geometry

- **Inline Sampling = ½ of the Group Interval**
  - Most streamers have 12.5 m interval = 6.25m CMP
- **Crossline Sampling = ½ of Streamer Separation per Source**
  - Conventional CMP Line Spacing = 25m to 50m
  - "High" Resolution CMP Line Spacing = 12.5m to 18.75m

The cost of the survey is greatly influenced by the required crossline sampling

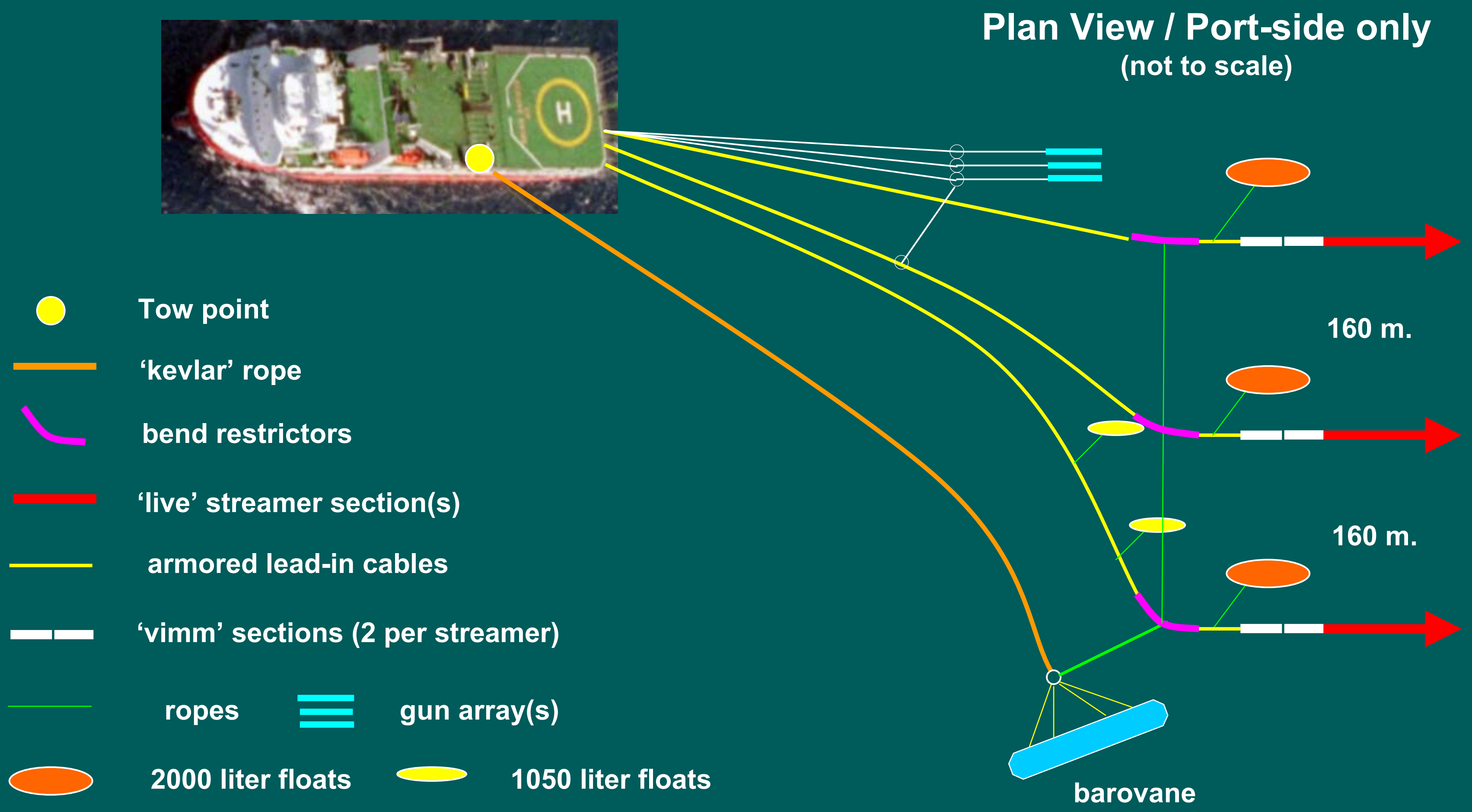
Multiple Source and Multiple Streamer Acquisition Configurations

- **For almost all current marine 3D surveys multiple subsurface lines are routinely recorded for each vessel traverse**

- **Three factors have been major incentives:**
  - Requirements for reduced overall survey costs
  - Requirements for reduced survey turnaround time
  - Requirements for denser spatial sampling

- **Technological advancements:**
  - Larger seismic vessels (so-called "super ships")
  - Increased compressor capacity
  - Better airgun arrays
  - Larger channel capacity recording systems
  - Navigation and positioning improvements (networks)
  - High efficiency diverters (paravanes, etc.)

LAYOUT



Veritas Viking - I : generic layout (Keathley Canyon 2001)

Multiple Source and Streamer Acquisition Relative Production Rates

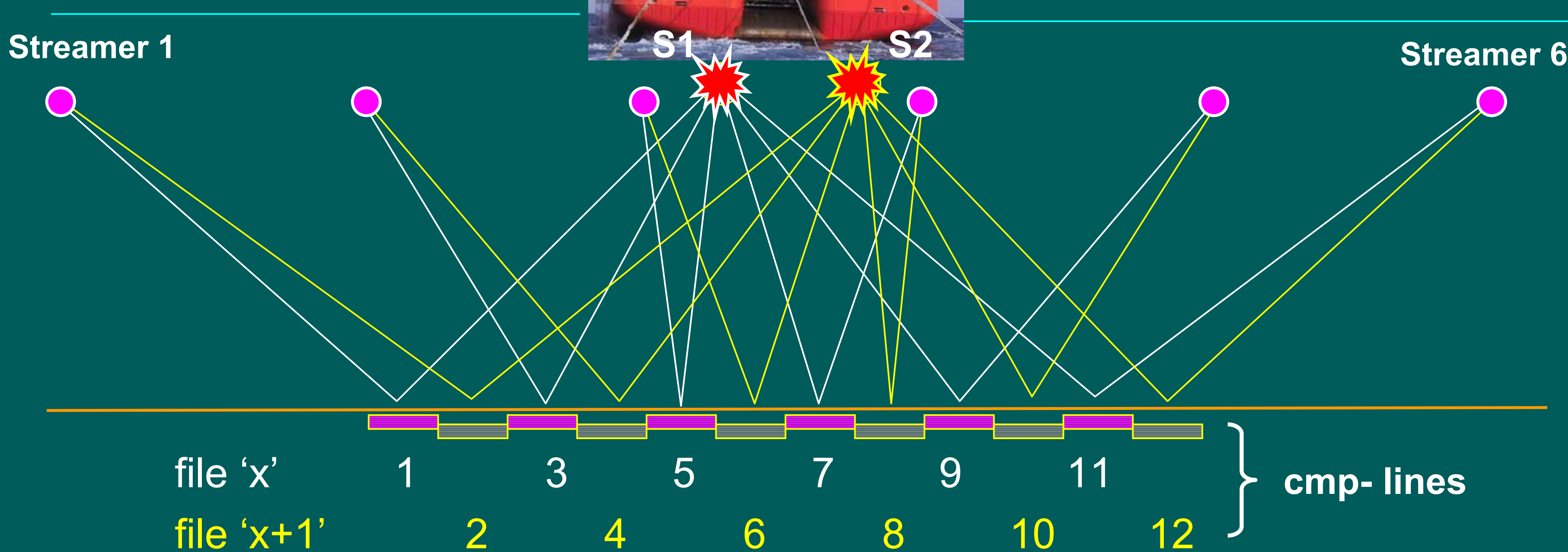
Acquisition Configuration	Subsurface Lines per Vessel Pass	Boat Track Km/Month	Subsurface Km/Month
1C - 1S	1	4800	4800
2C - 1S	2	4050	8100
2C - 2S	4	3750	15000
3C - 2S	6	3000	18000
4C - 2S	8	2750	22000
6C - 2S	12	2500	30000
12C - 1S	12	2250	27000

Source and streamer spacing can be varied to achieve required subsurface line spacing

MARINE LAYOUT

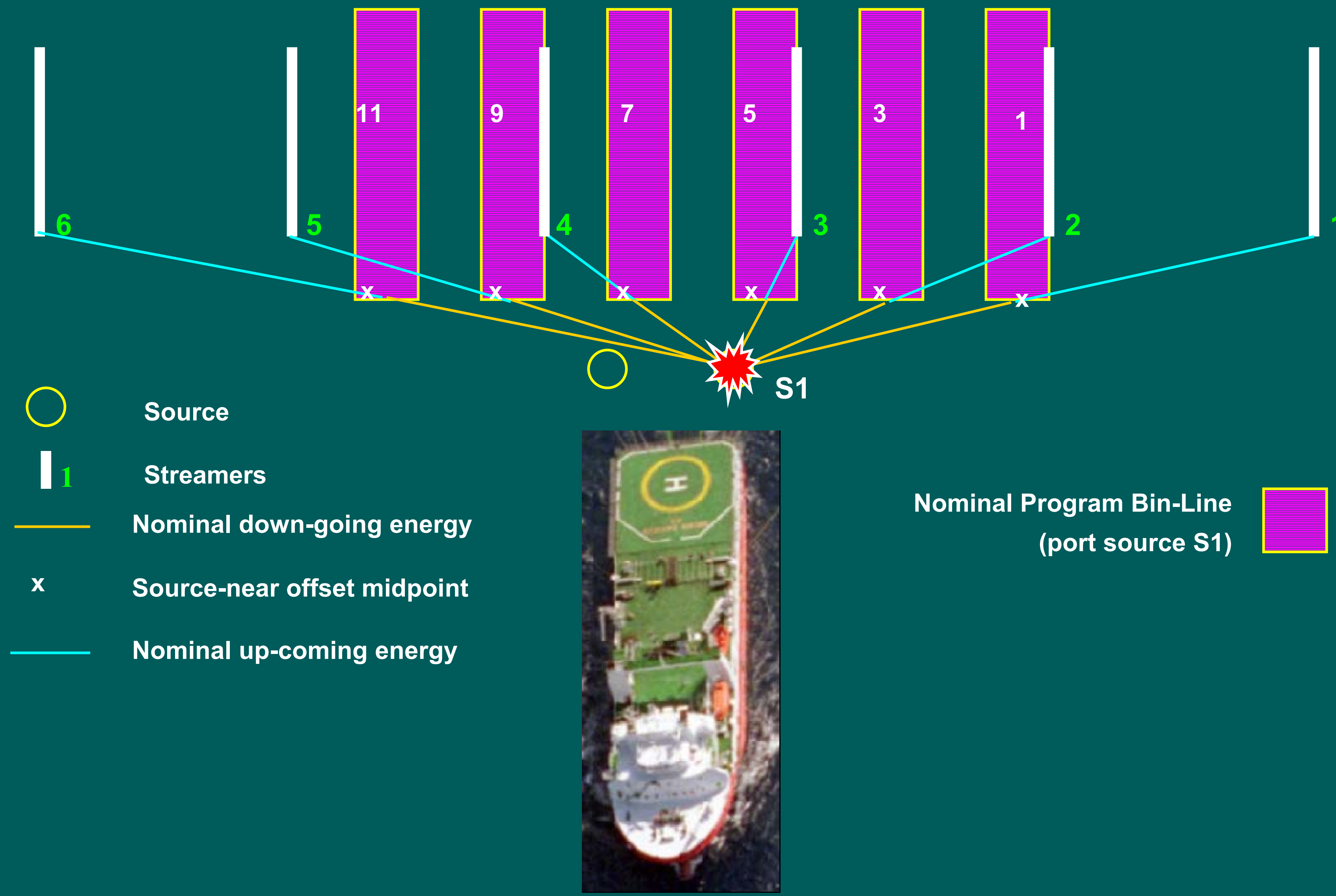
Alternating sources:
25 meters downline
@ 10 sec. interval

Six streamers:
6000meters length
@ 480 channels



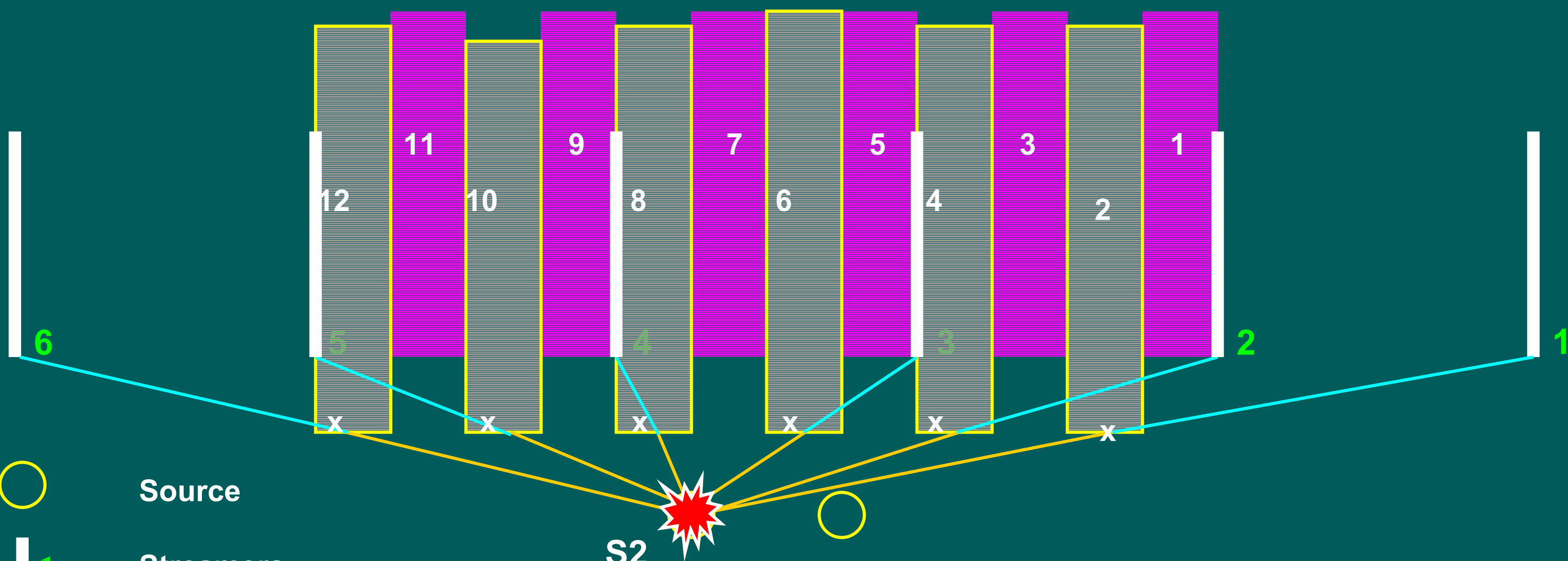
Dual Source + 6 Streamers = 12 cmp lines

Marine 3D CMP Lines



Dual Source + 6 Streamers

Marine 3D CMP Lines



Source

Streamers

Nominal down-going energy

x Source-near offset midpoint

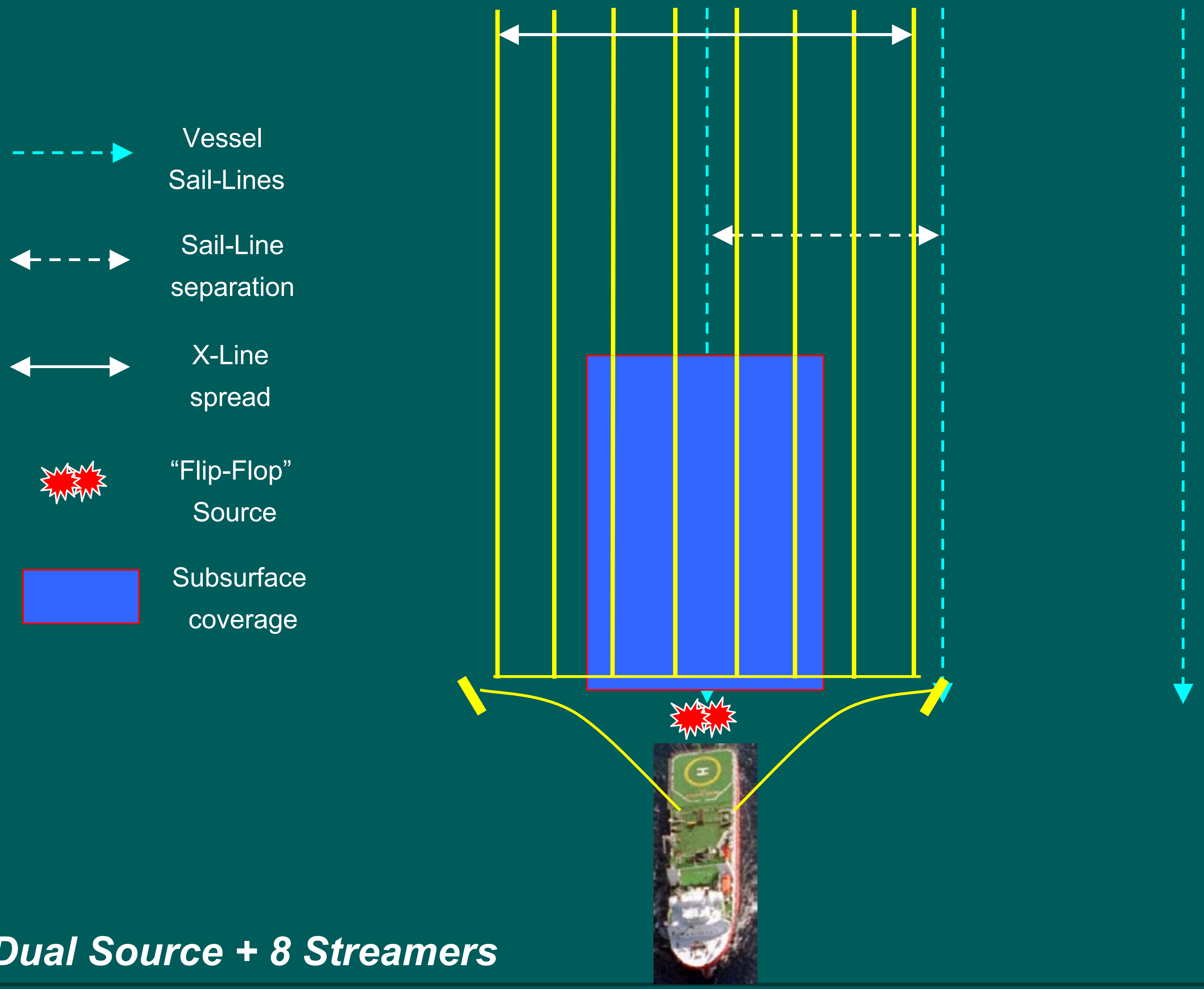
Nominal up-coming energy

Nominal Program Bin-Line (port source S1)

Nominal Program Bin-Line (starboard source S2)

Dual Source + 6 Streamers

LAYOUT



Dual Source + 8 Streamers

LAYOUT

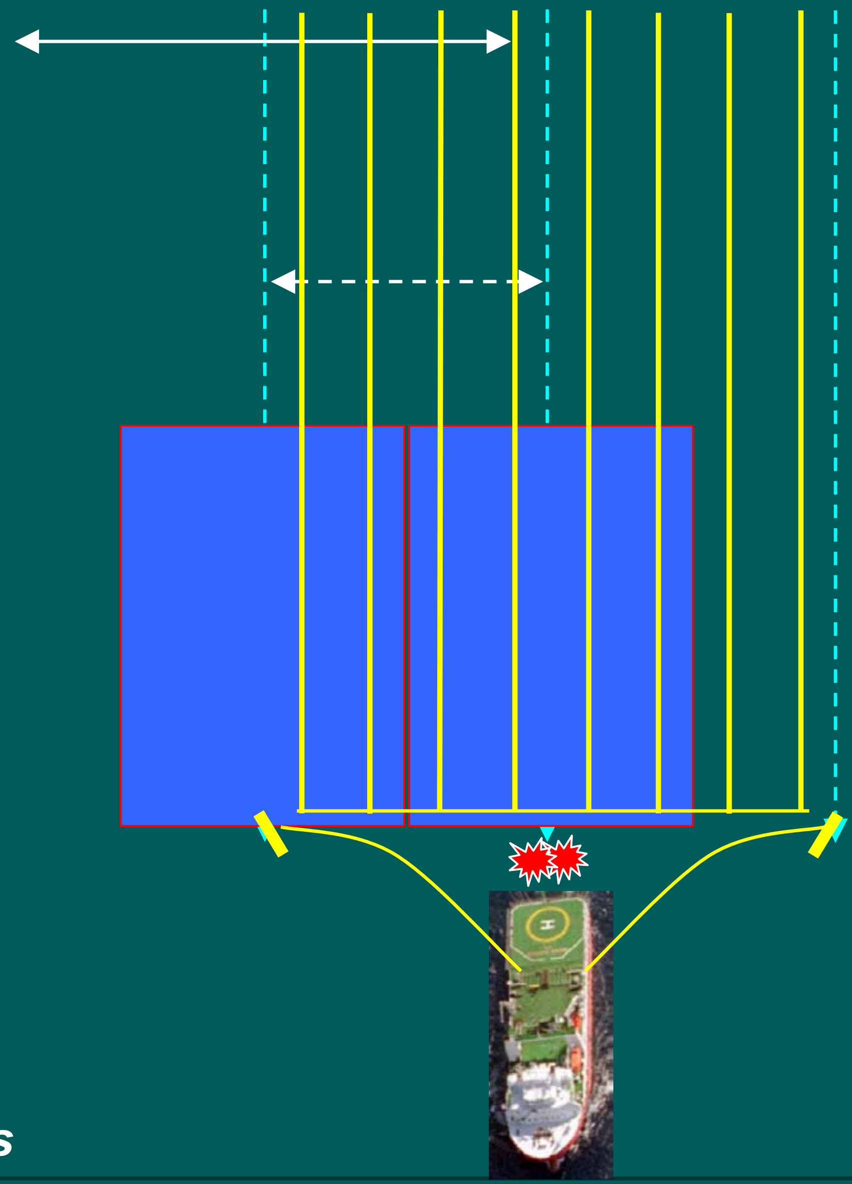
Vessel Sail-Lines

Sail-Line separation

X-Line spread

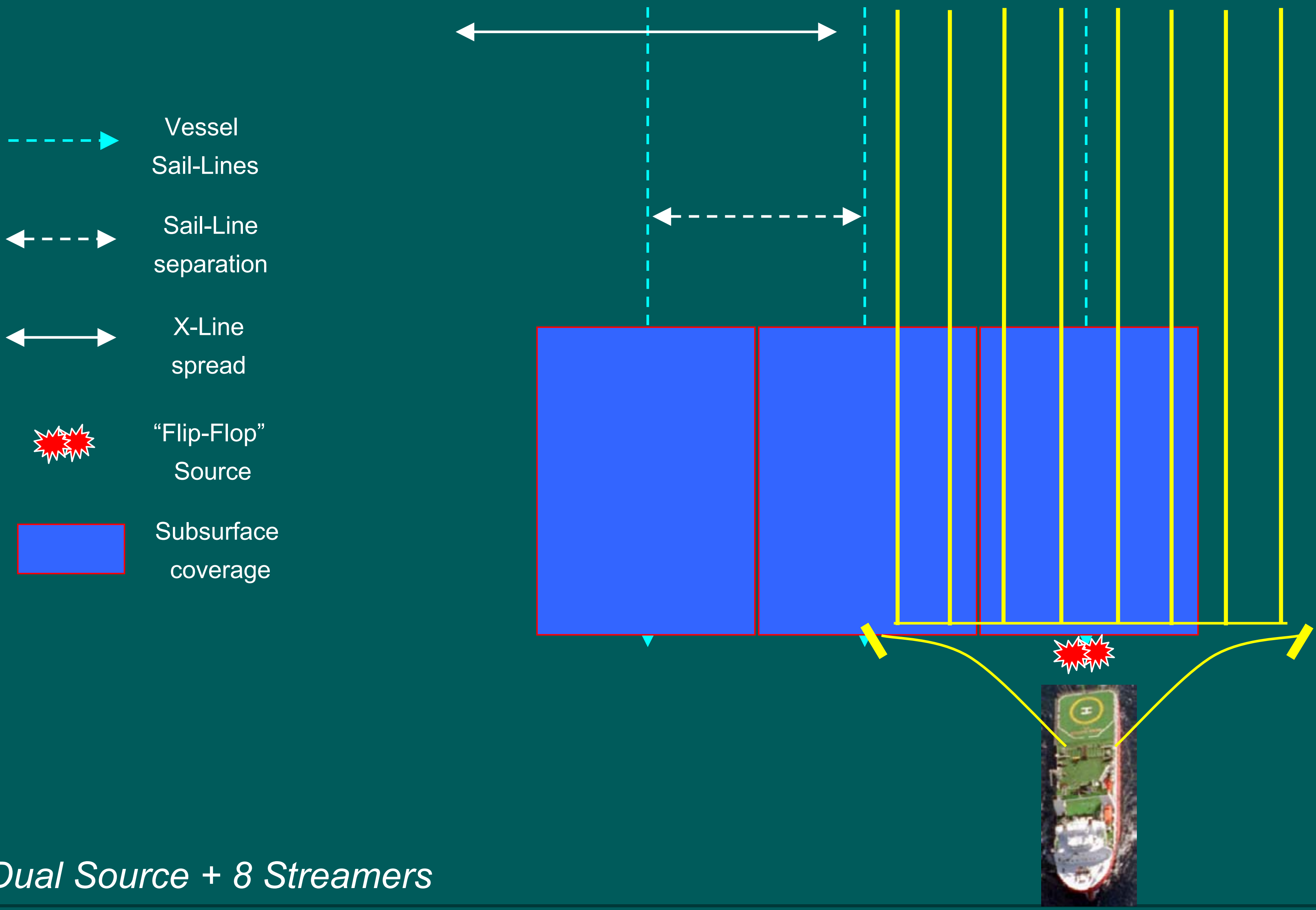
"Flip-Flop" Source

Subsurface coverage



Dual Source + 8 Streamers

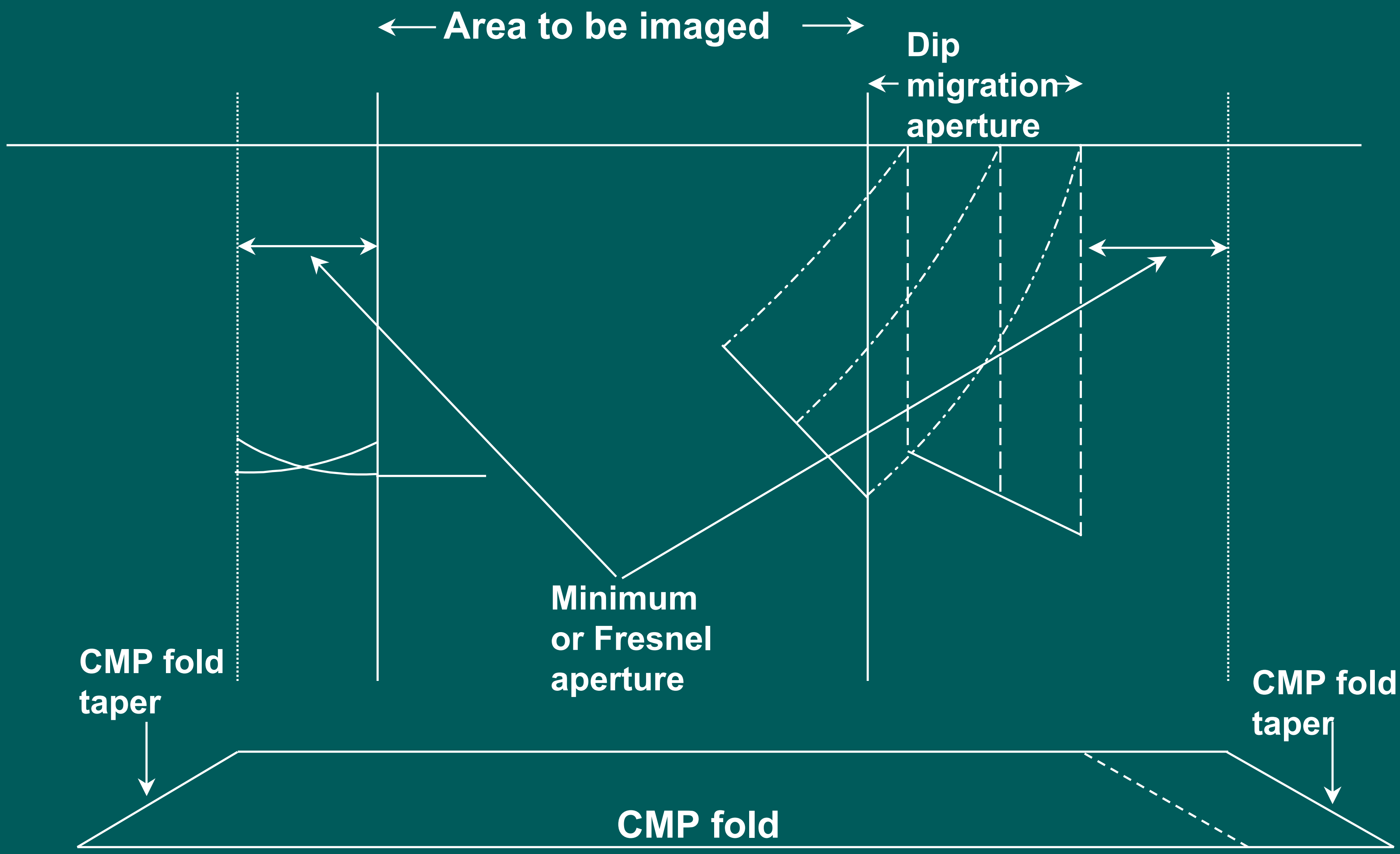
LAYOUT



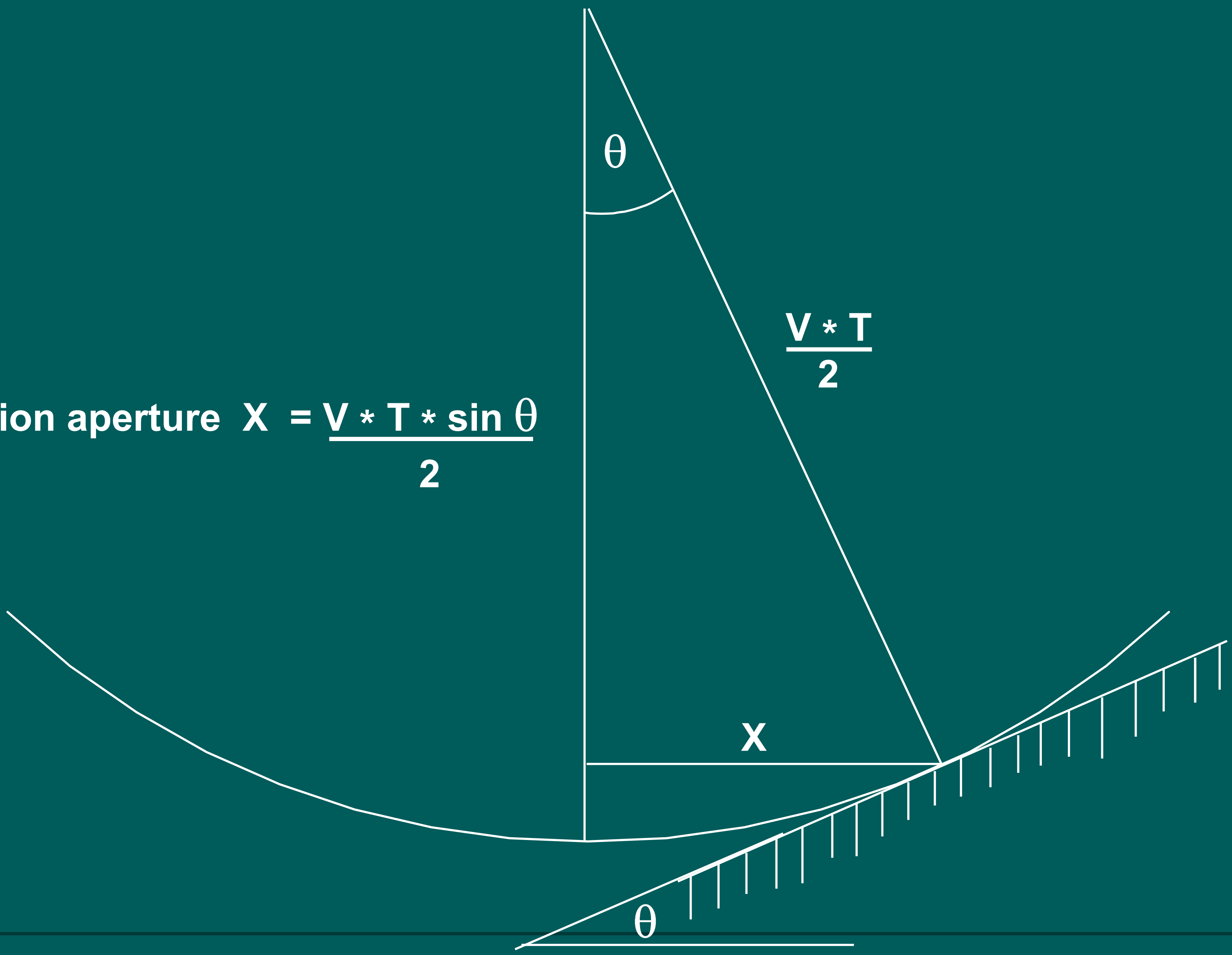
Dual Source + 8 Streamers

Survey Area

Image Apertures



Migration aperture defined by dips
Constant velocity / straight raypaths



Migration aperture X $= \frac{V * T * \sin\theta}{2}$

Migration aperture defined by dips
Straight raypath example

For typical Gulf of Mexico velocity function

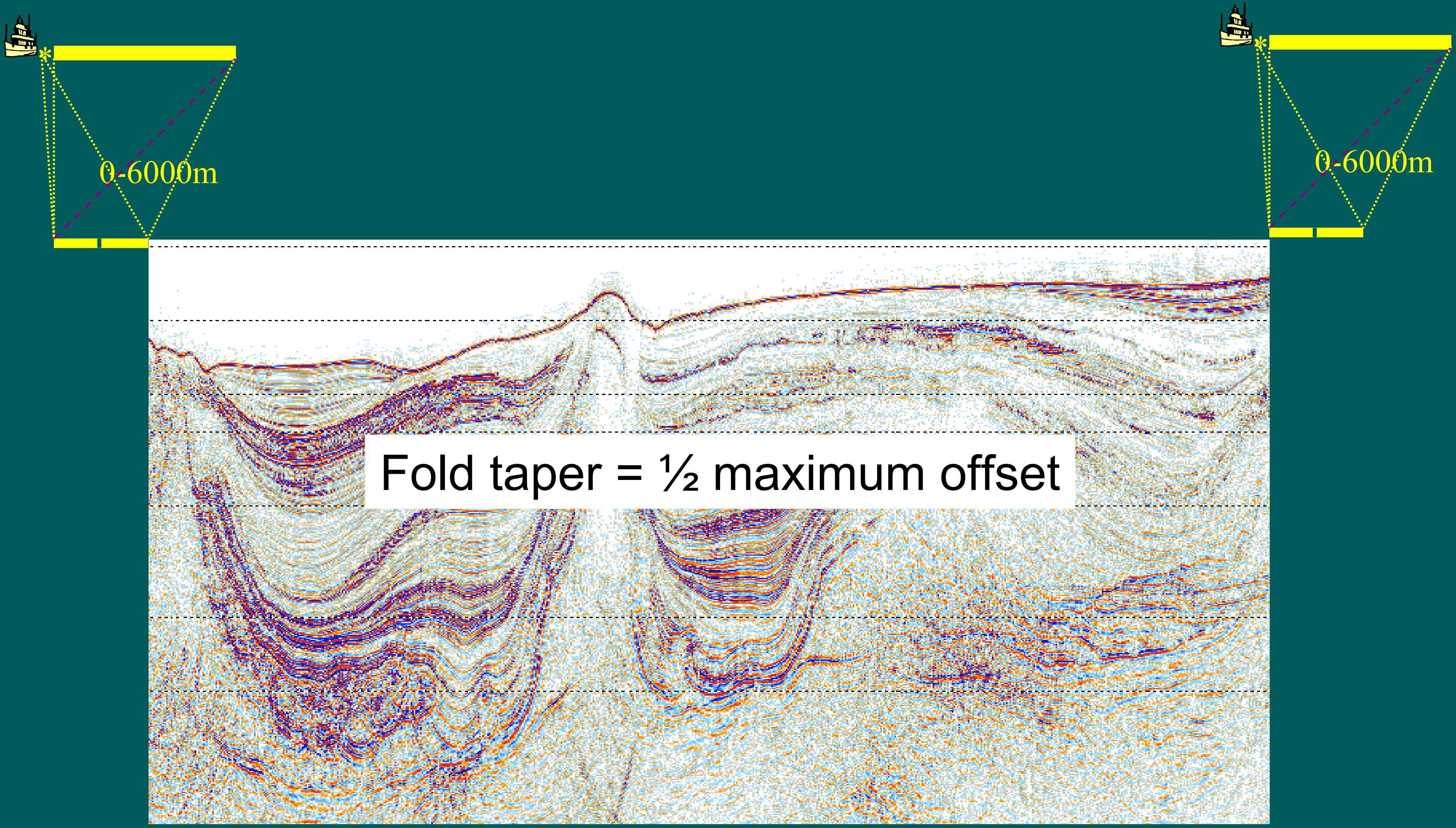
$$V = 1500 + 0.6 Z$$

V_{rms}	T_0	15	30	45	60	75	90
		(<--------------- dip in degrees					-------------------->)
		(<--------migration aperture in metres					----------->)
1756	1.000	227	439	621	760	848	878
1910	1.500	371	716	1013	1241	1384	1433
2086	2.000	540	1043	1475	1807	2015	2086
2285	2.500	739	1428	2020	2474	2759	2856
2512	3.000	975	1884	2664	3263	3640	3768

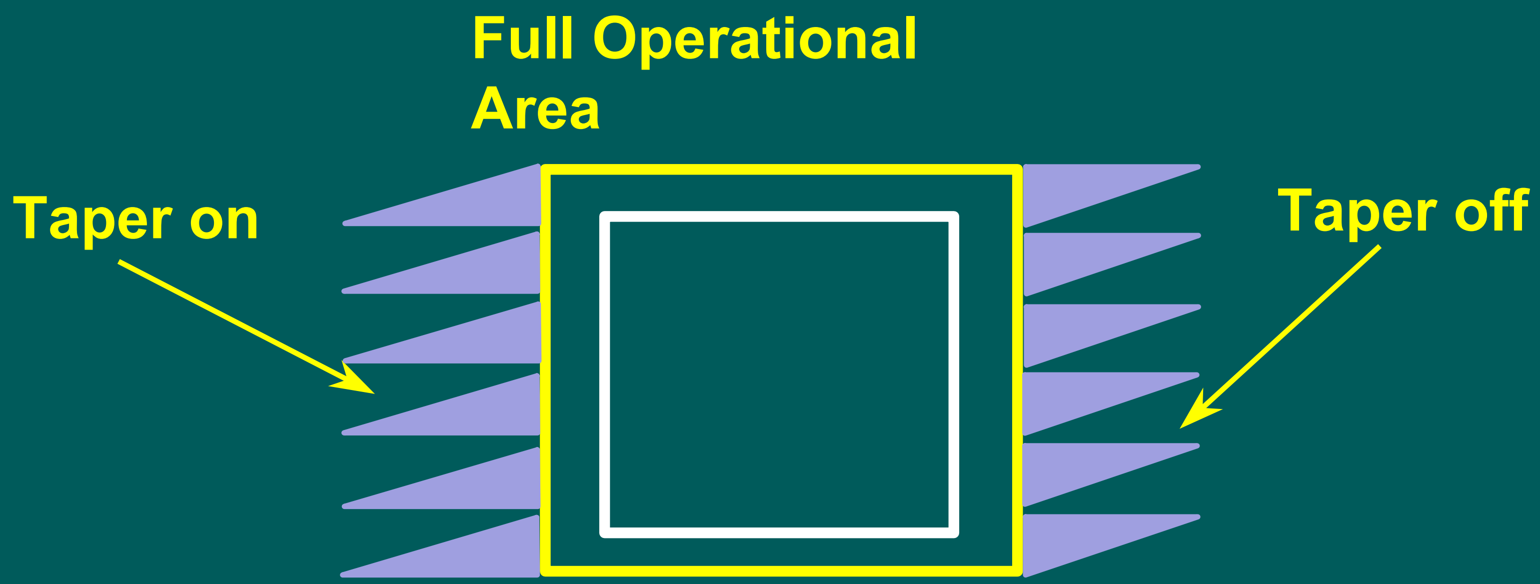
Diffraction energy

- According to Claerbout (Imaging the Earth's Interior)
  - Approximately 70% of diffraction energy is within the Fresnel Zone
  - Migration is focussing/collapsing data within the Fresnel Zone
  - Diffraction energy within the Fresnel Zone must be adequately sampled
  - Dip of diffraction energy at edge of Fresnel Zone is approximately 15 degrees
- For adequate spatial sampling
  - Always consider minimum dip to be not less than 15 degrees
- Some people consider minimum dip to be not less than 30 degrees
  - Approximately 95% of diffraction energy is within 30 degree range

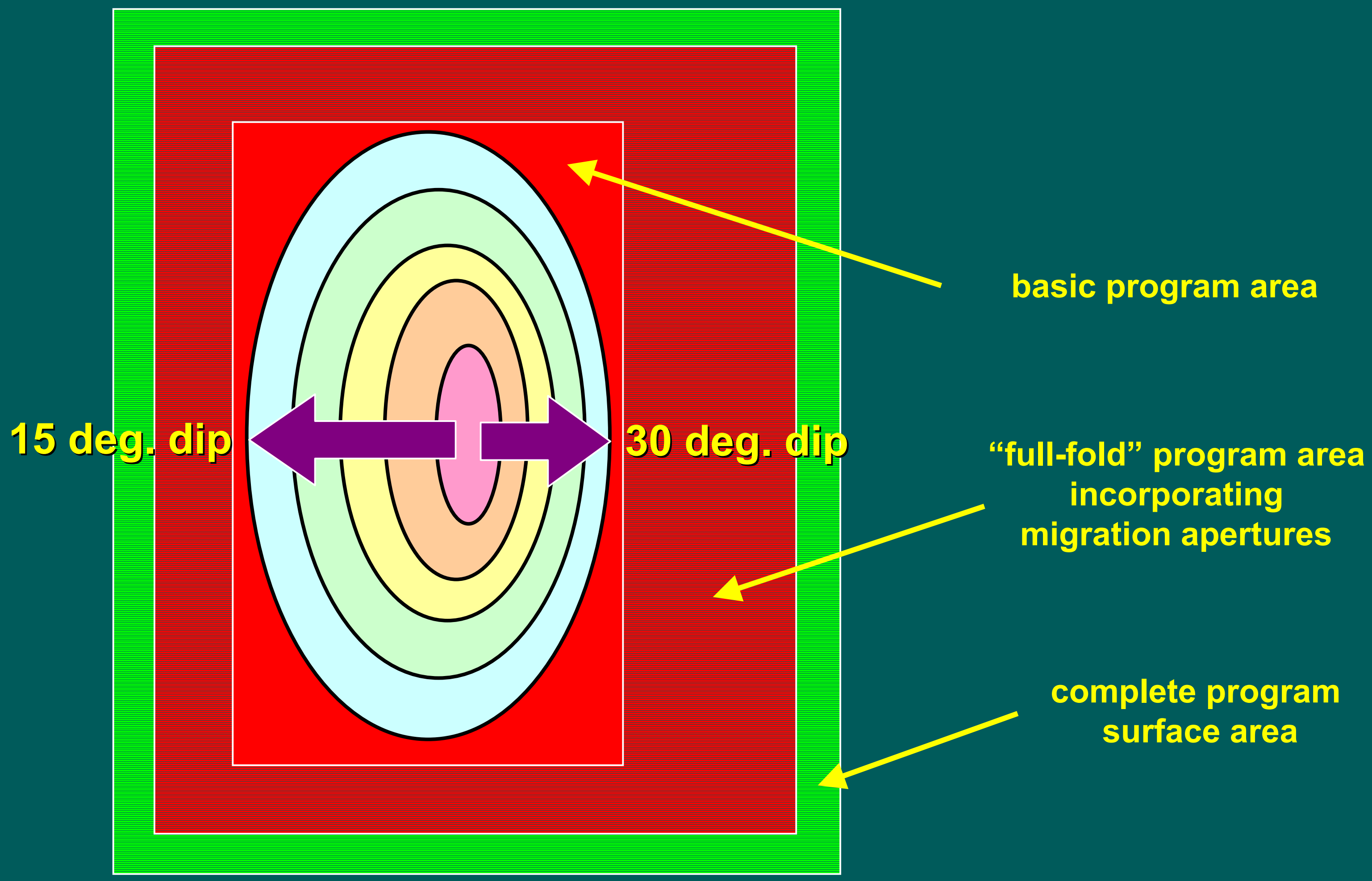
Fold Taper



Taper On and Taper Off:
Impact on Survey Size



Survey Surface Area



Migration - 9: Migration Aperture/ “fringe” - 3D case

The Concept of Fold

"Fold" refers to the number of traces collected at each CMP location.

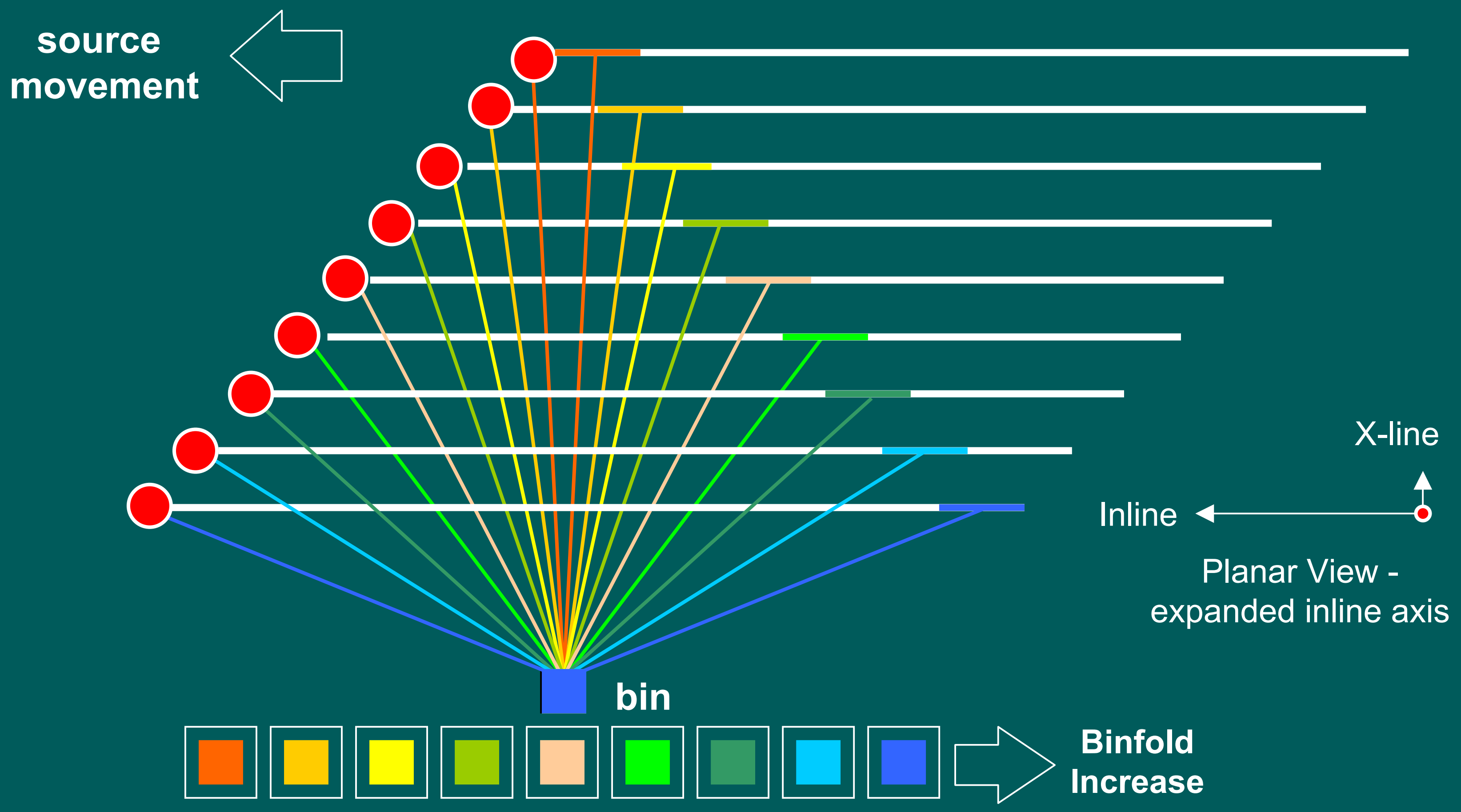
In the strictest sense "Full Fold" refers to a CMP containing a trace from each receiver group in the streamer cable.

In order to achieve full fold the shot point interval has to be ½ the group interval.

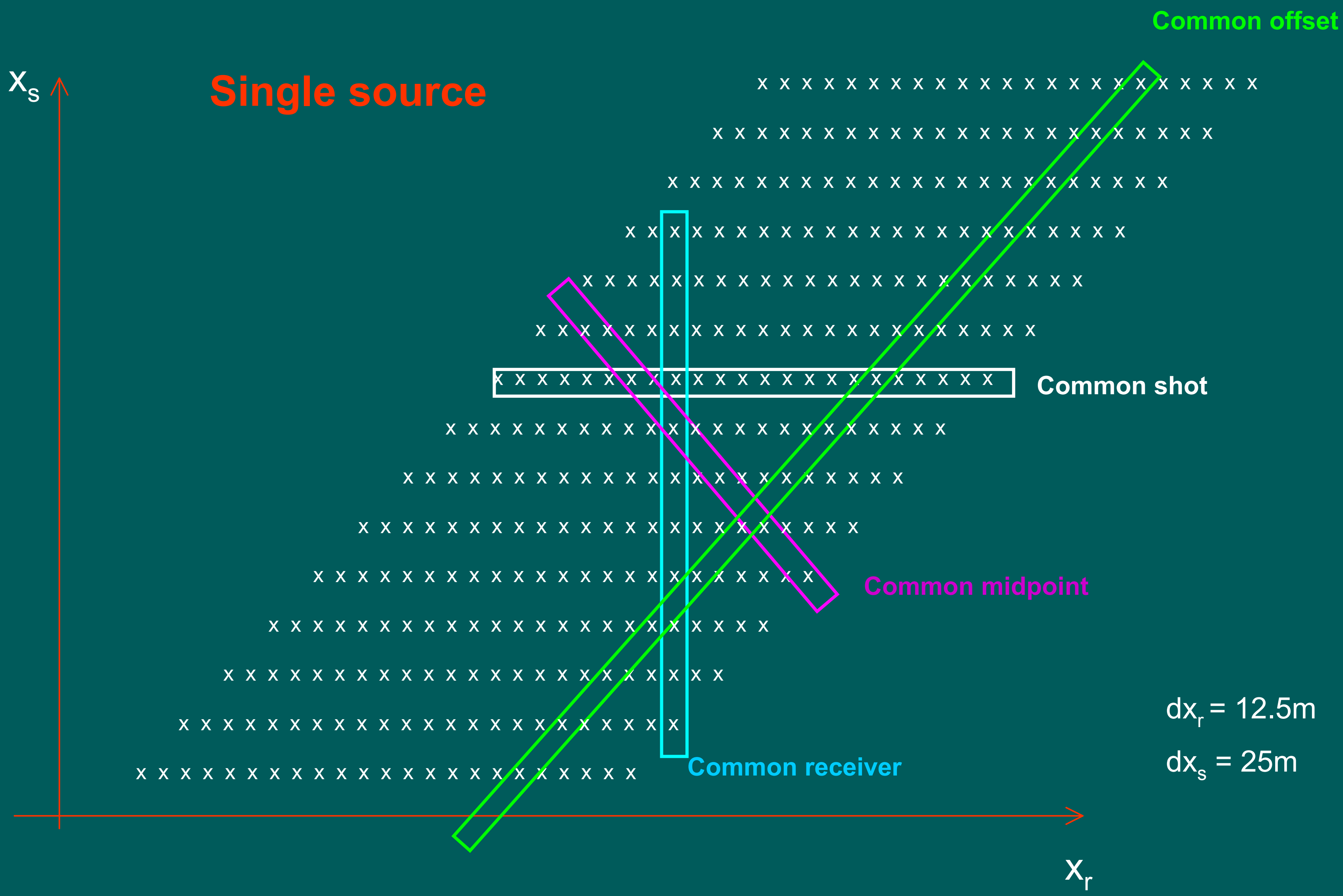
Therefore if the shot point interval equals:

Multiple of Group Interval	Effective Fold
1	1/2
2	1/4
3	1/6
4	1/8
n	1/(2*n)

Bin Fold


source
movement
bin
X-line
Inline
Planar View -
expanded inline axis
Binfold
Increase

Pre-stack sampling



Vessel Speed and Record Length

- **Computation for record length is: R = (SI / V) - O**
  - R is the maximum record length in seconds
  - SI is the shot interval in meters
  - V is the OTG vessel speed in meters/second
  - O is the recording system overhead in seconds

Example

SI = 25m

V= 2.5 m/s

O = 0.75 s

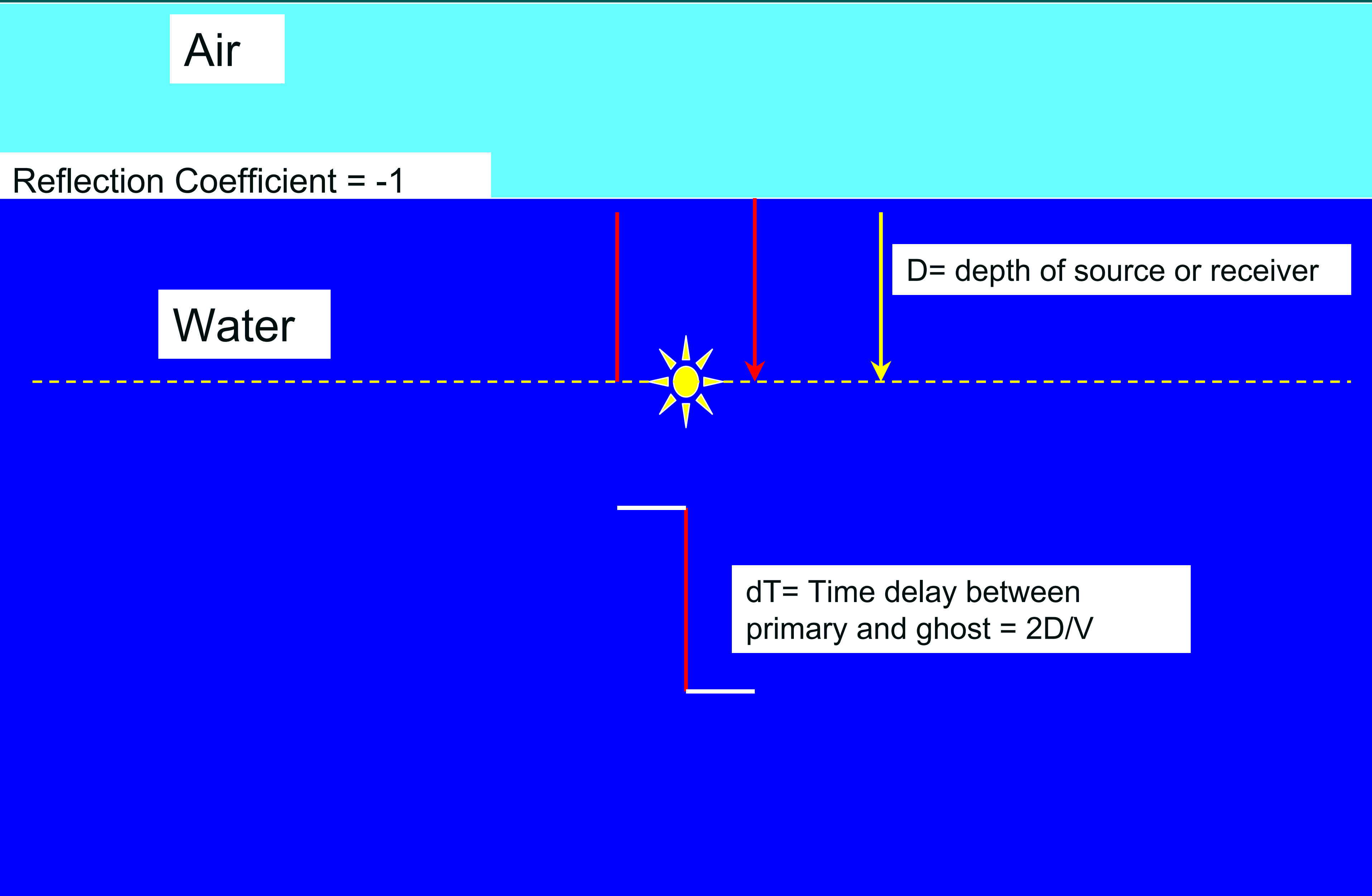
R= (25m / 2.5m/s)-0.75s = 9.25s

9250 ms / 1024 samples /binary sec = 9.03 s > 9.0 sec record

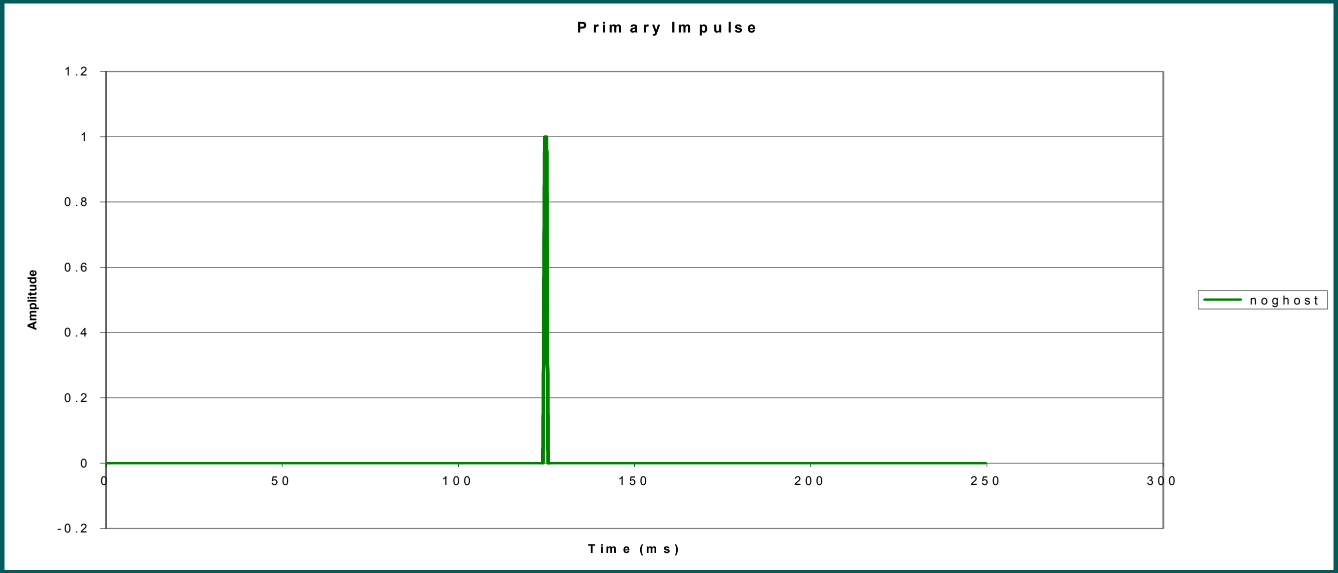
Temporal Sampling = Vertical Resolution

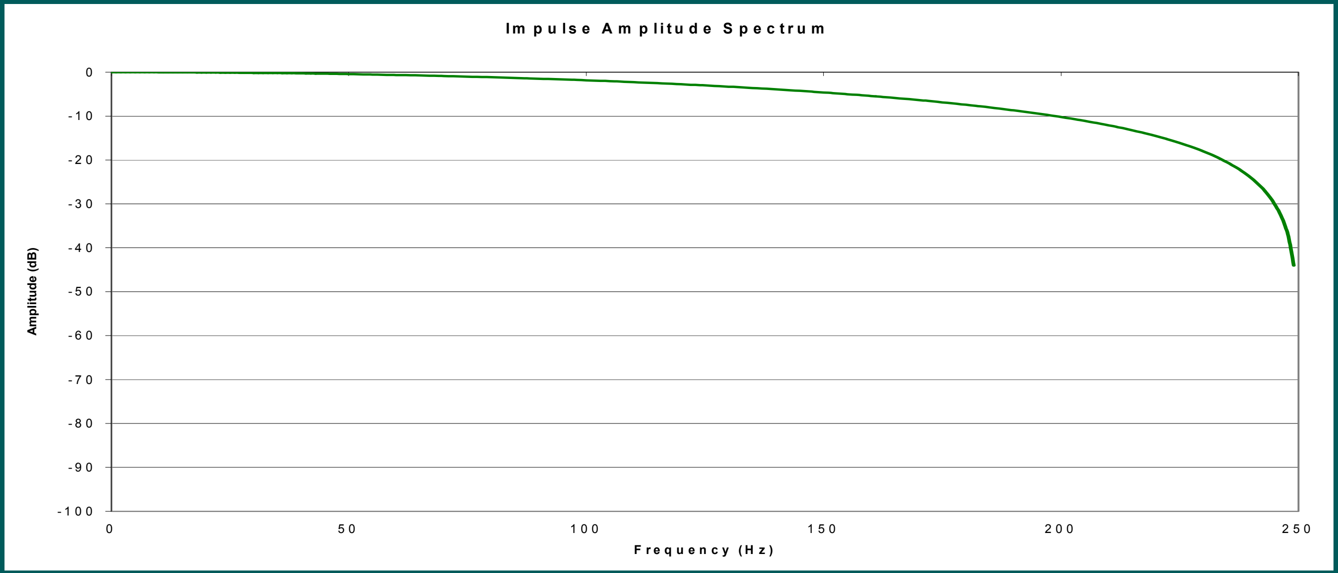
The bandwidth of marine seismic data is primarily related to the depth of tow of the sources and receivers.

Surface Reflections = Ghosting

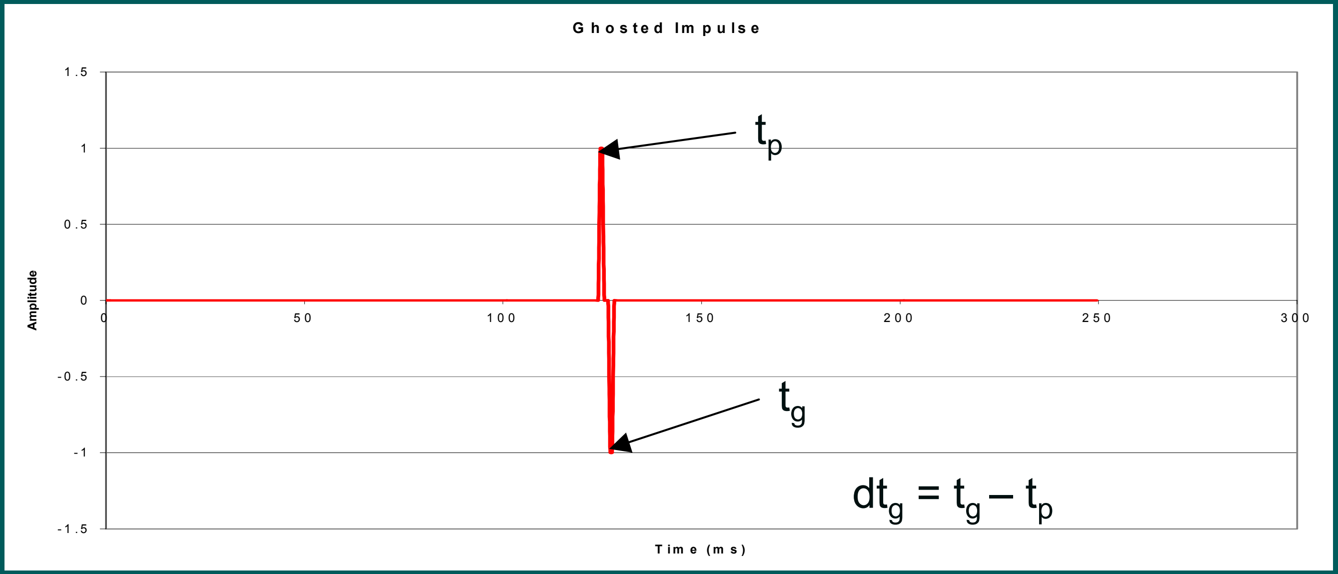


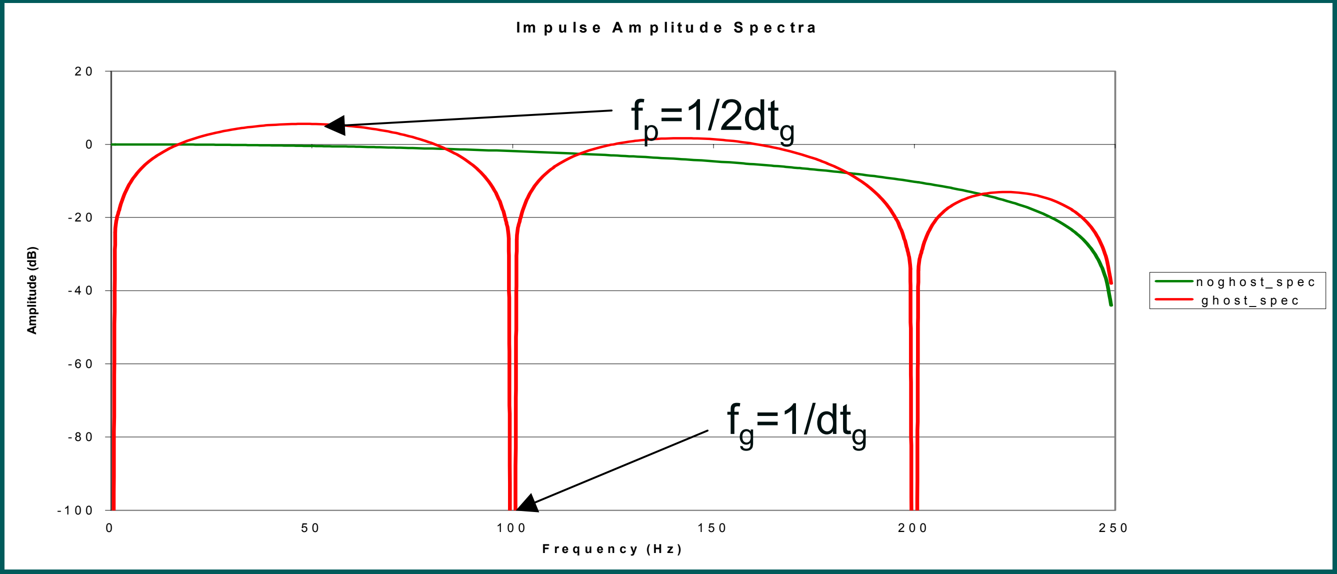
Impulse Response



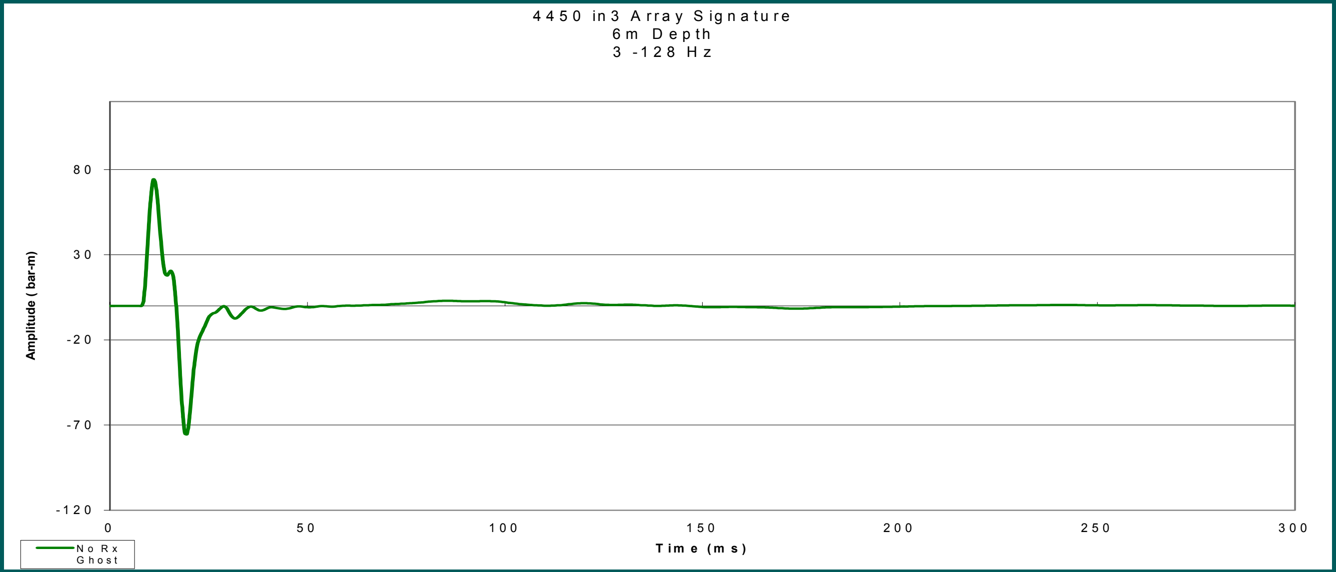


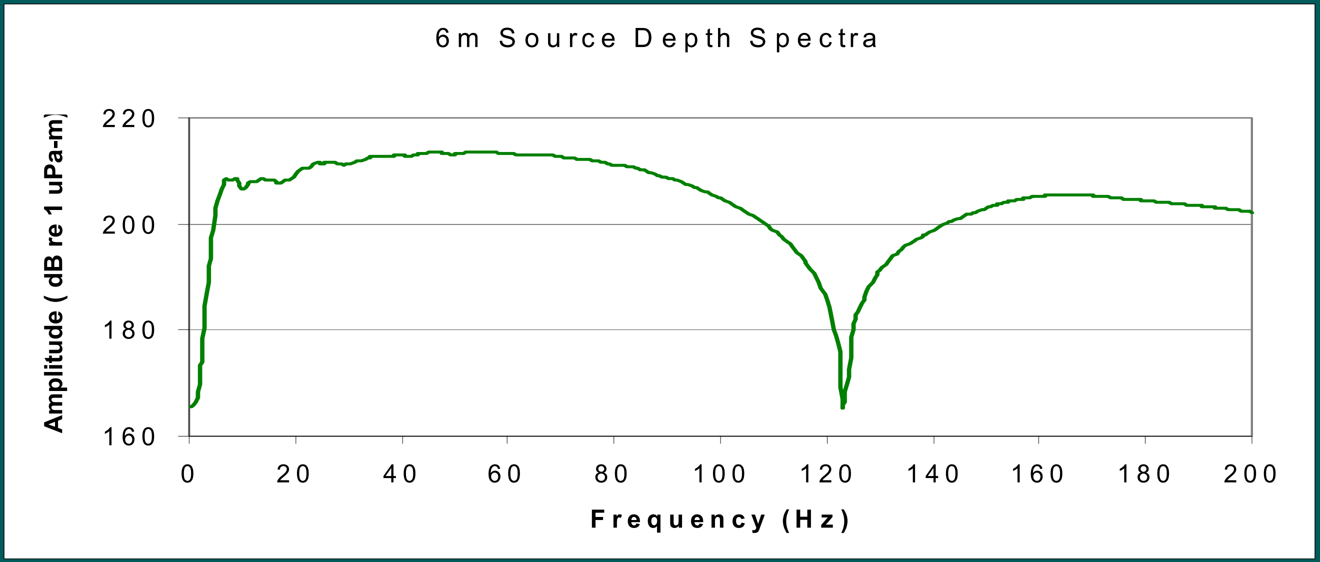
Ghosted Impulse Response



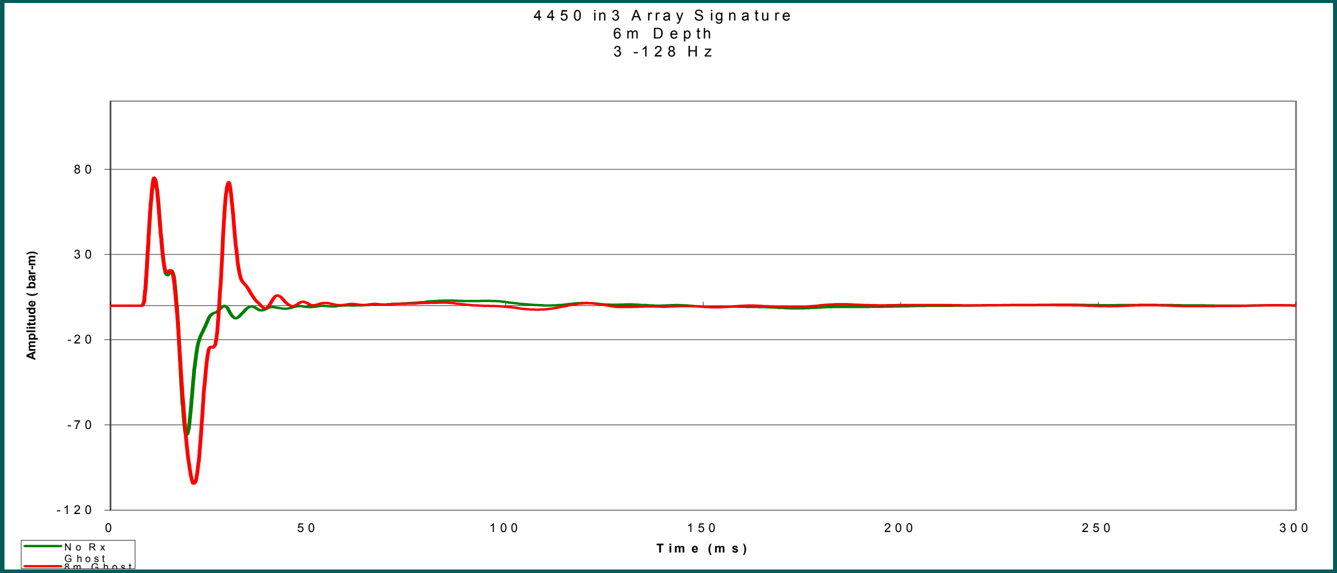


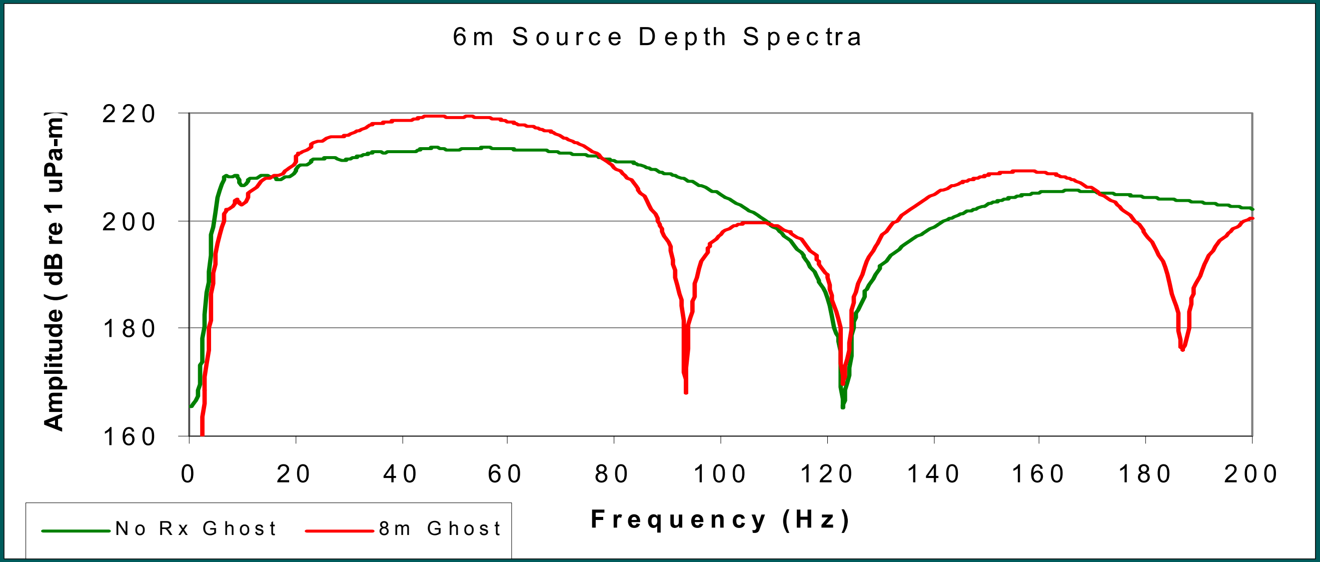
Source Ghost Response



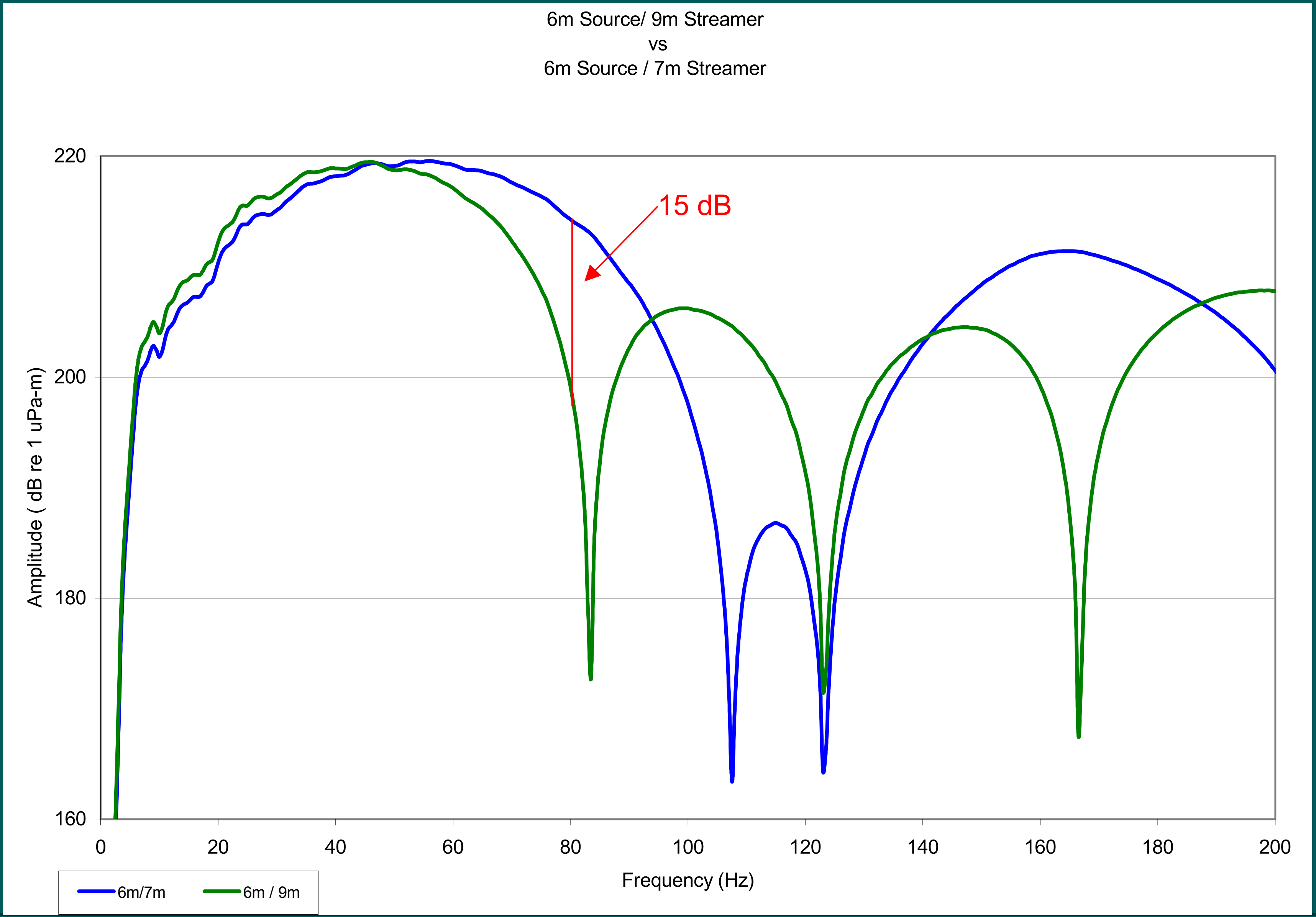


Source and Receiver Ghost Responses

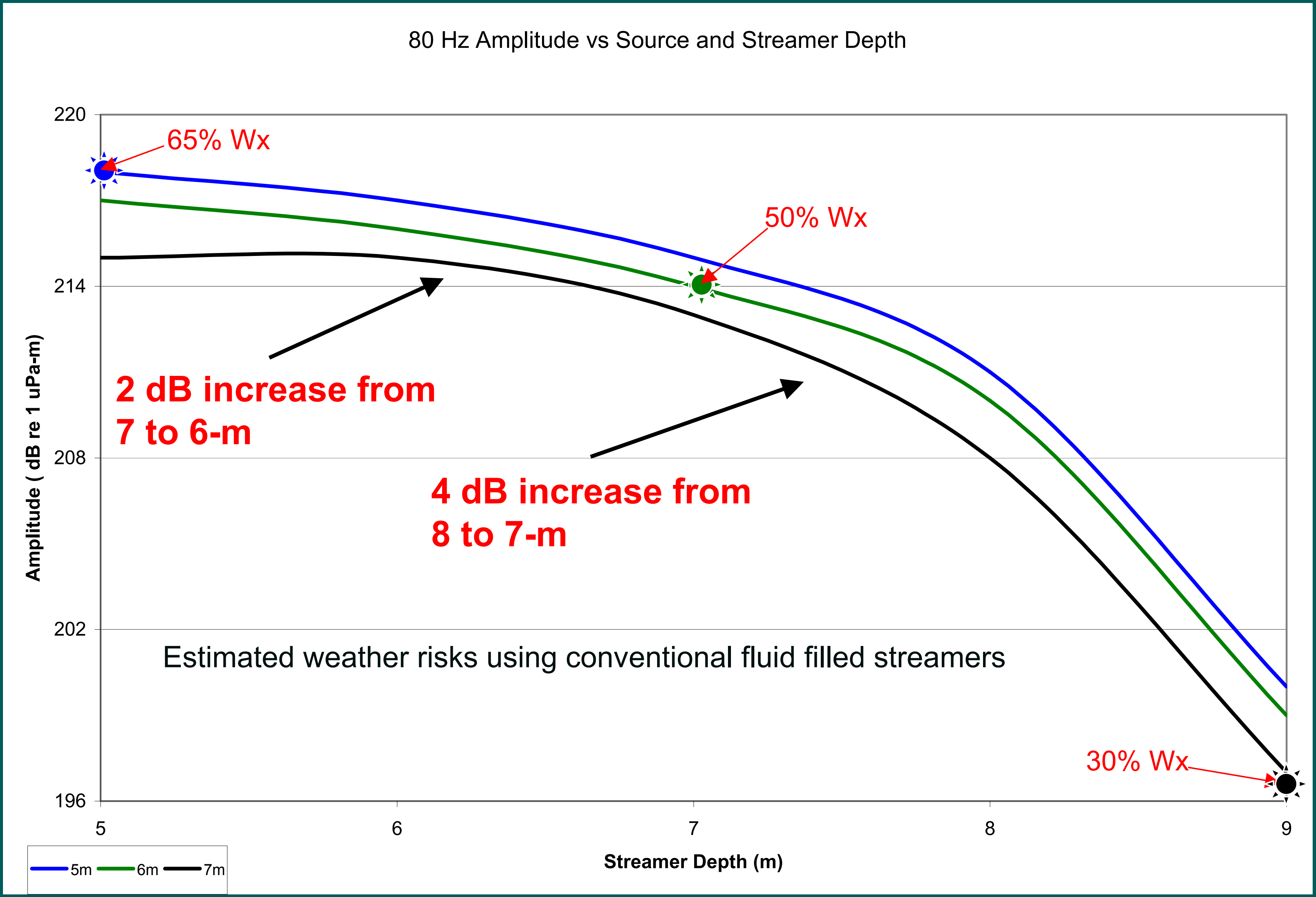




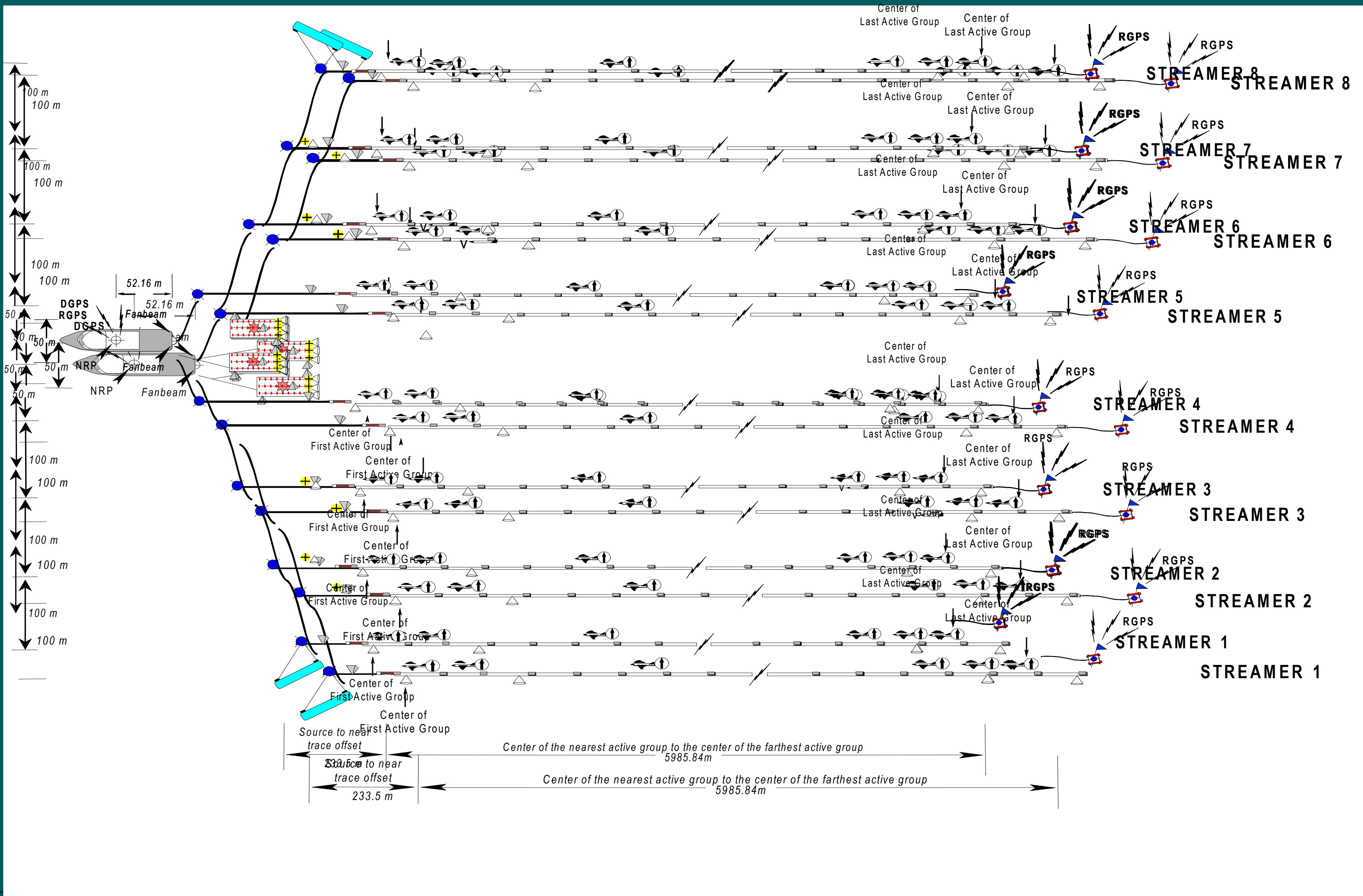
Source / Streamer Ghost Responses



80 Hz Signal Amplitude: Weather Risks



In-Water Positioning Networks



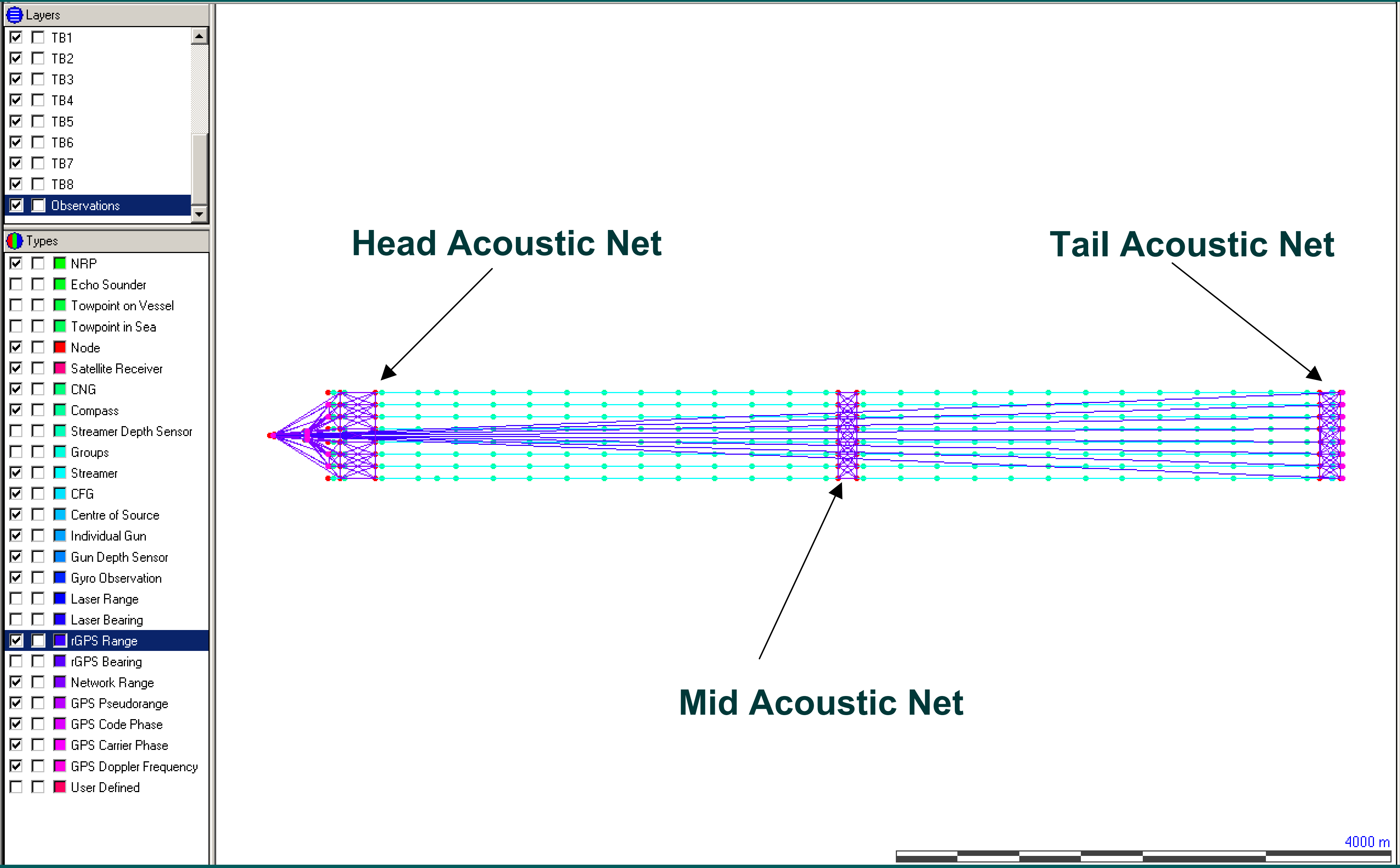
Positioning Network Design – Past to Present

Network design and implementation has improved dramatically over the last decade.

The main factors for this are:

- Improved reliability in navigation recording system and streamer telemetry.
- Improved data quality and reliability from compass and acoustic providers.
- Increased towing capacities provide a wider baseline that improves the geometry for positioning networks.

Segmented In-Water Positioning Network

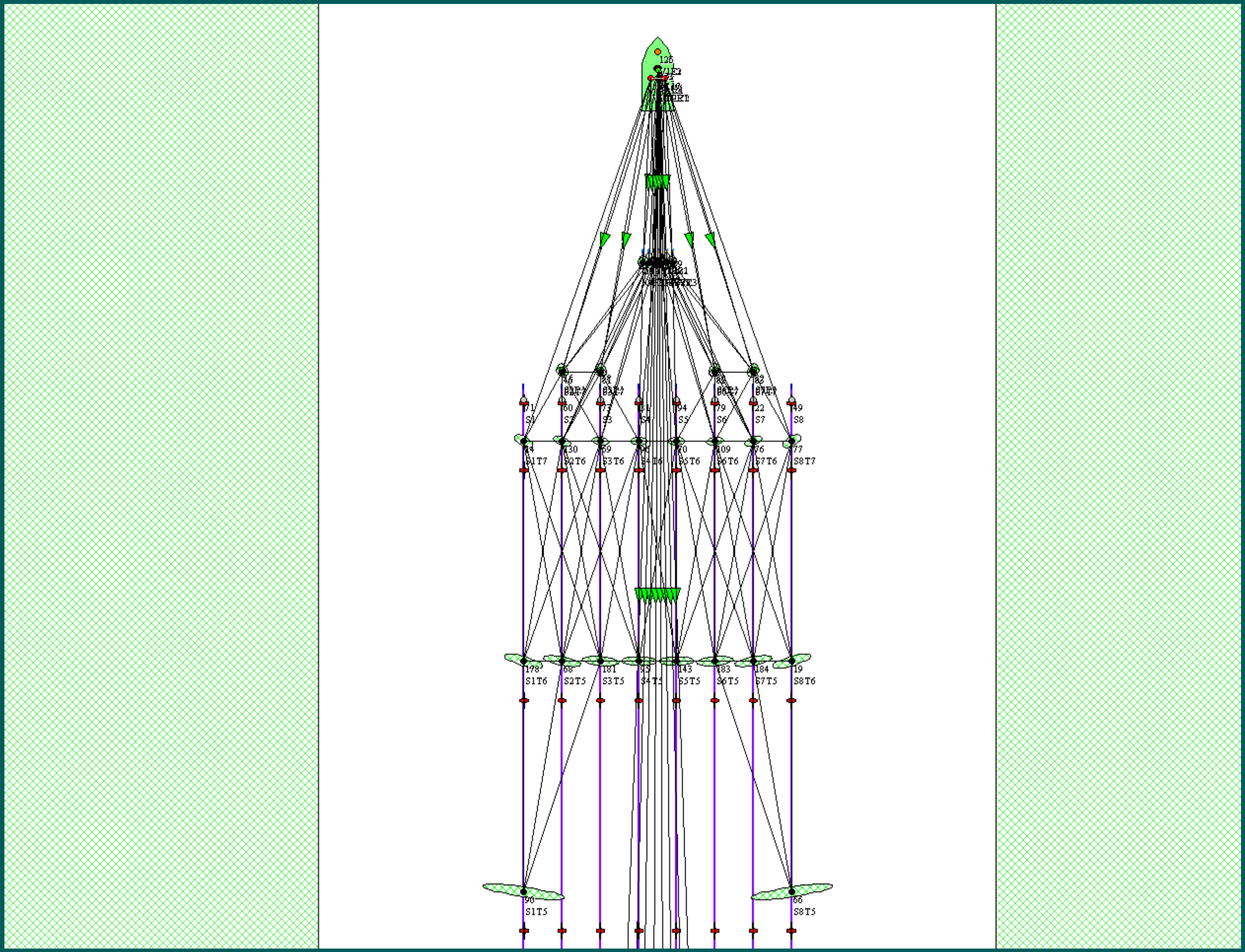


Forward Network Design

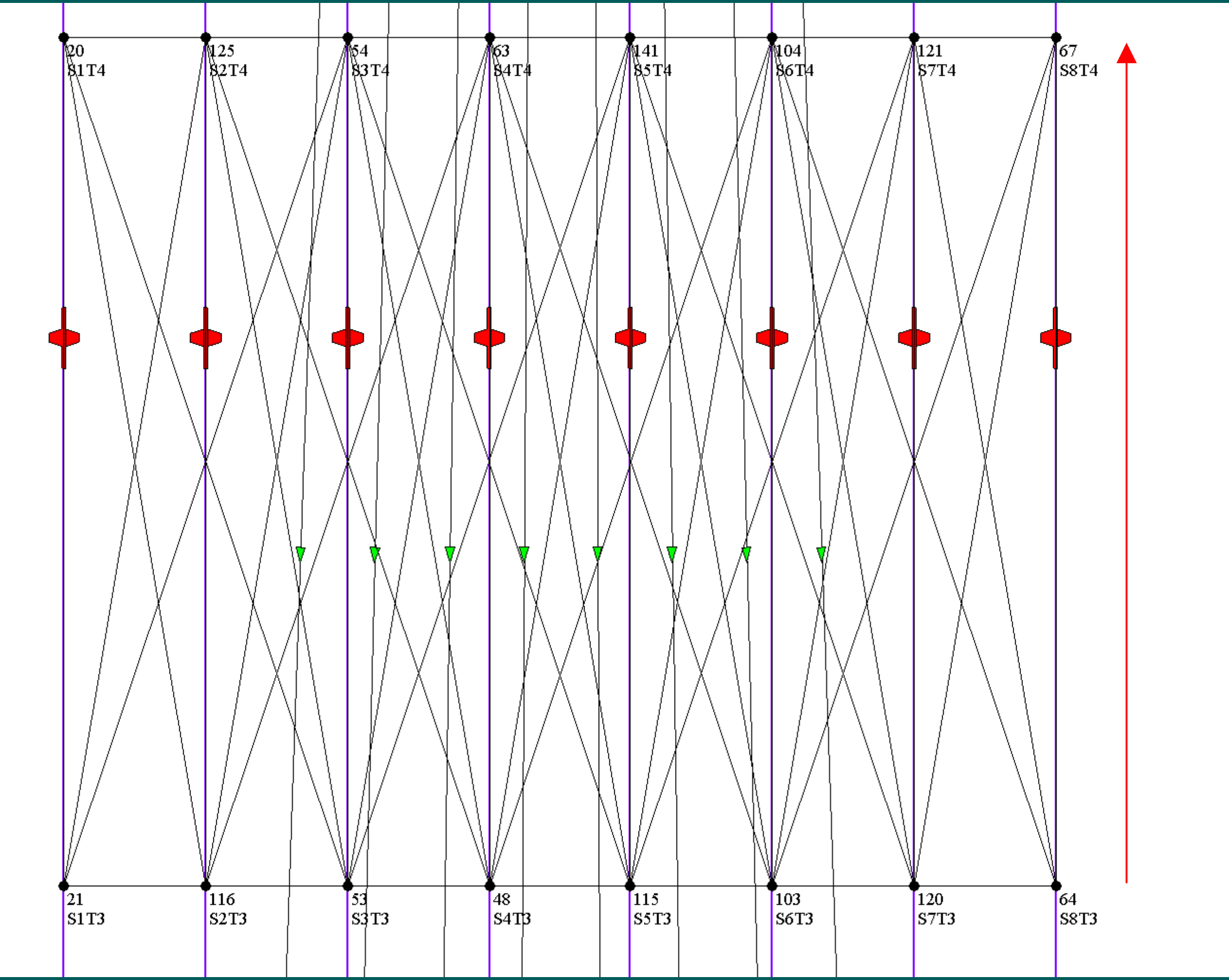
This is the forward network configuration used in the current survey conducted by the Veritas Vantage.

Green arrows indicate observation direction from rGPS antenna to surface located buoy nodes on source sub-arrays and cable heads.

Black circles indicate acoustic sub-surface nodes, except for gun centers and streamer reference points (Near Trace Location).

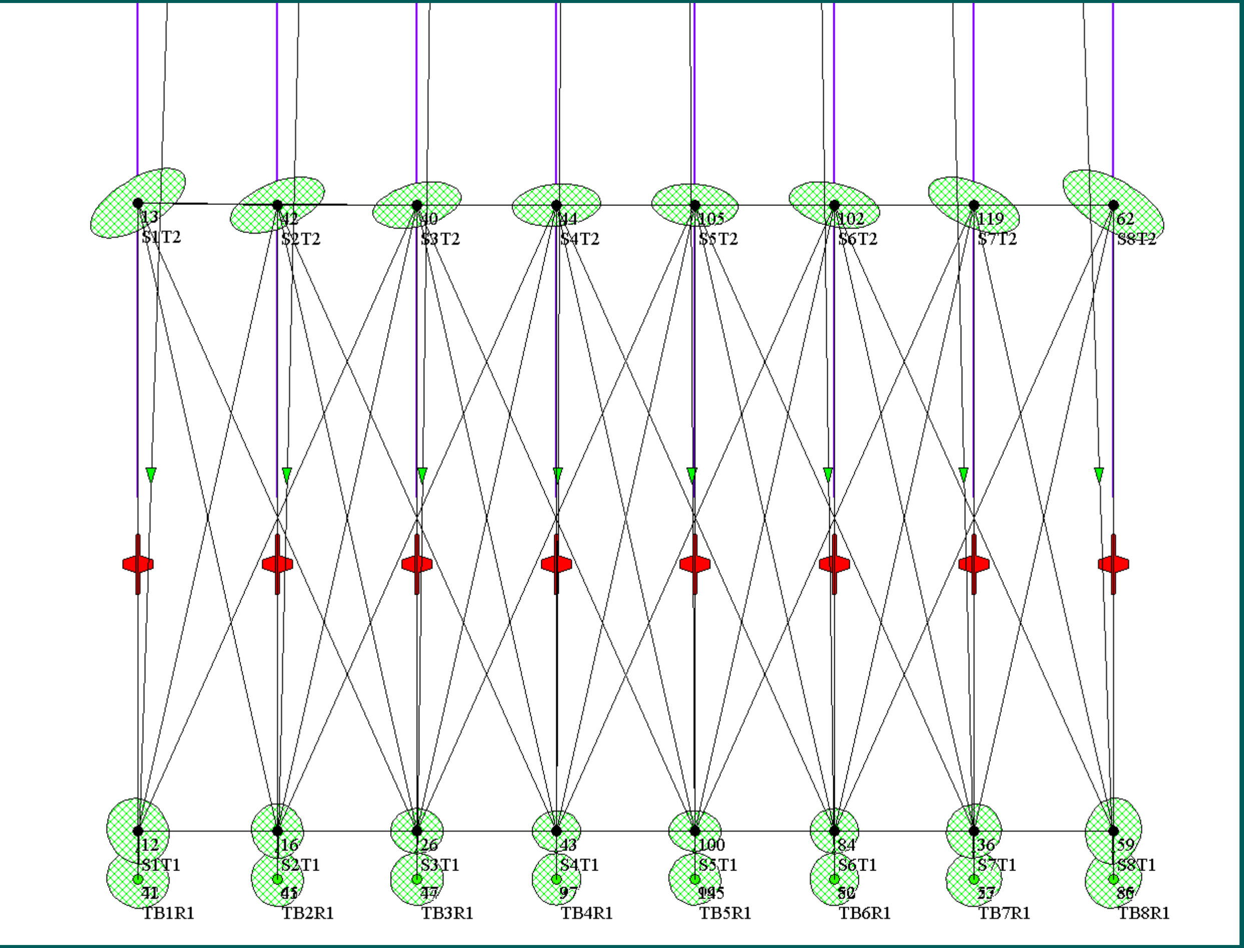


Mid-Network / In-Line Distance



Tail-Network Design

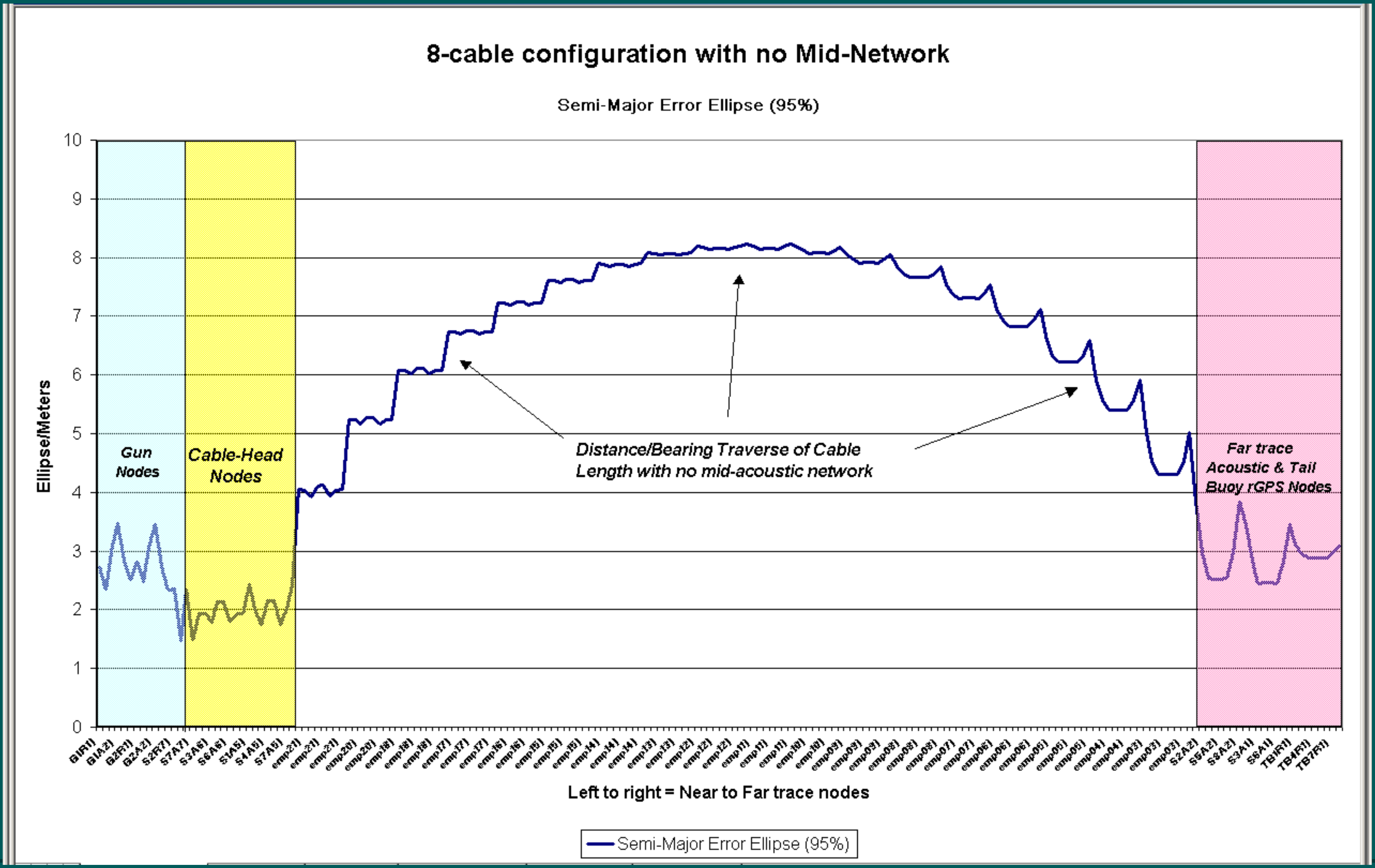
With rGPS Range/Bearing on all Tail Buoys, Ellipse error ellipse at far traces are all less than 2.5meters at 95% confidence.



Front & Tail Network – Early 1990's

Early networks utilized a front network that positioned the guns and cable heads consisting of acoustics, laser & rGPS.

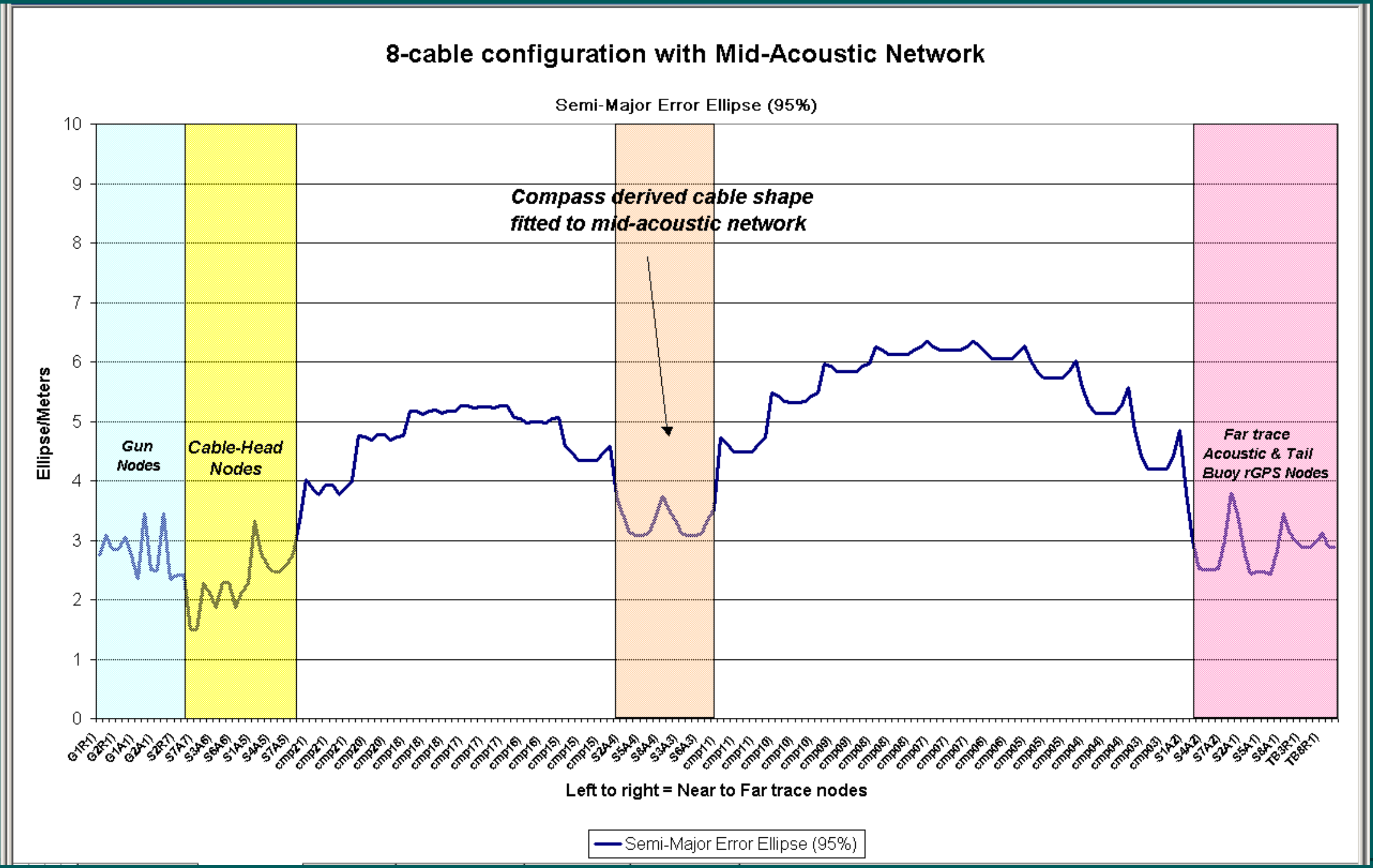
A separate tail network of acoustics and rGPS positioned the far traces. This also provided inline and cross-line (rotation) adjustments for the streamer shape. Compasses situated every 300m along the streamer provided readings with which to model the streamer shape.



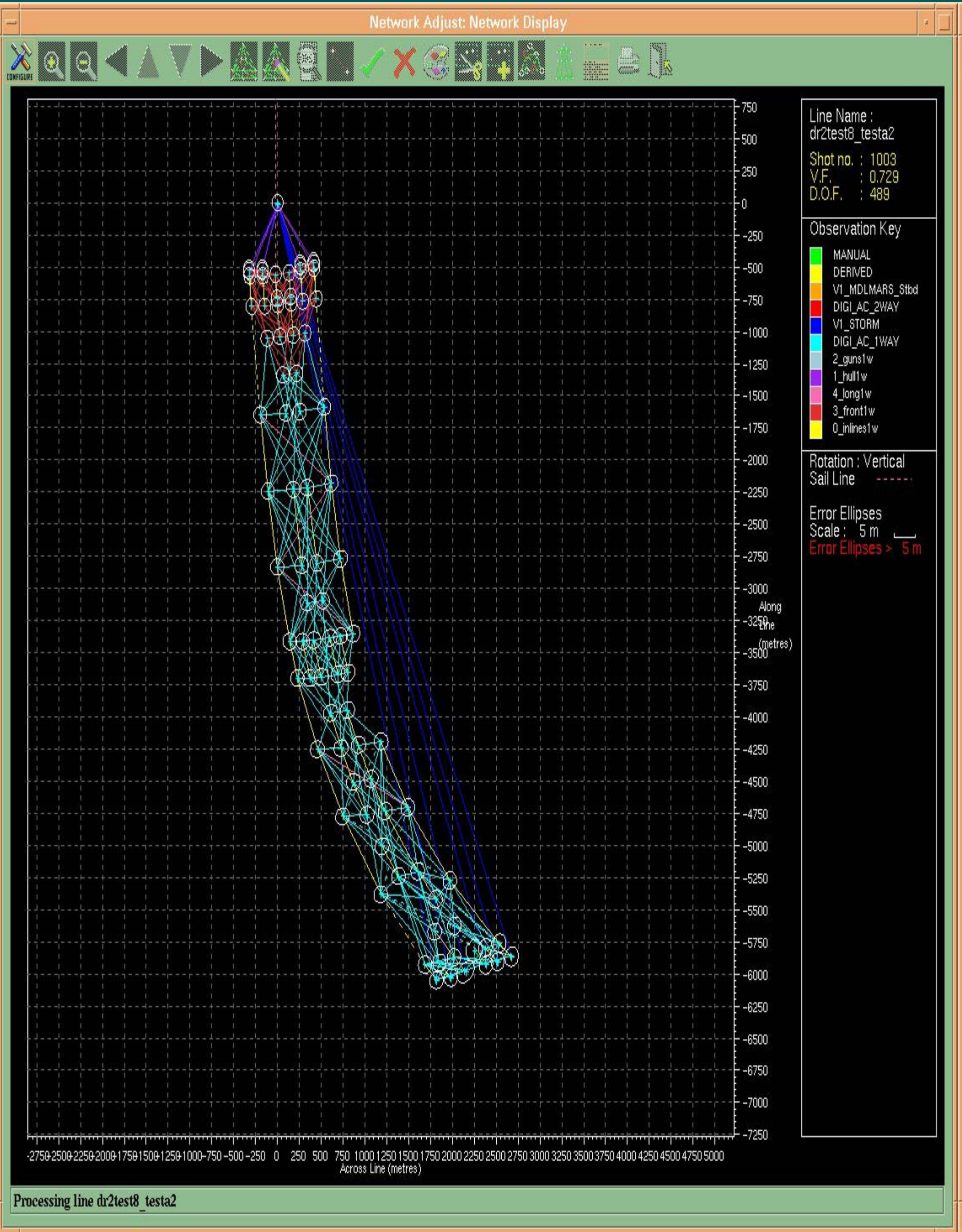
Front, Mid & Tail Network (1996-present)

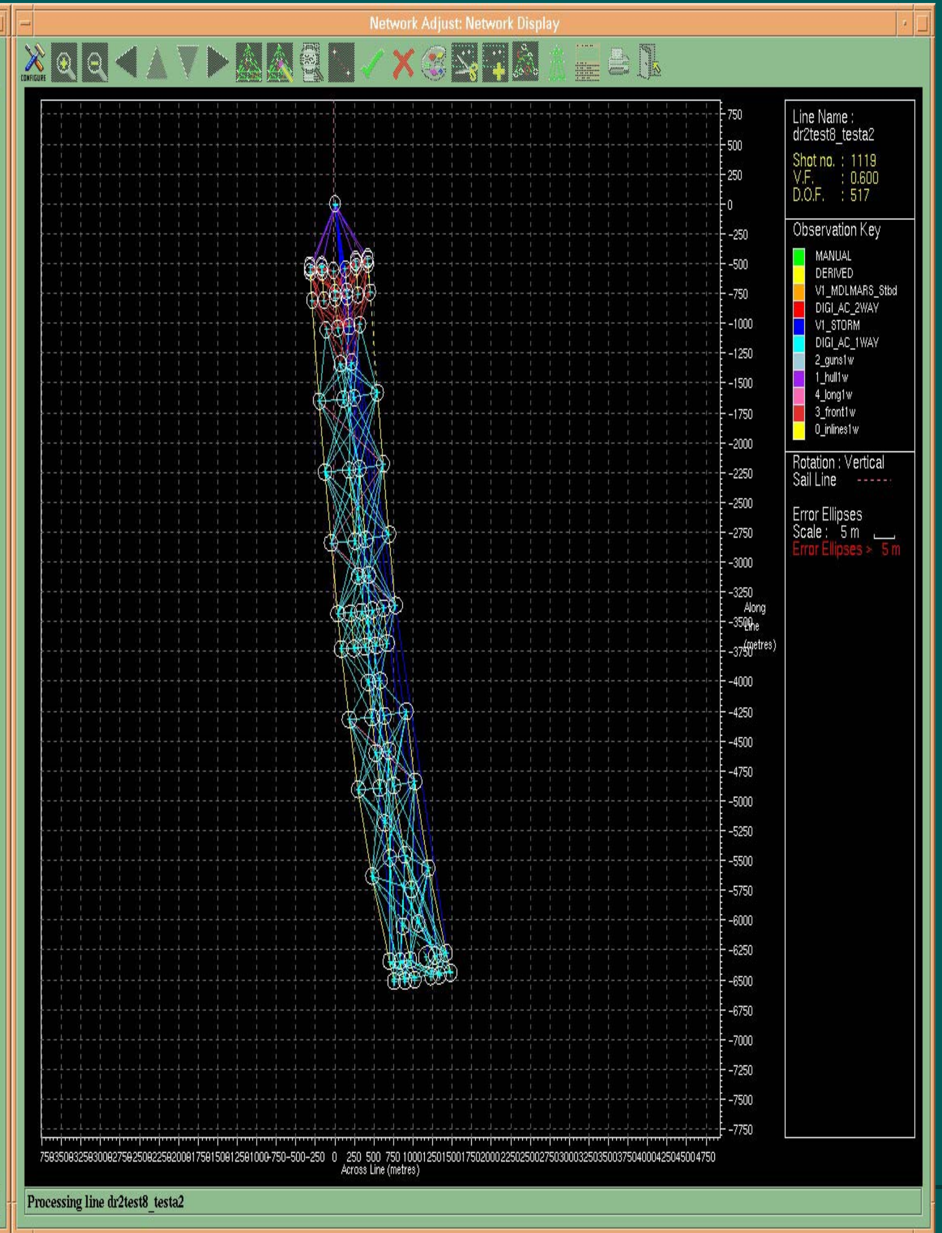
Current Veritas method utilizes an additional mid-acoustic network. This creates a precise grid of locations for nodes defined within the middle portion of the streamers.

The front and tail networks determine the geodetic controls used as anchor points to start the iterative process of calculating the best fit of the streamer shape through this mid-net. The total network solution also provides inline and cross-line (rotation) adjustments for the streamer shape.



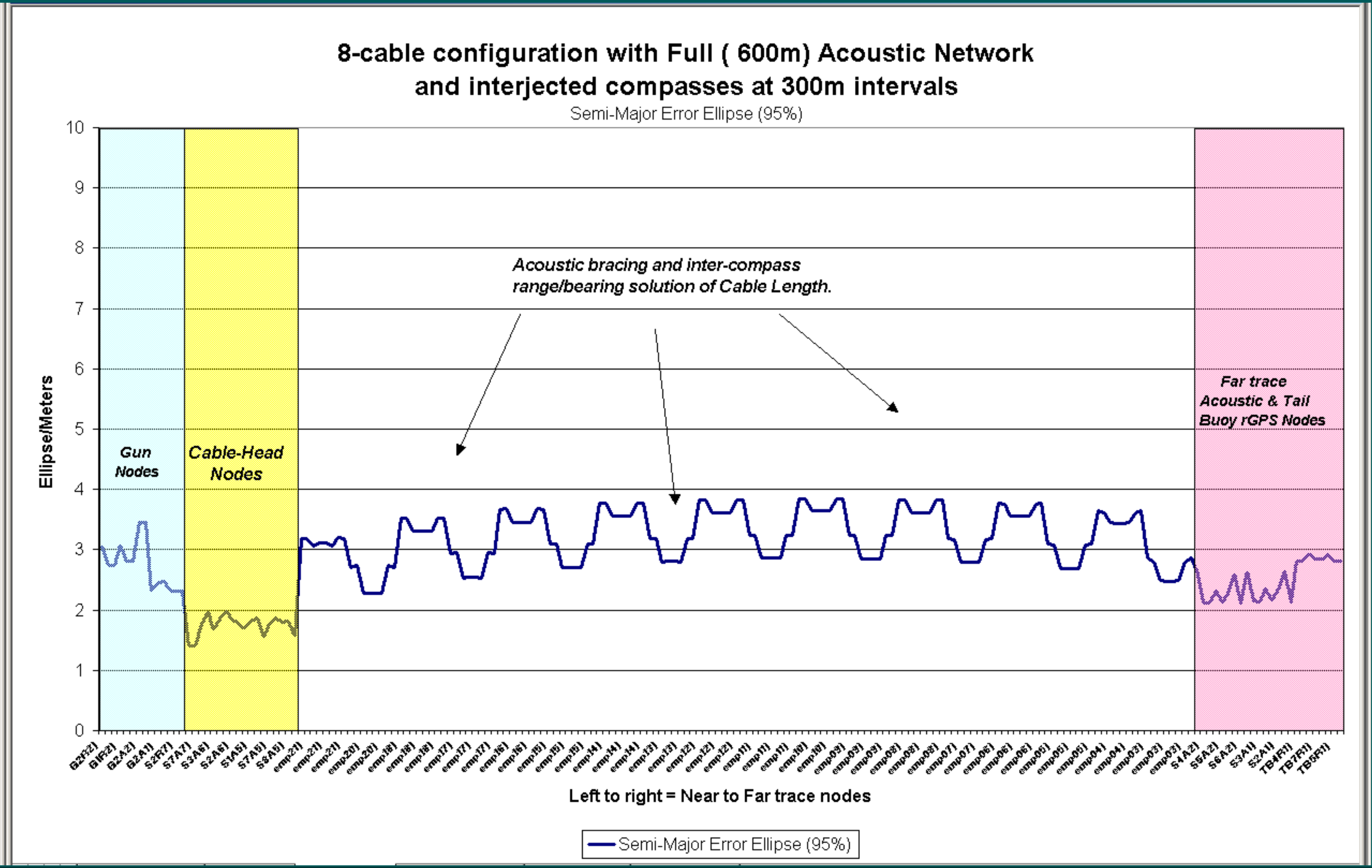
Full-Braced Network / 150m separation (6-cables)





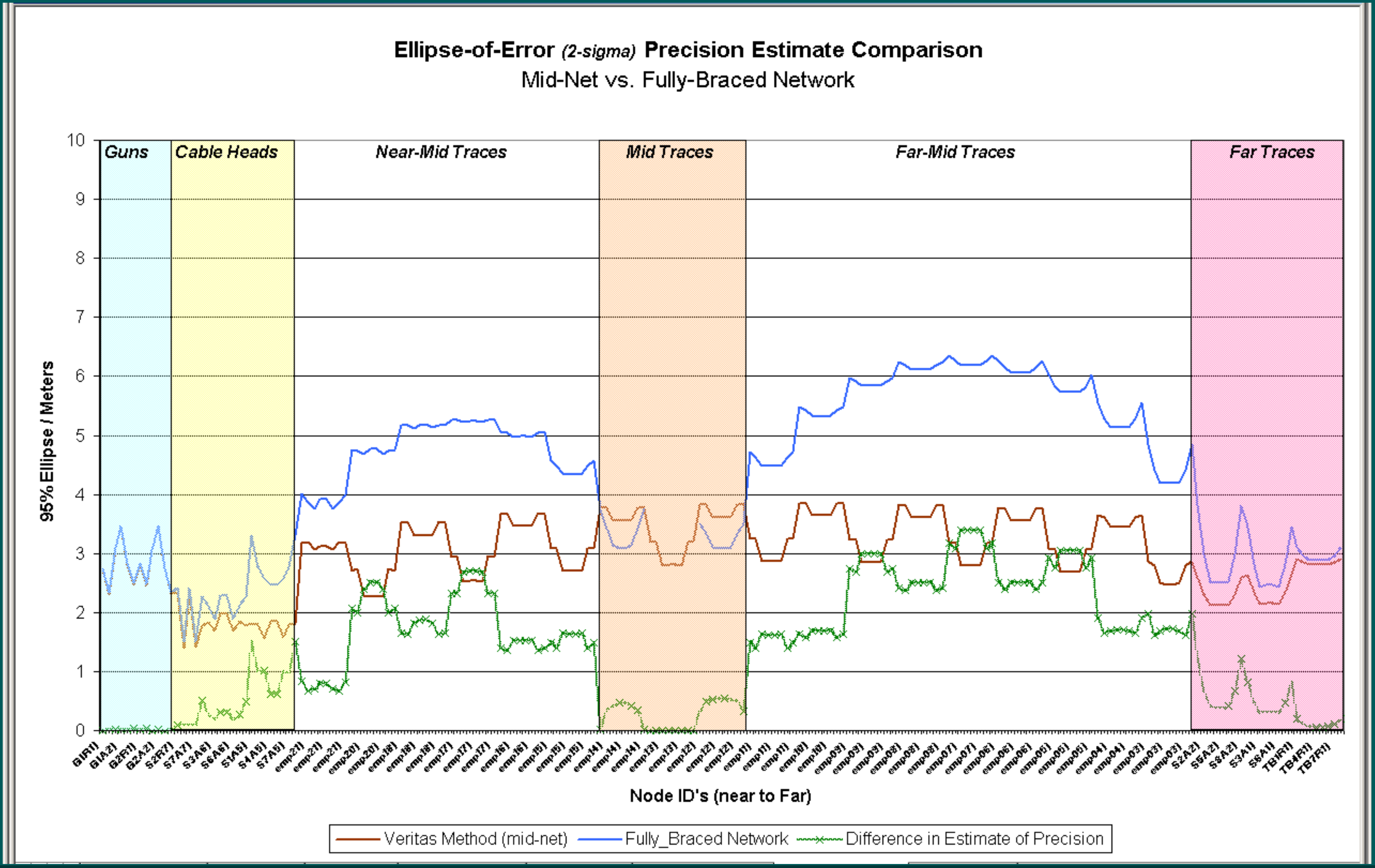
Full-Braced Network Capability

Veritas has the capability to provide a fully braced acoustic network. This would consist of the current front and tail network geometry. An array of acoustic pods located every 600m along the streamers would provide a connected, or fully braced network along the entire streamer length. Compasses located every 300m would provide additional observations to support the modeling of the receiver positions.



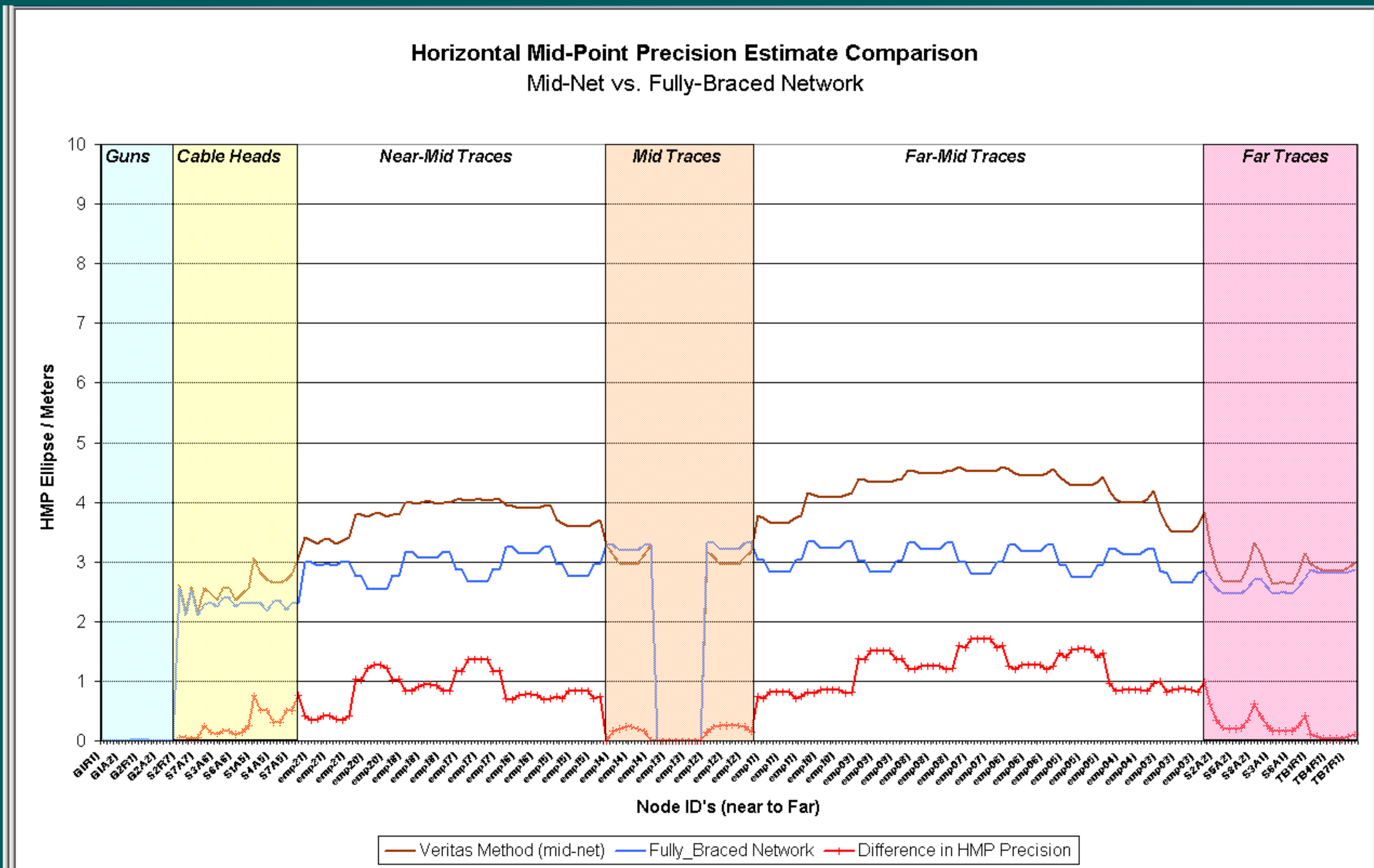
Node Precision Comparison

As can be seen below, there is an improvement in the estimated precision of a fully braced network. When compared to the current mid-net configuration, maximum *improvement* is observed at the far-mid portion of the streamers and is on the order of 3 to 3.5 meters.



HMP Precision Comparison

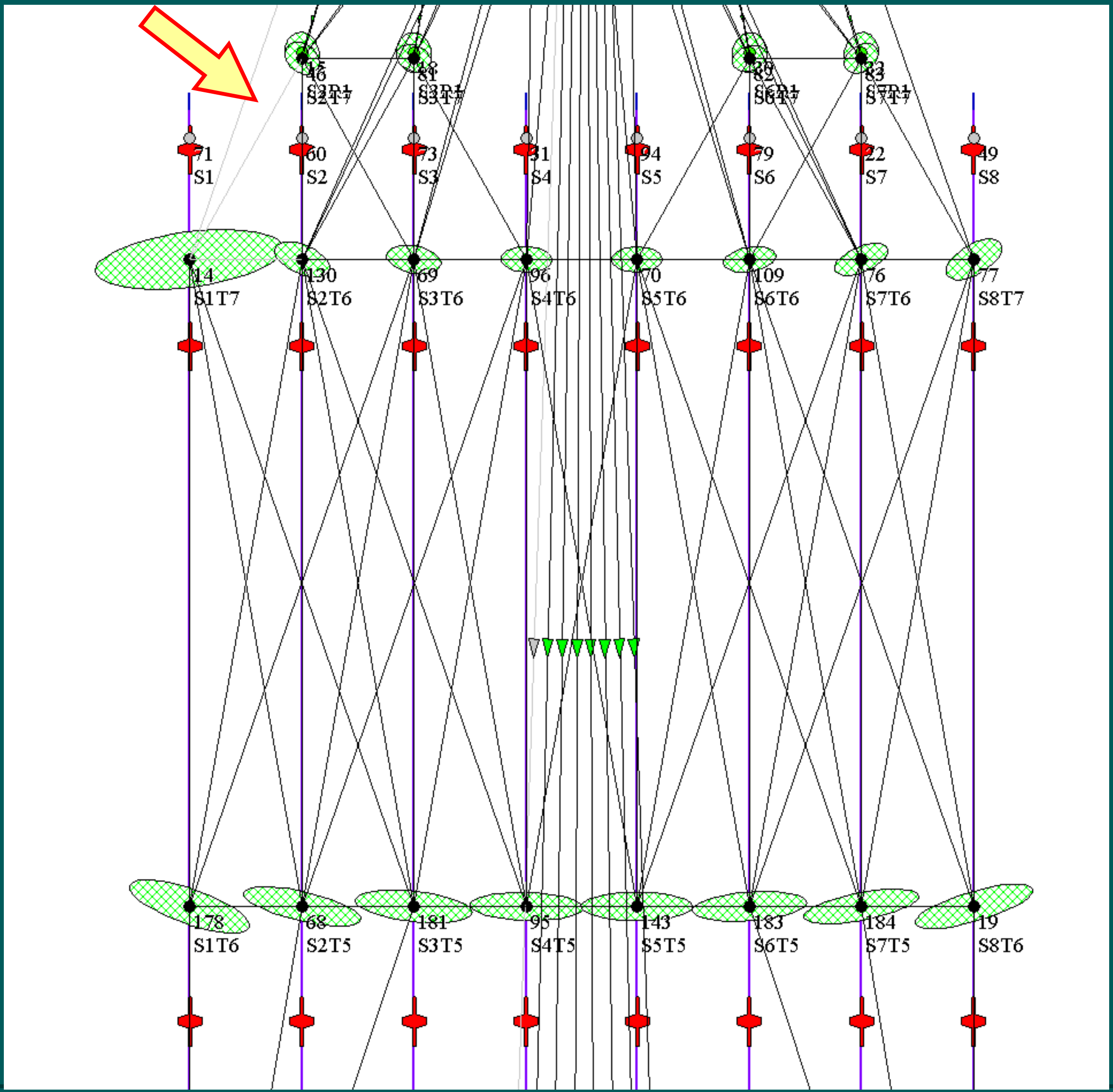
Horizontal Mid-Point (HMP), is the reflection point for each source/receiver pair. The HMP positioning precision can be seen below. The improvement in the estimated precision of the HMP using a fully braced network can again be seen in this comparison of Mid-net versus a fully braced network. When compared to the current mid-net configuration, maximum *improvement* is on the order of 0.5 to 1.7 meters.



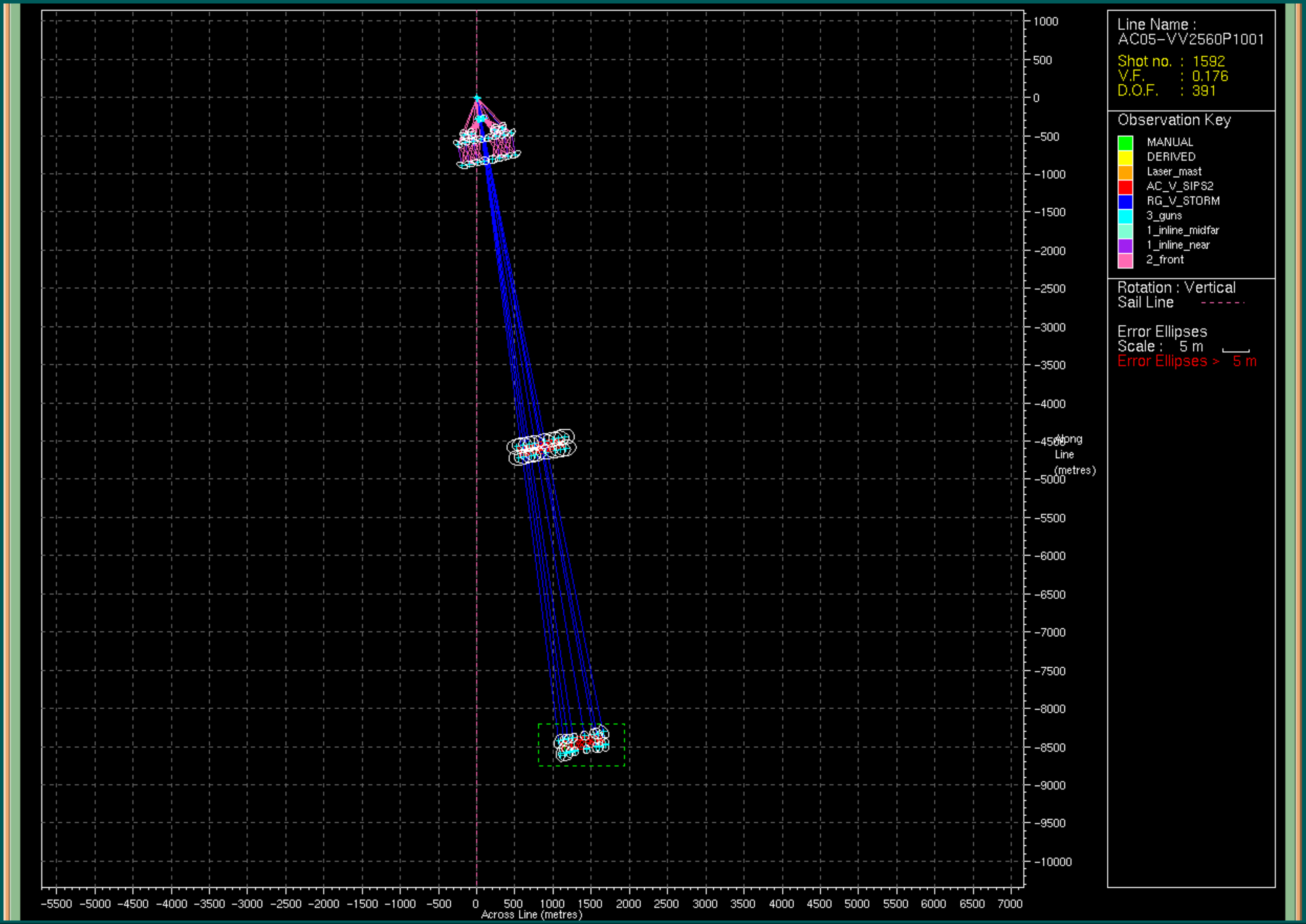
Forward Network Design (Drop-Out Analysis)

In order to predict the effects of data loss within the network, a set of “worst case” scenarios are calculated.

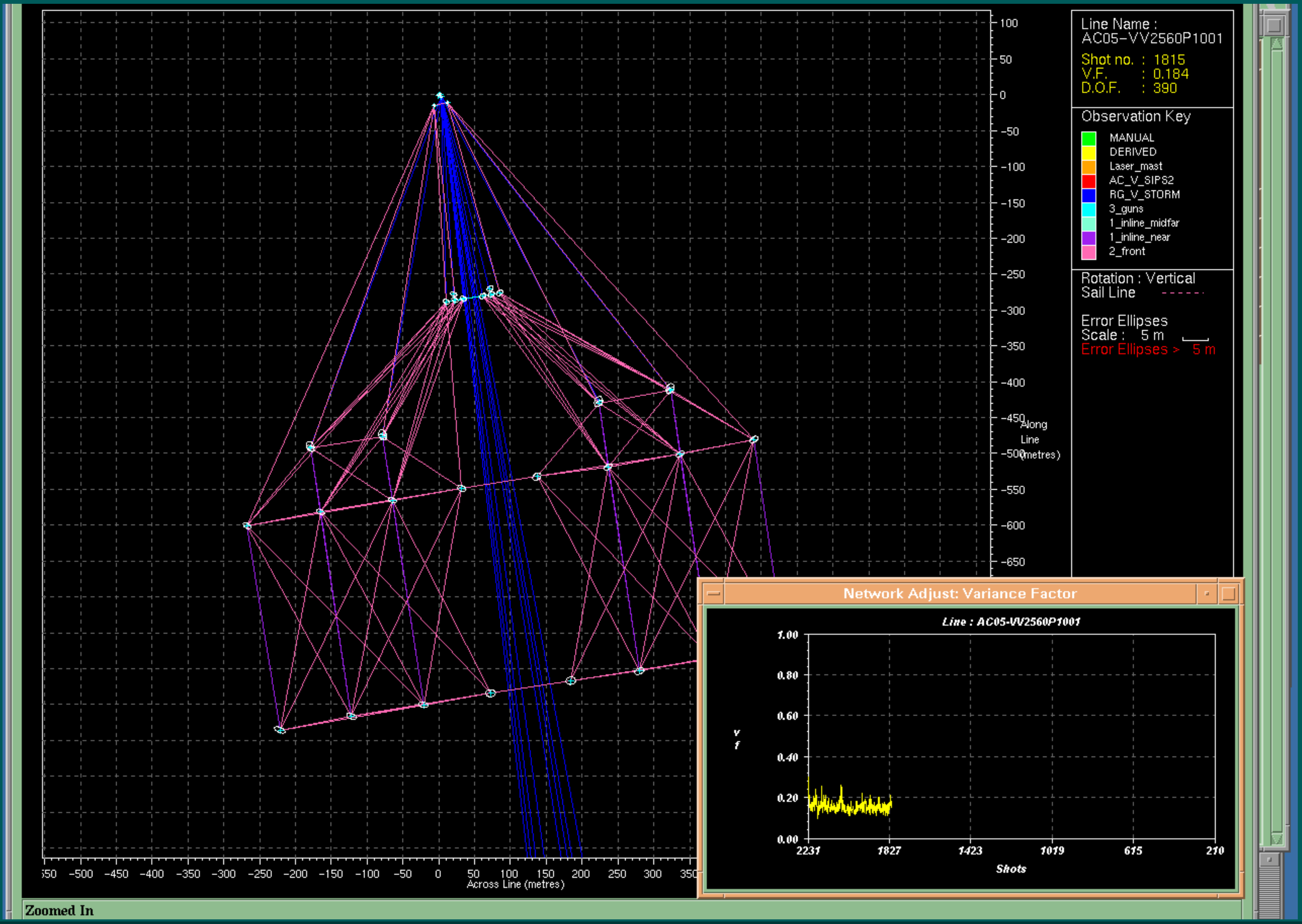
This test shows an acoustic loss of hull and gun acoustics to the outer port near-trace pod.



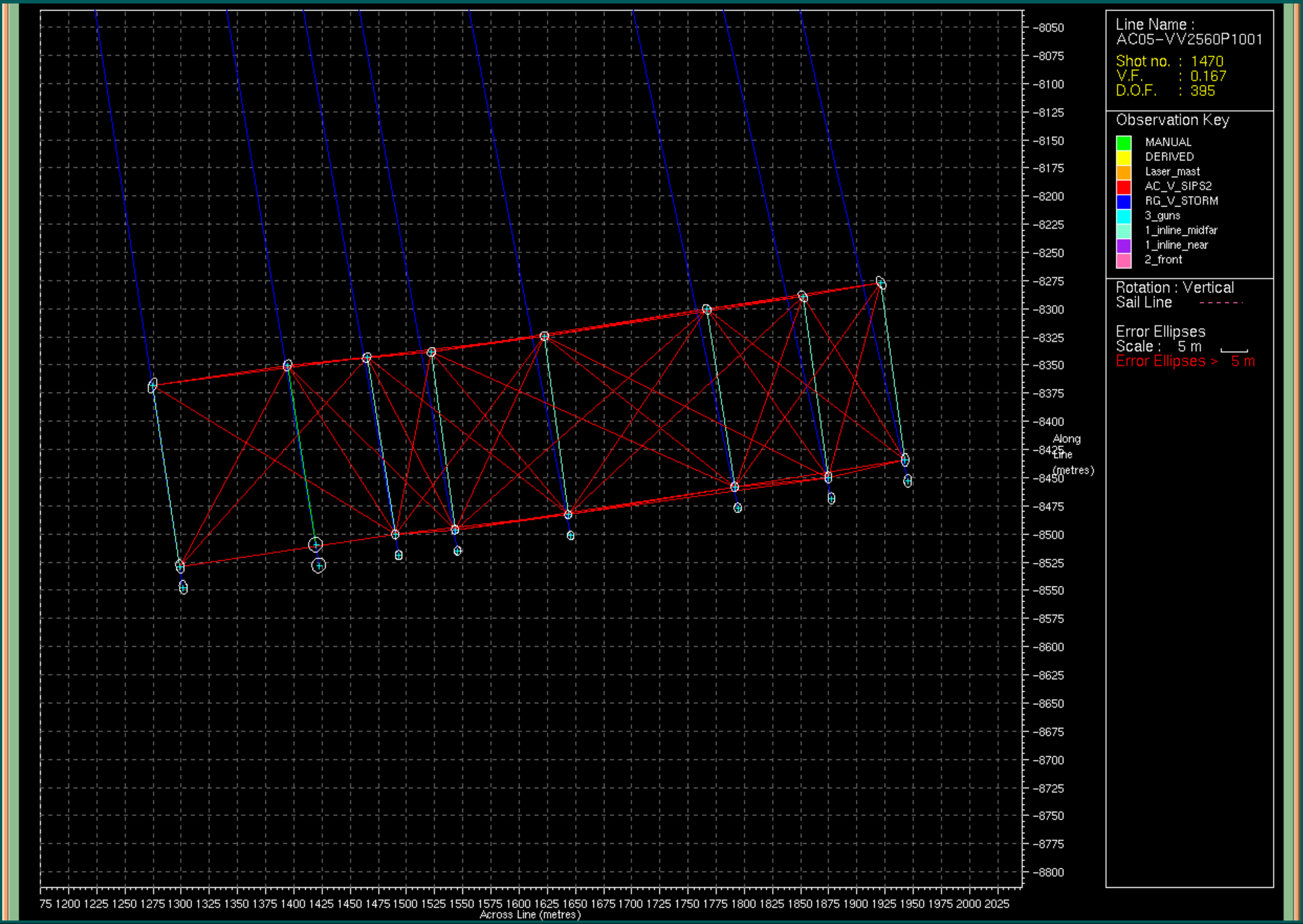
Least Squares Calculation



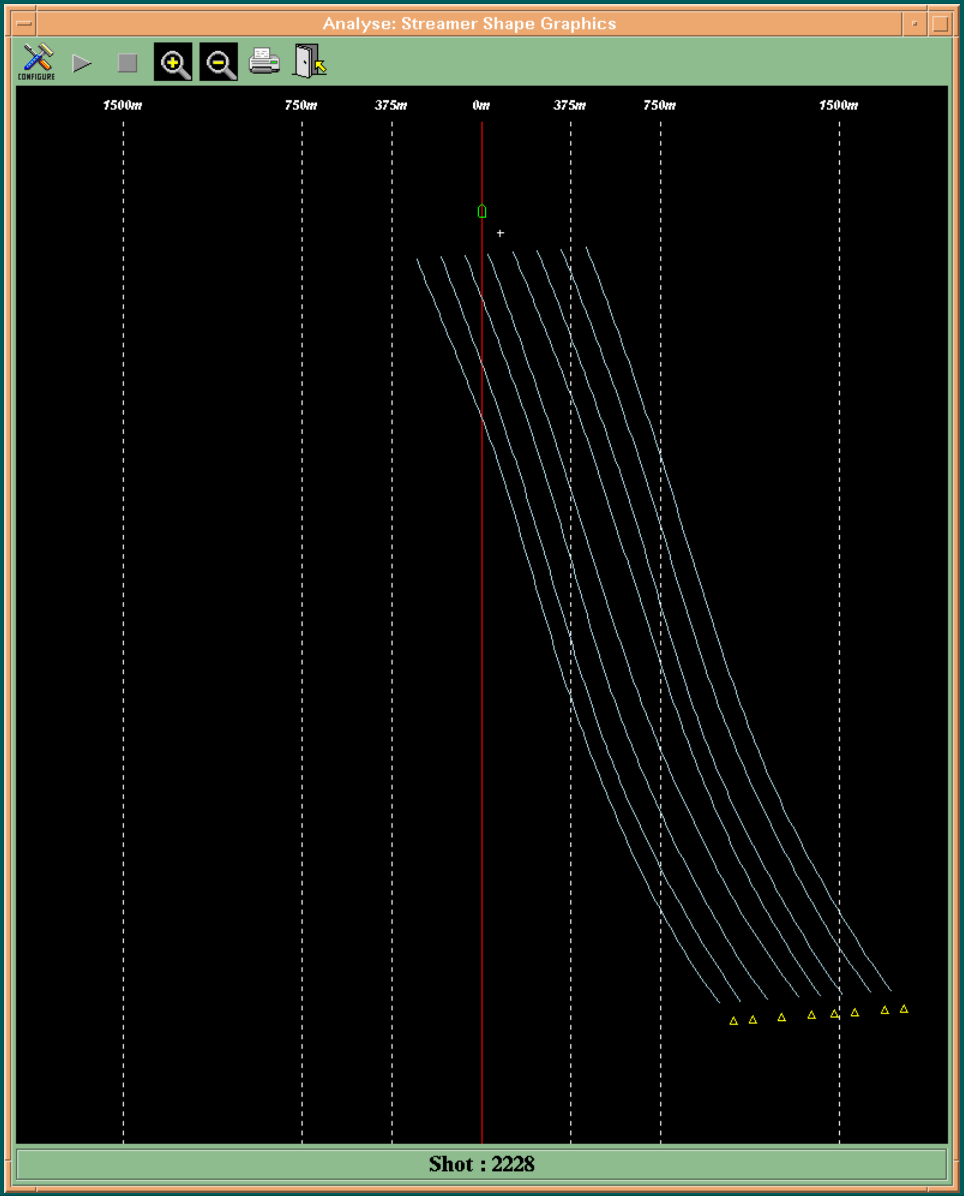
Least Squares Calculation



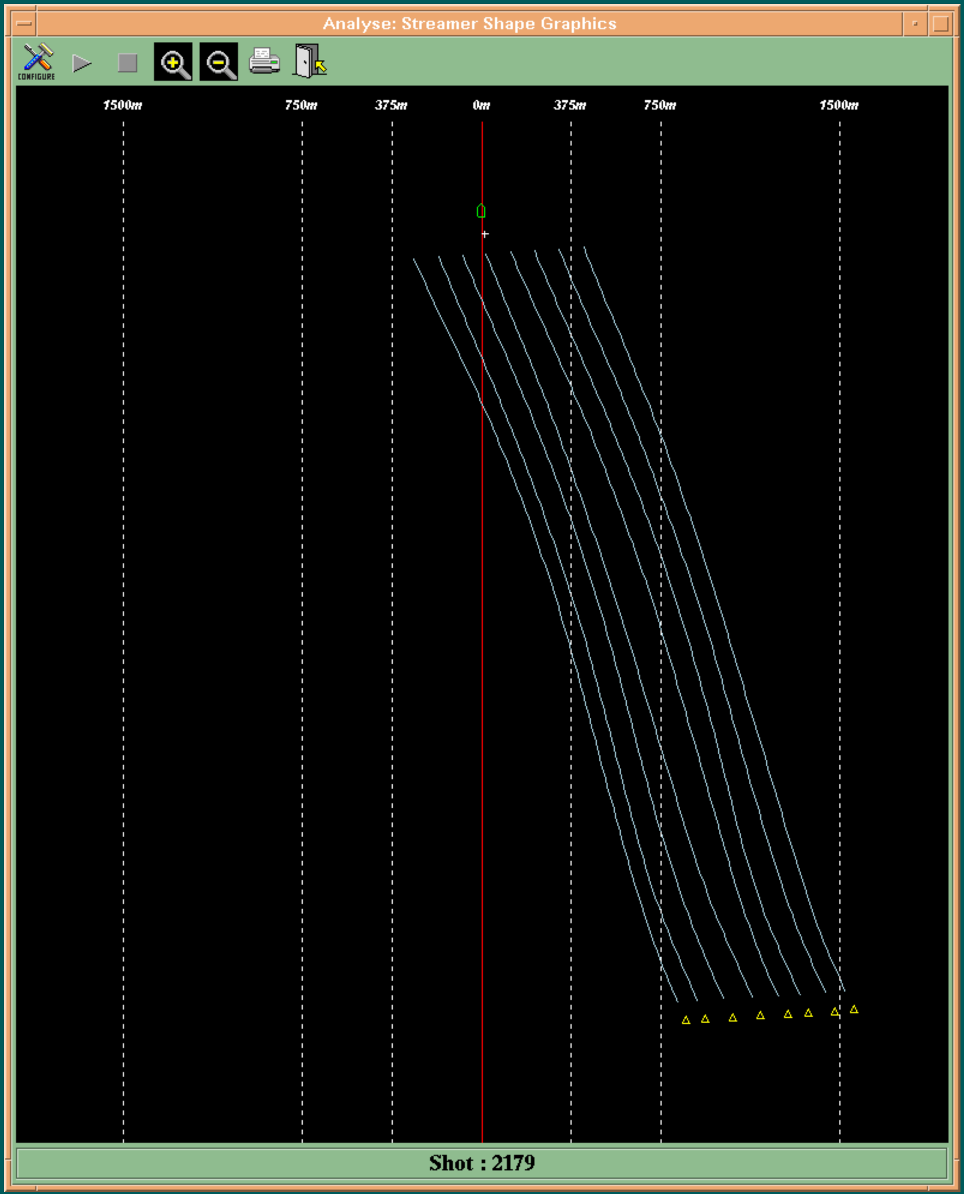
Least Squares Calculation



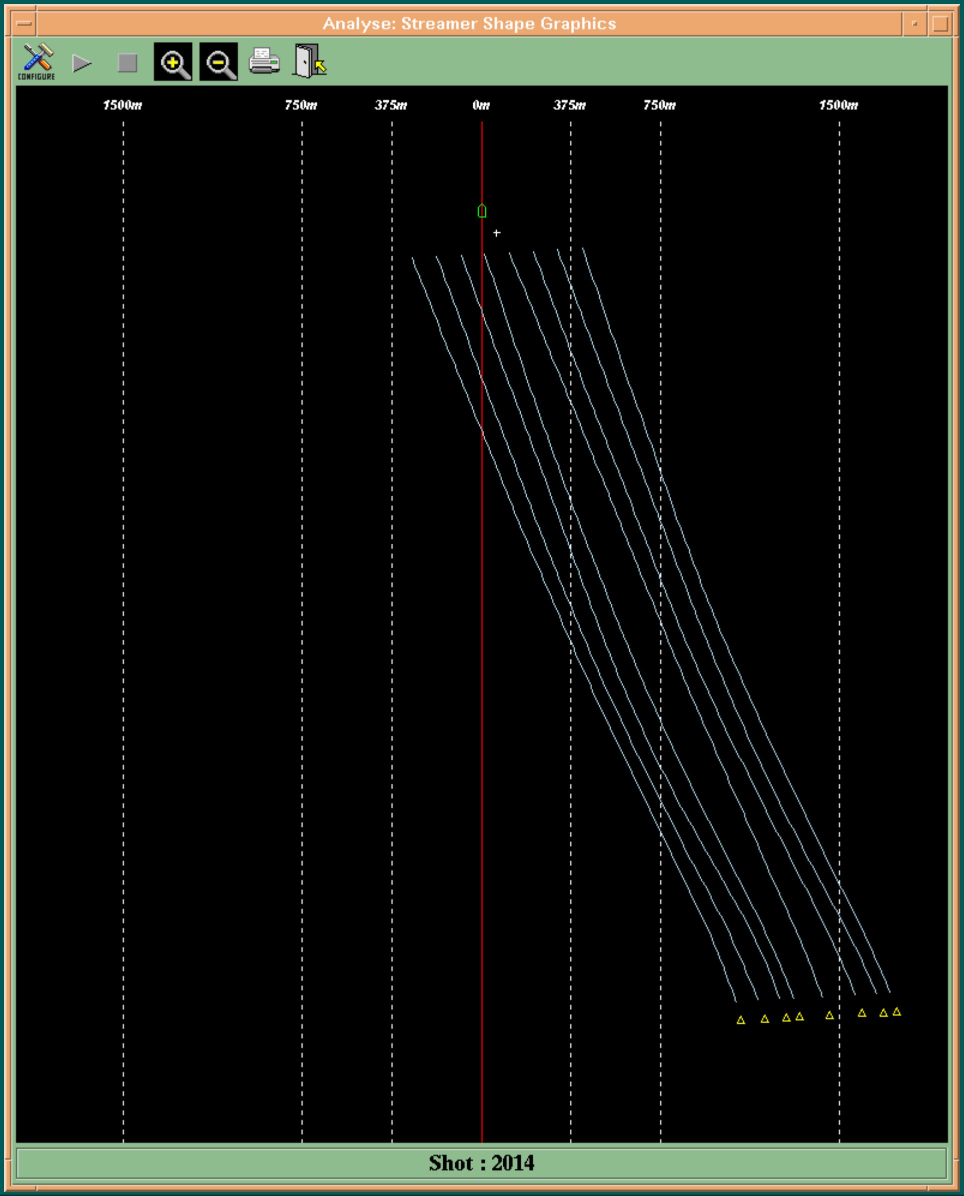
Streamer Shaping View

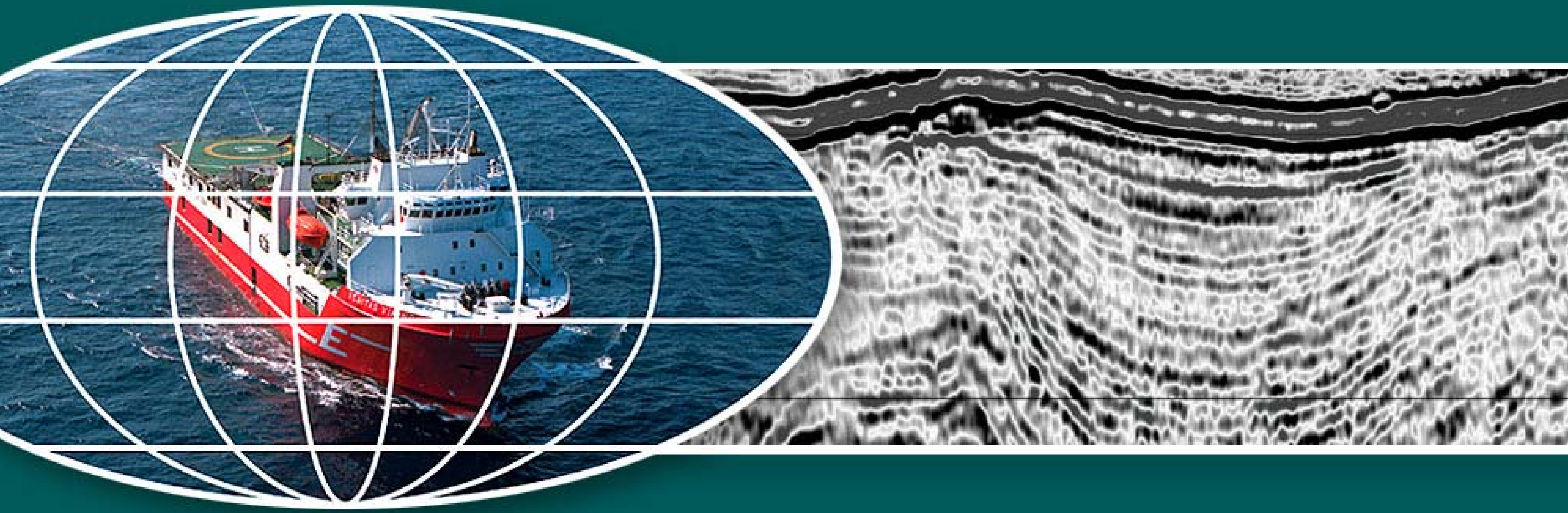


Streamer Shaping View



Streamer Shaping View





Marine 3D Survey Quality Control

Project QC Stages

Pre-Mobilization

- Project Plan Document
  - Geodetics
  - Navigation
  - Seismic
  - Operating Specifications

Mobilization

- Systems' Set-up
- Initial Parameter Checks

On Board QC

- On-Line QC
- Off-line QC
- Database population

Post Survey

- Data Archiving
- Final Report Support

Onboard Survey QC

- Assurance and verification of seismic survey coverage
- Assurance and verification of seismic data quality.
- Assurance and verification of positioning data quality.

Real Time QC

On Line

Observers

- Recording System
- Guns
- Streamers

Navigators

- GPS
- Spectra
- In-Water Network

Seismic

- S / N
- Bin Coverage

Off-Line QC

Navigation Processing

P 1/90

HMP Precision

Seismic Processing - QC

Noise Analysis

Swell

Strum

Seismic Interference

Low Fold Cube

LMO

Areal Attributes

Final Seismic QC

Accept (Green)

Reject (Red)

Hold for further analysis (Yellow)

Time Limit (48 hrs?)

Seismic Pre- Processing

nav merge, resample, filter, etc..

Generate SEG-Y

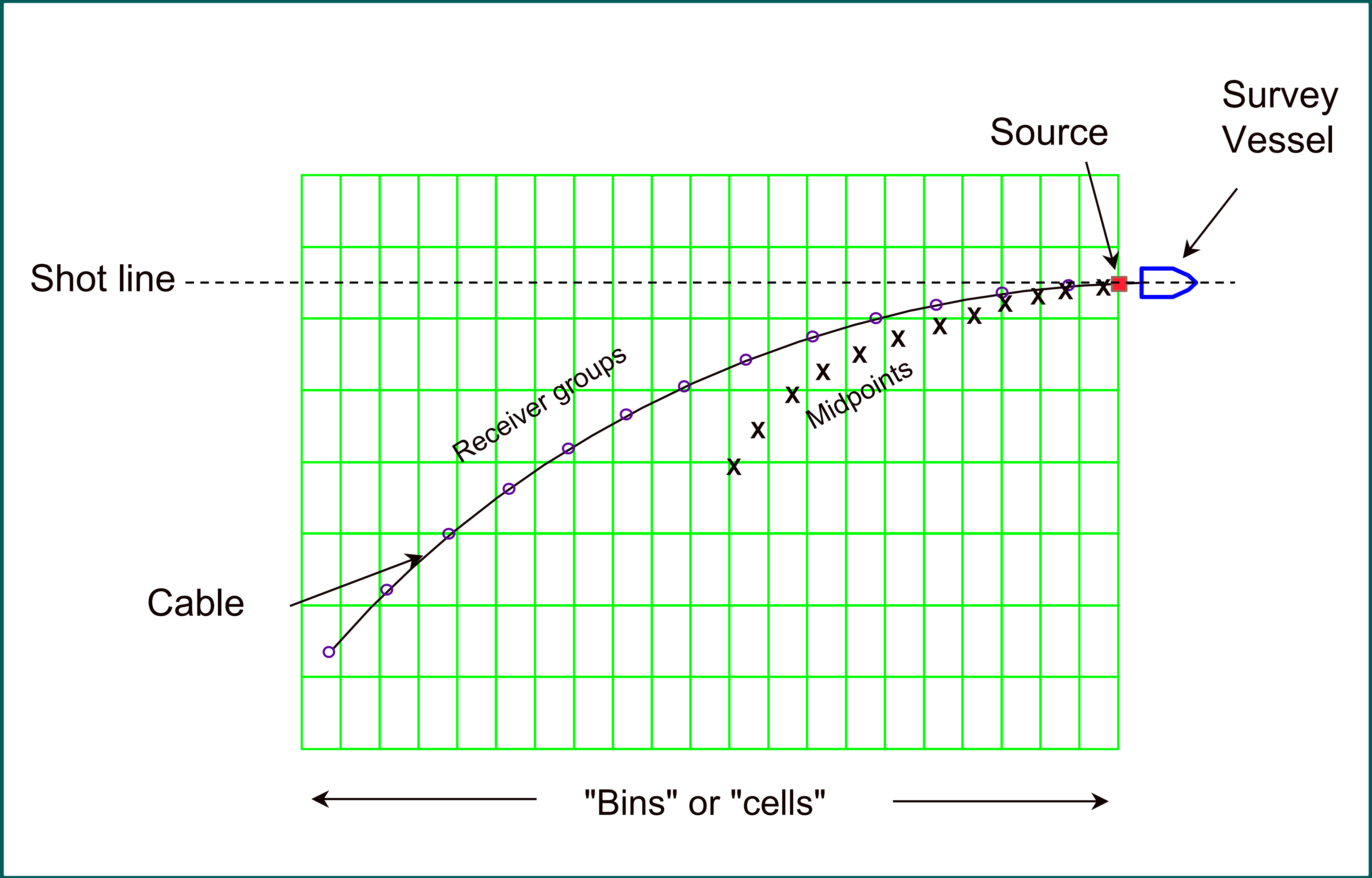
Fast Track Cube

examples

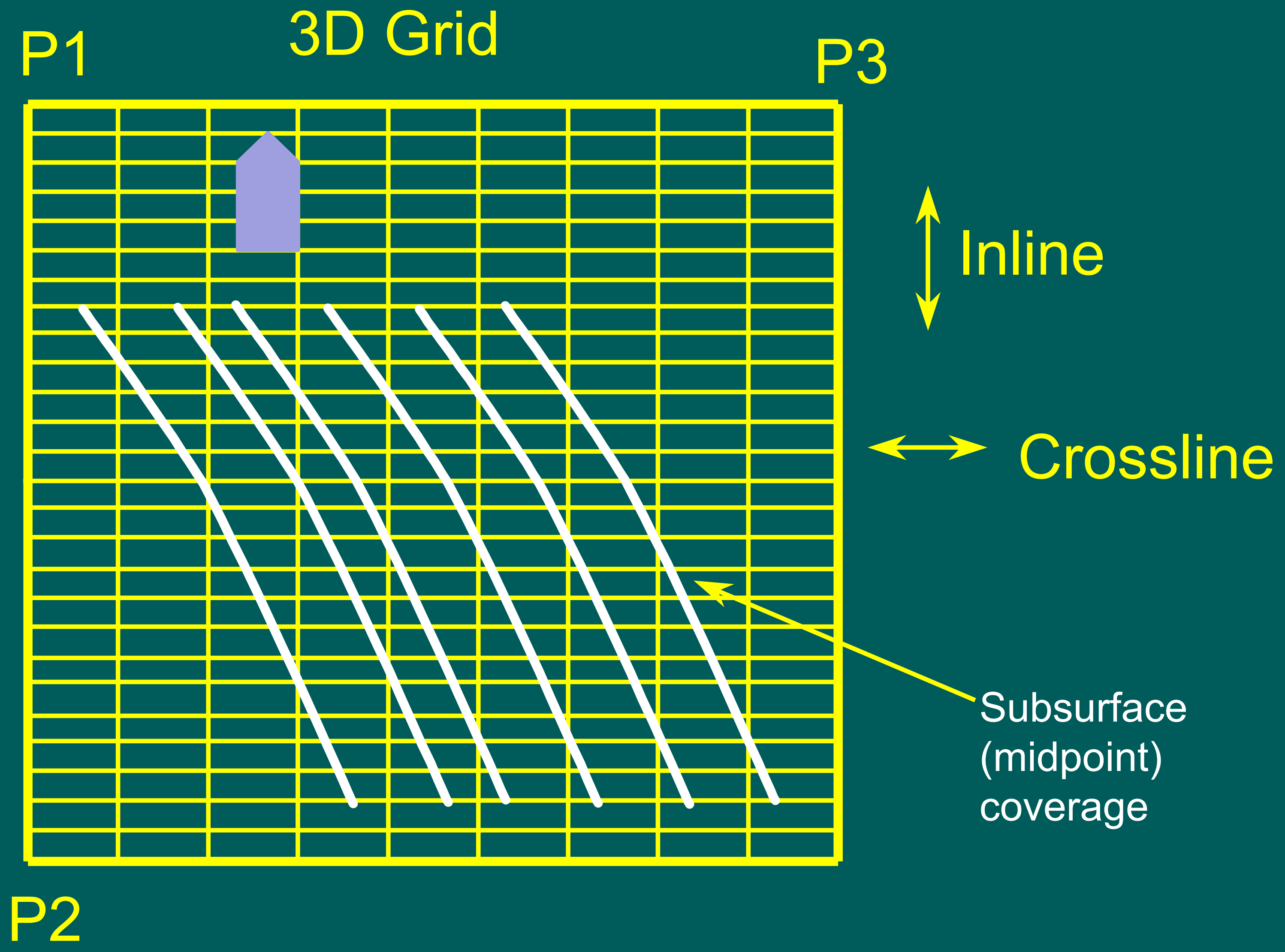
Marine Survey QC

- Assurance and verification of seismic survey coverage
- Assurance and verification of seismic data quality.
- Assurance and verification of positioning data quality.

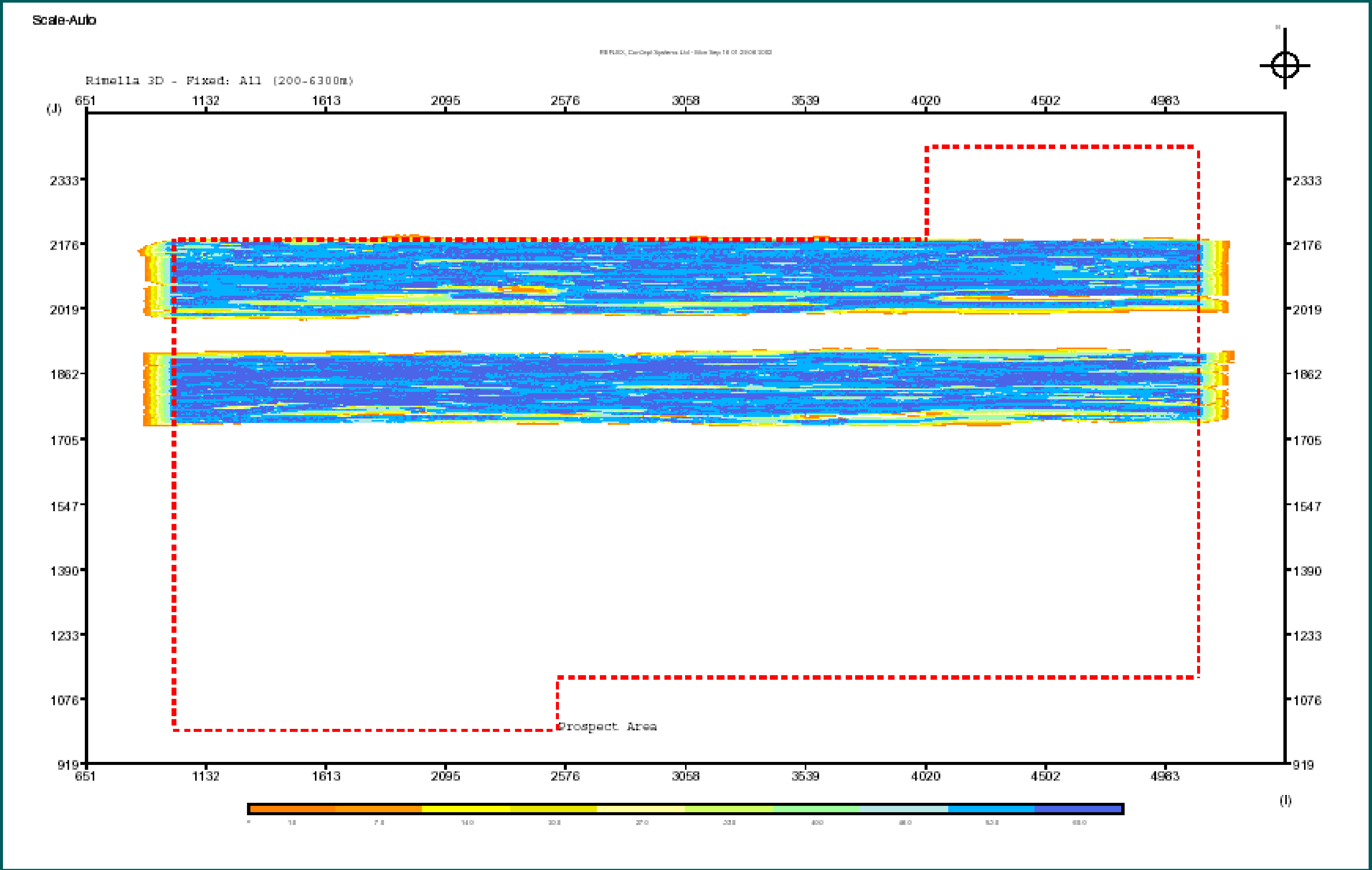
Mid-point Scatter and “Bin” Definition



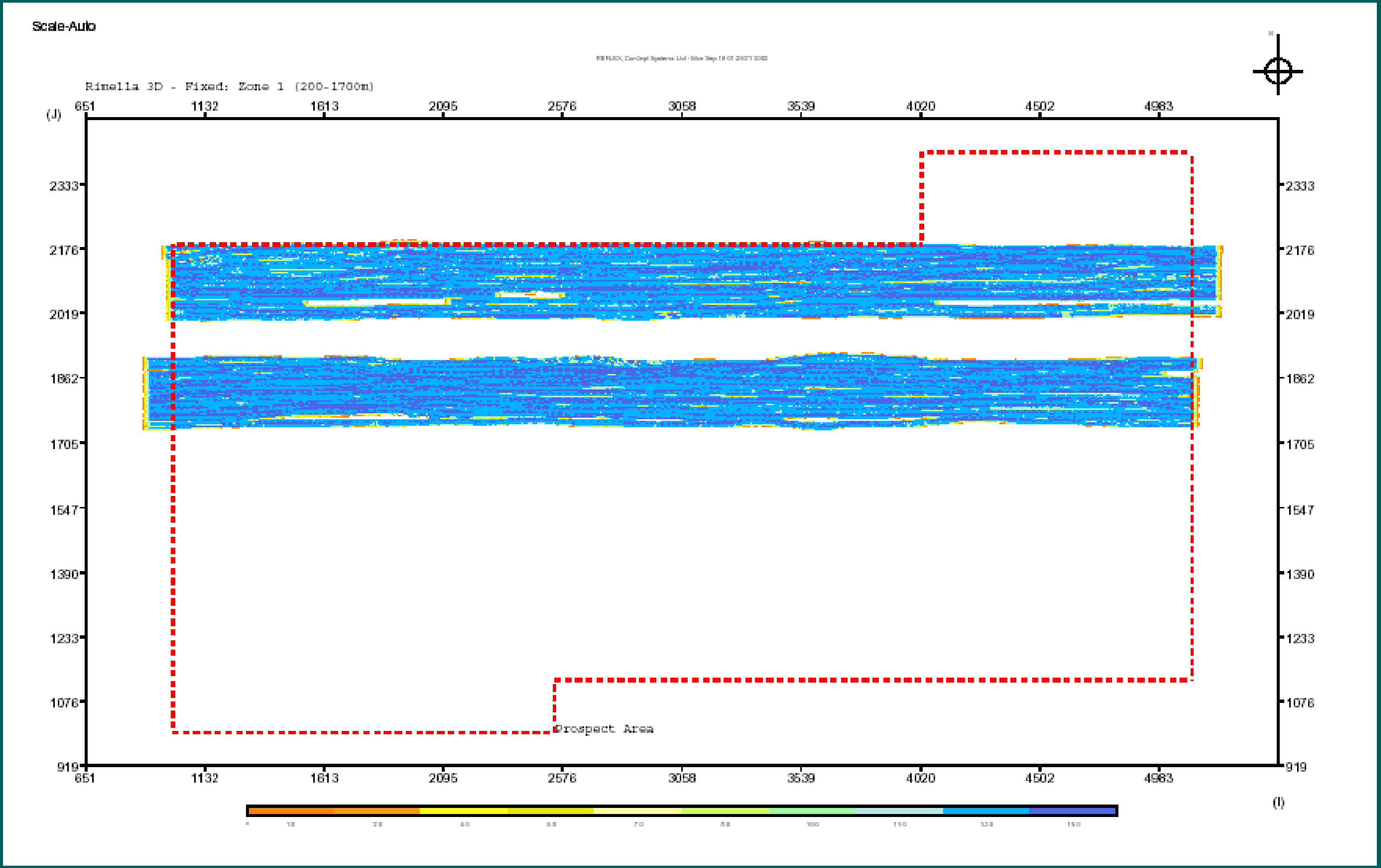
3D Subsurface Coverage



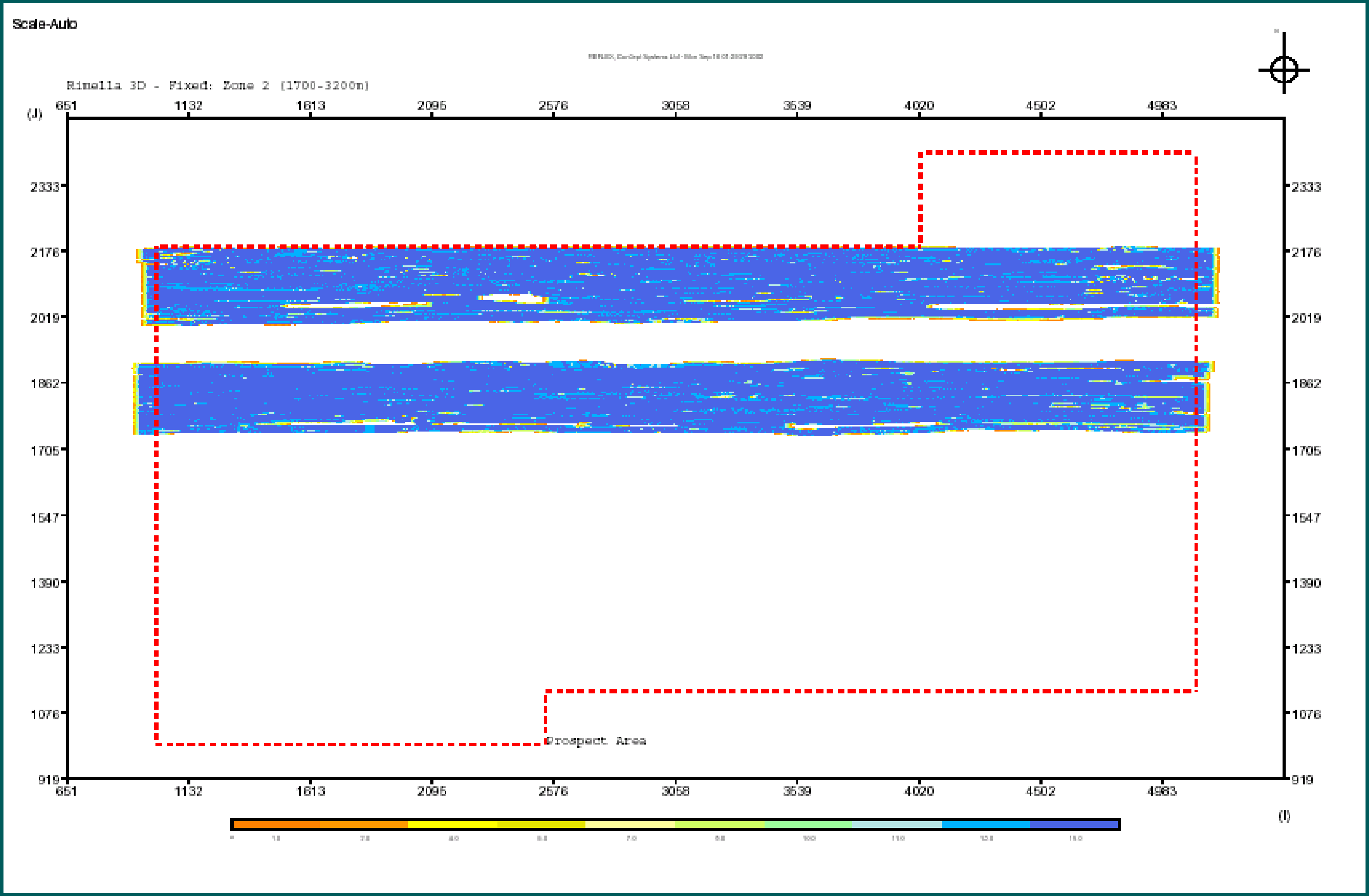
3D Offset Binning: All Offsets



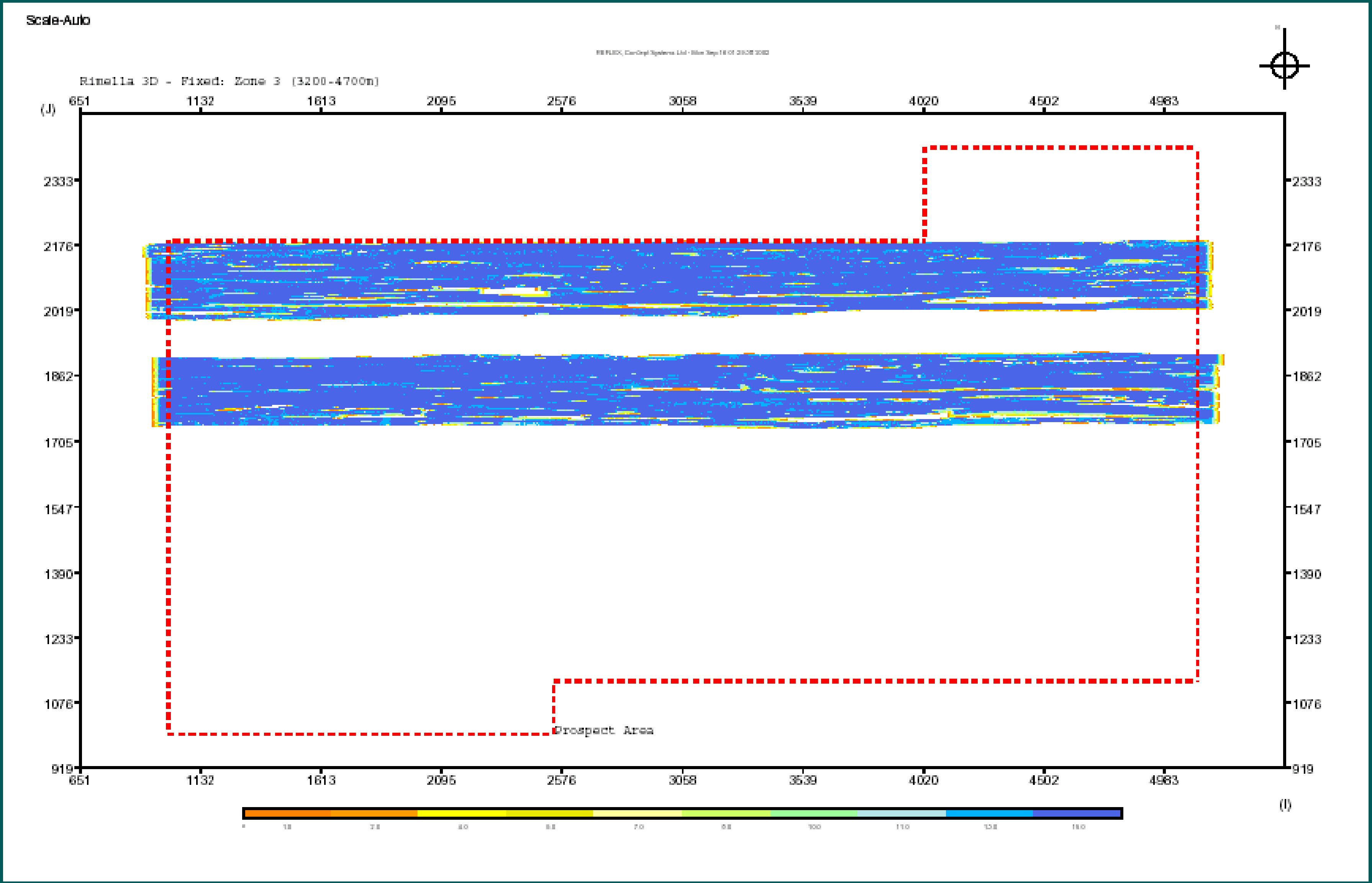
3D Offset Binning: Zone 1 (Nears)



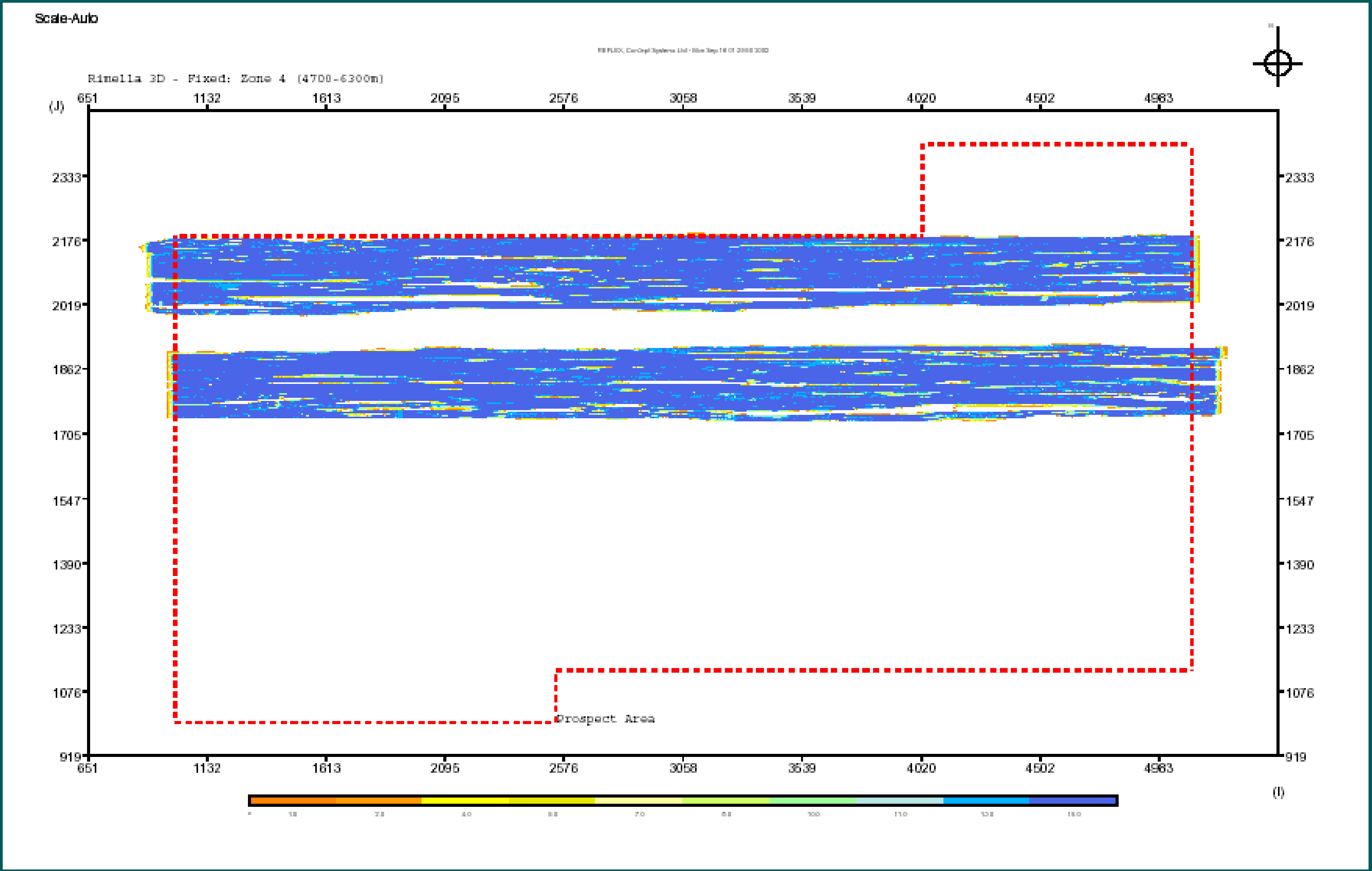
3D Offset Binning: Zone 2 (Near-Mids)



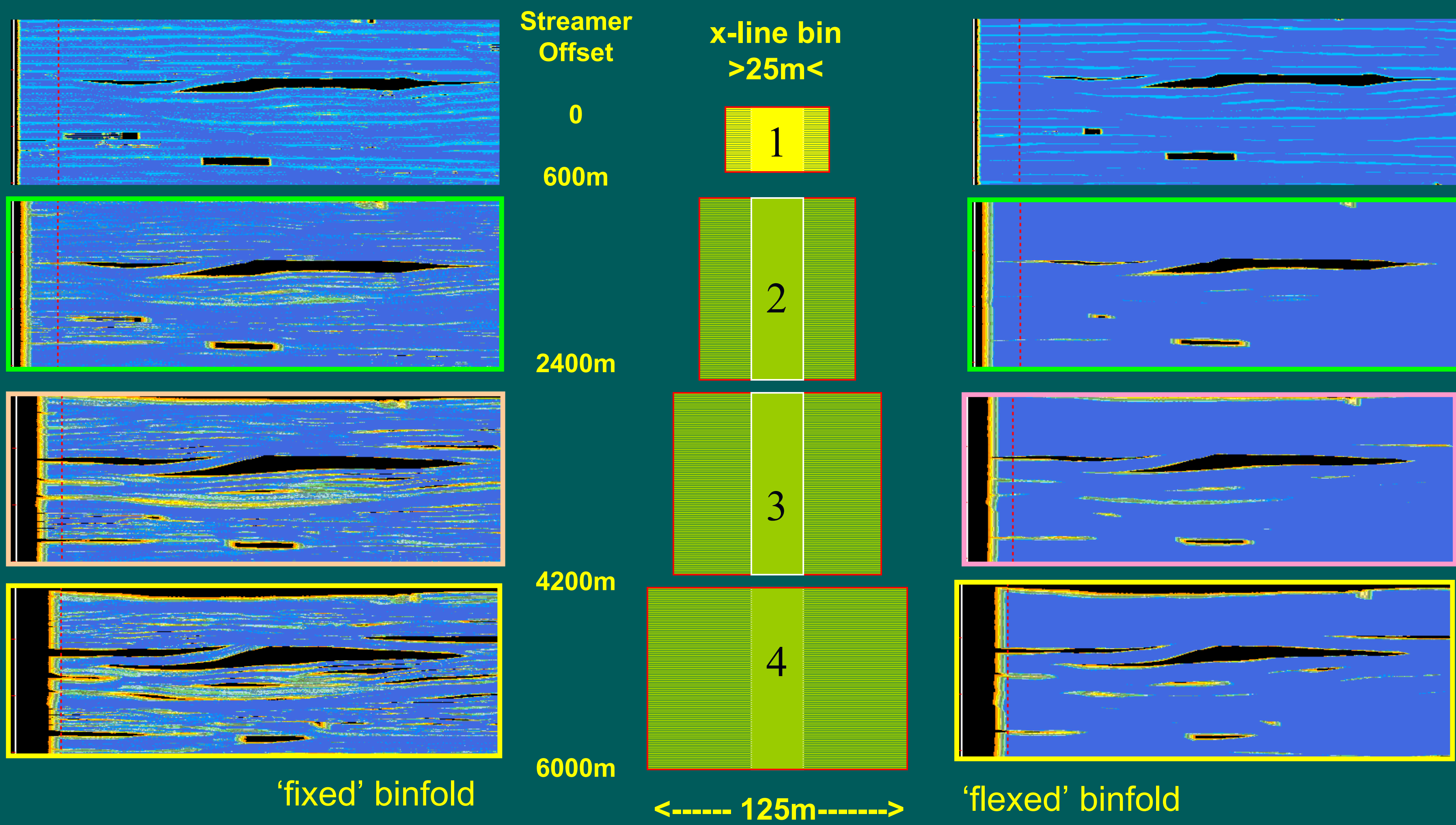
3D Offset Binning: Zone 3 (Far-Mids)



3D Offset Binning: Zone 4 (Fars)

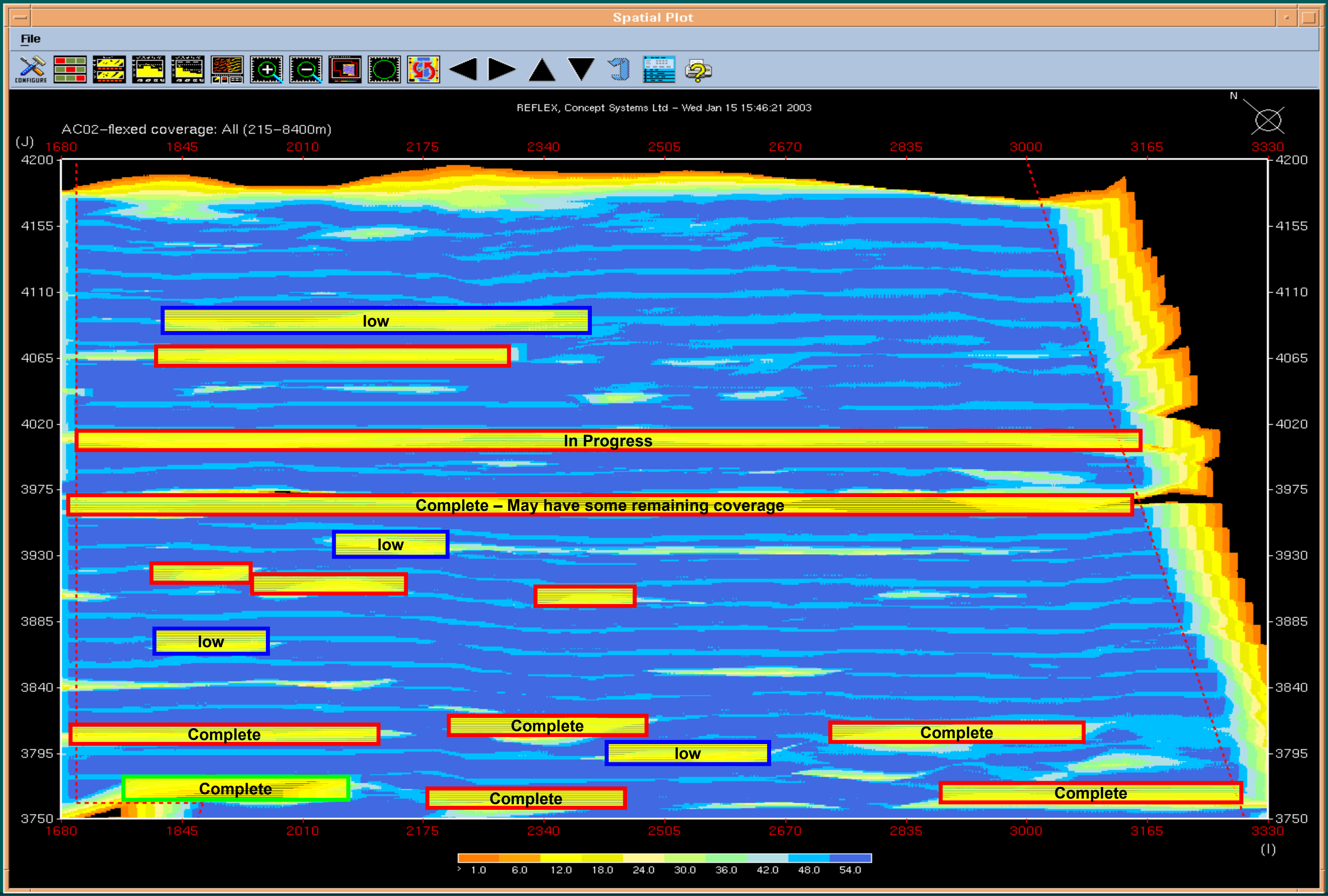


Binning

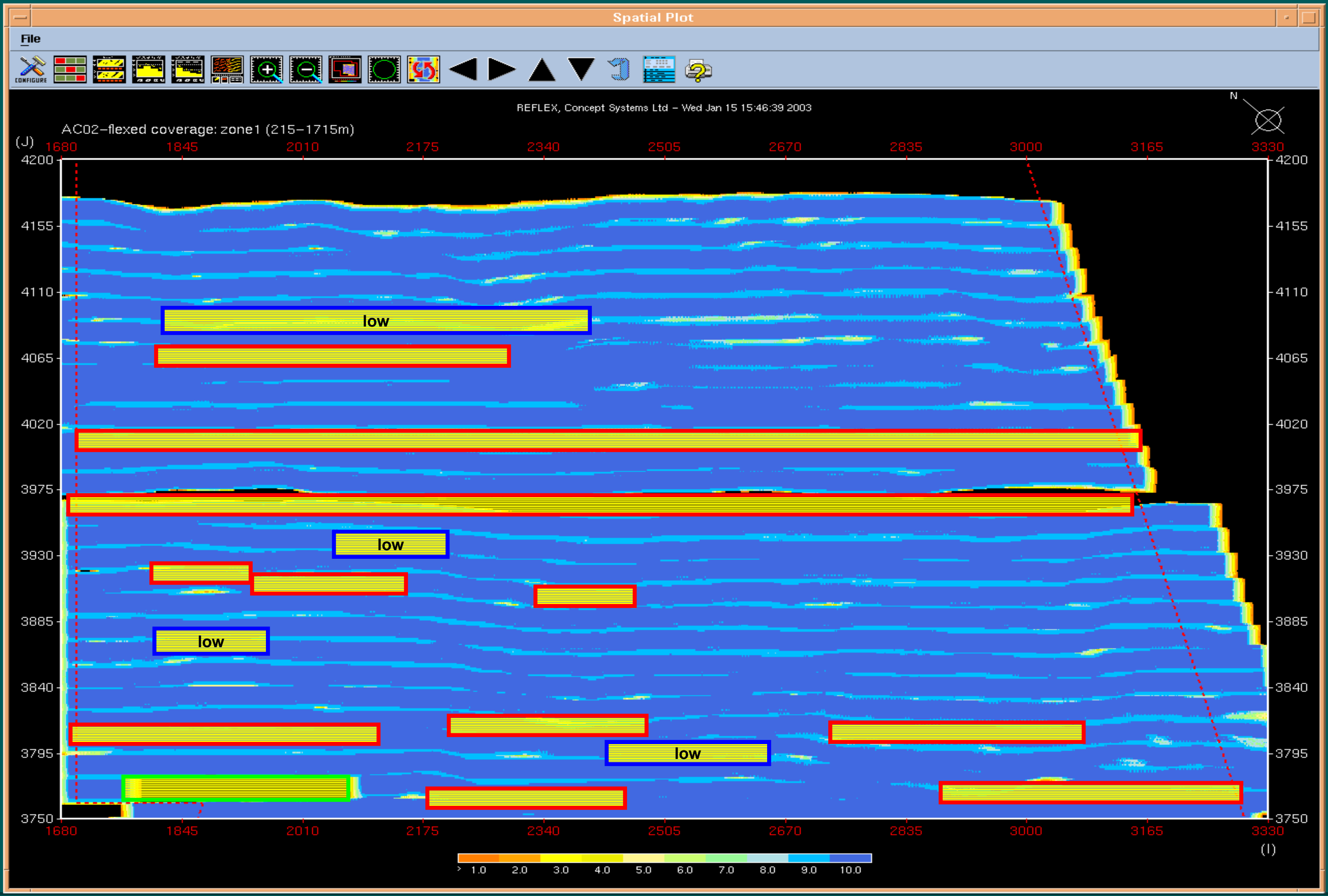


Effect of flexed-binning on fold displays

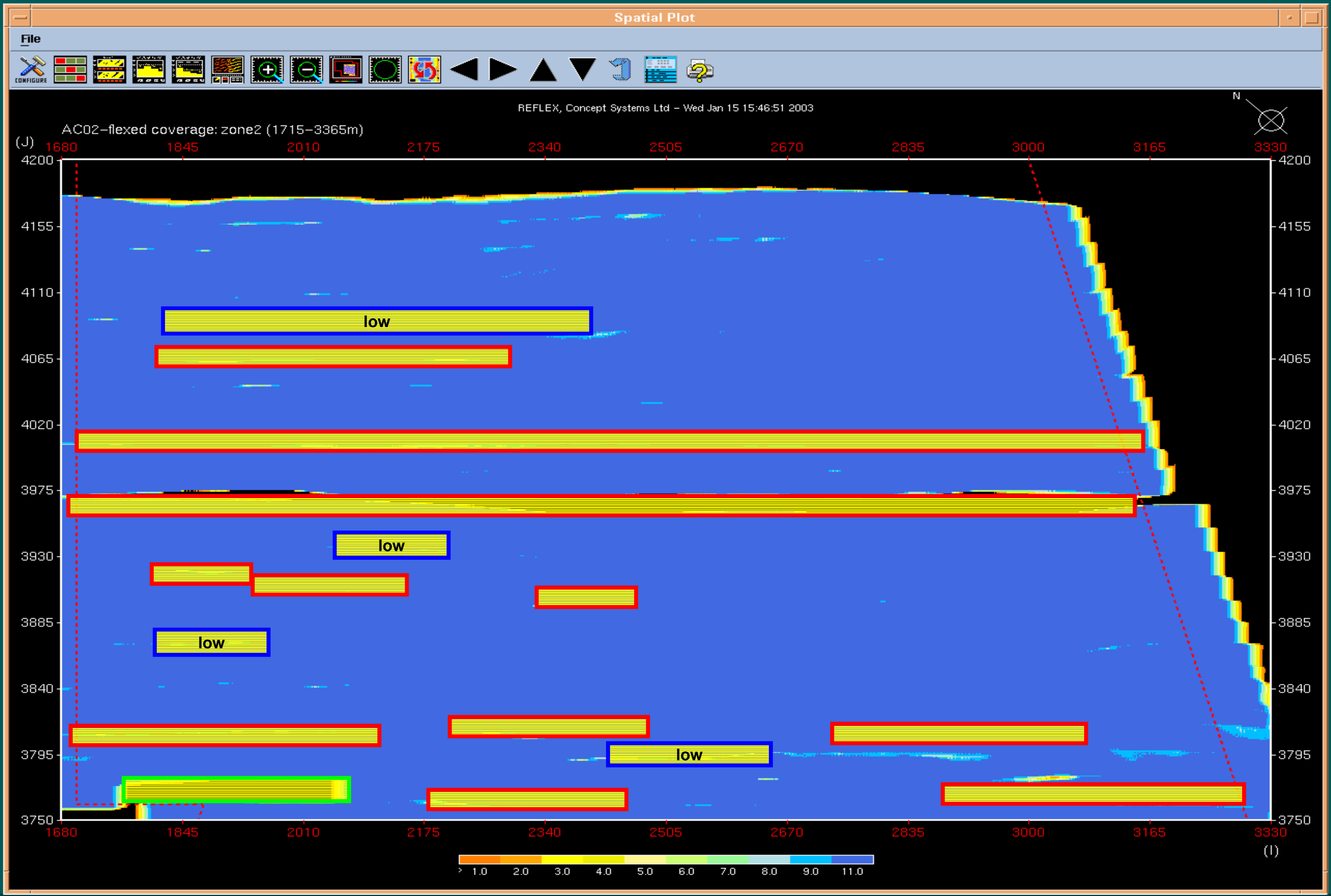
All Offsets – Racetrack 1 Flexed



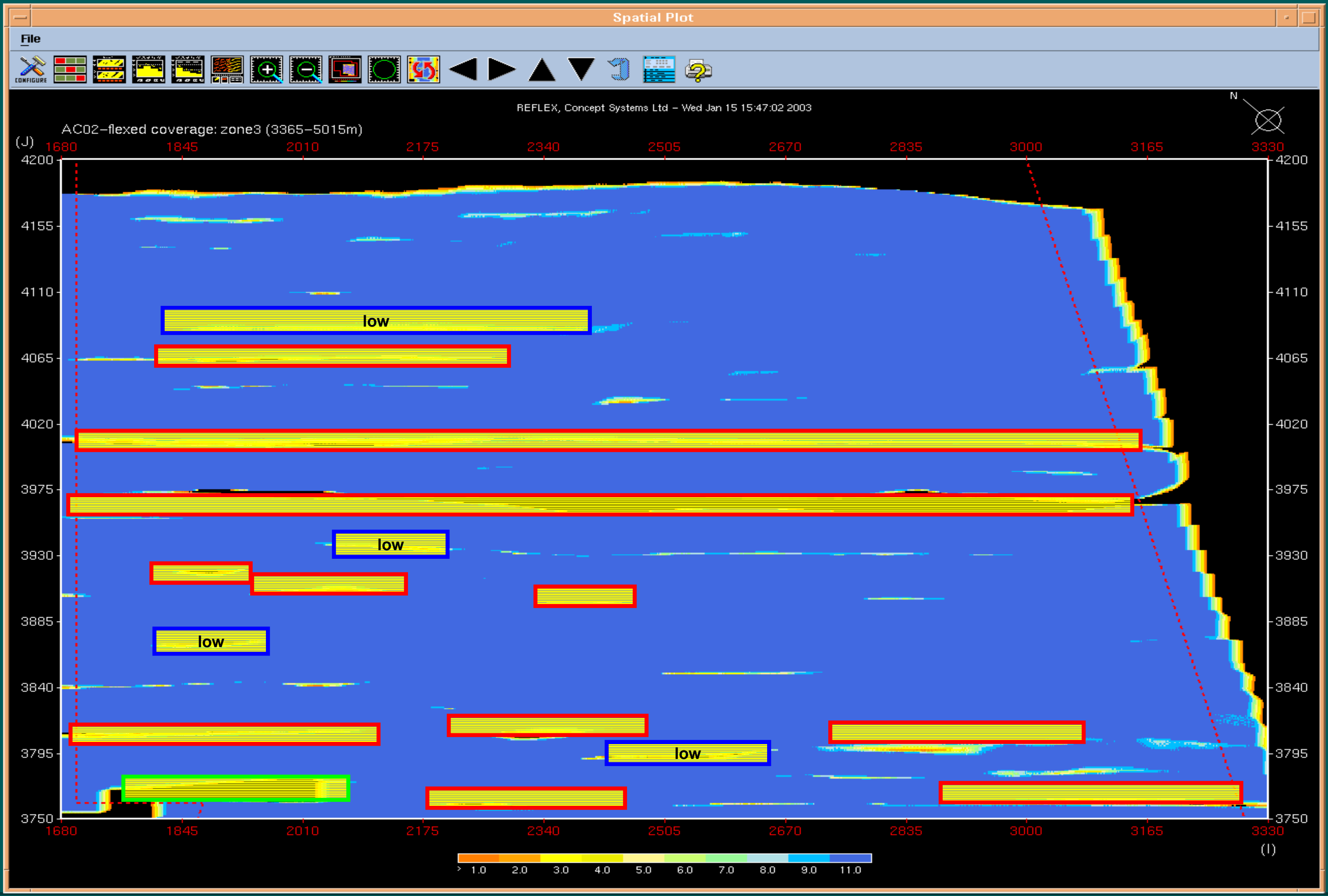
Zone 1 – Racetrack 1 Flexed



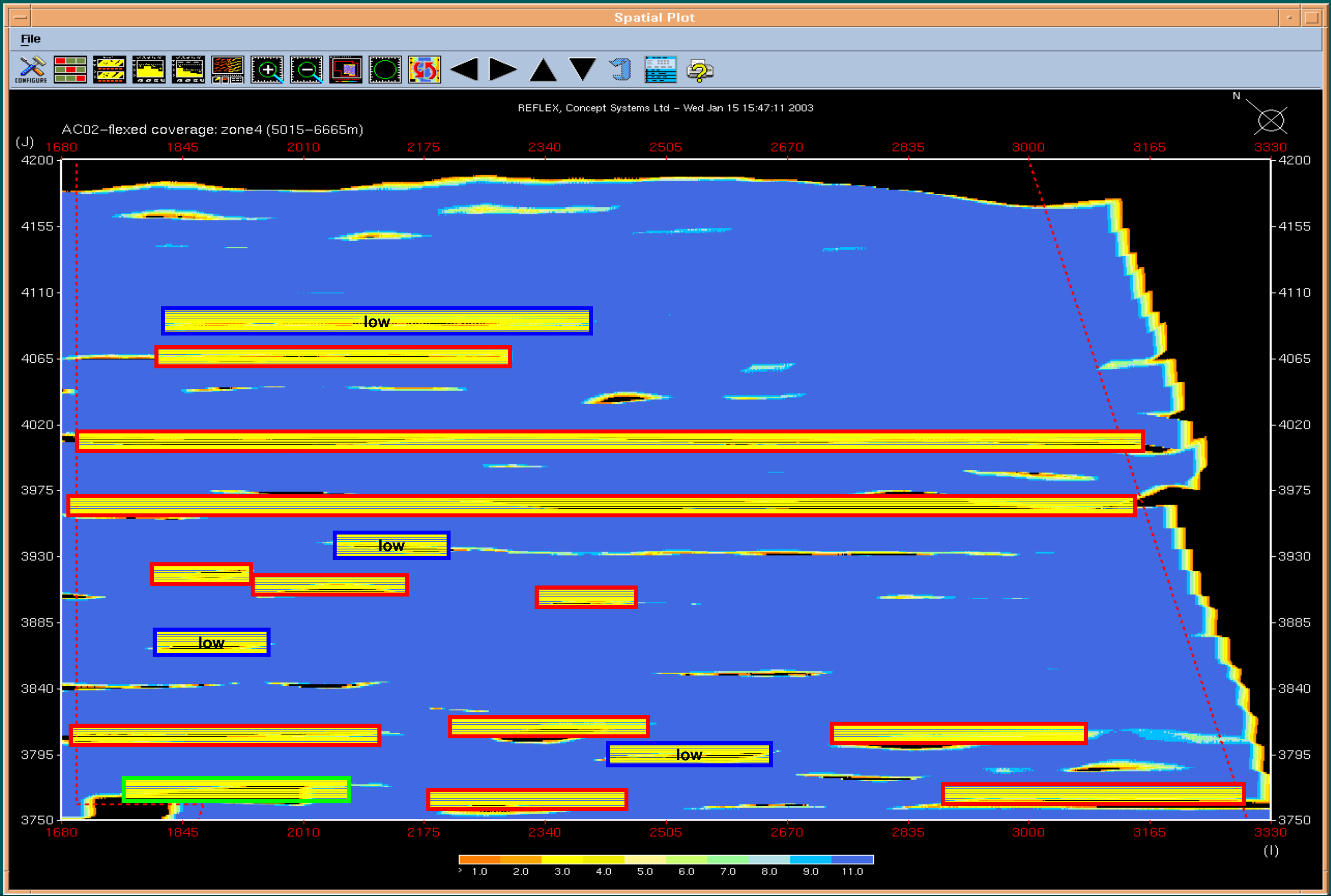
Zone 2 – Racetrack 1 Flexed



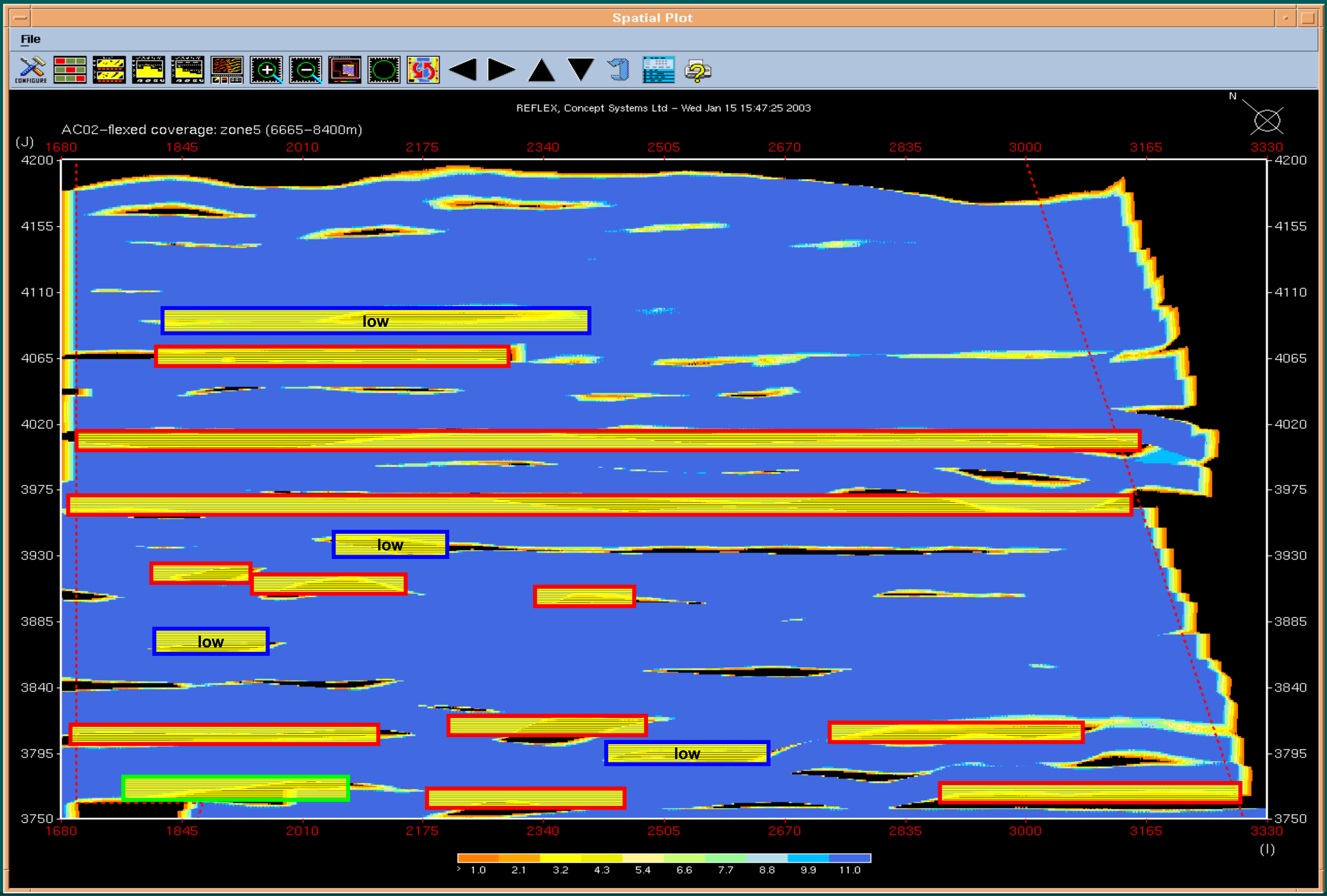
Zone 3 – Racetrack 1 Flexed



Zone 4 – Racetrack 1 Flexed



Zone 5 – Racetrack 1 Flexed



Infill Planning Summary

- Images include up to sequence 158
- Time estimates from Sequence 159 SOL (03:04 15/Jan/2002)
- Time to record all remaining passes 42 hrs

- Time to line change all remaining passes 24 hrs
- Total time to record and line change 66 hrs
- Regional Downtime to date 40.0%
- Technical Downtime to date 0.01%

- **Total time including all Downtime 92 hrs**
- **Final Infill Percentage 18%**
- **Completion Date 19th Jan**

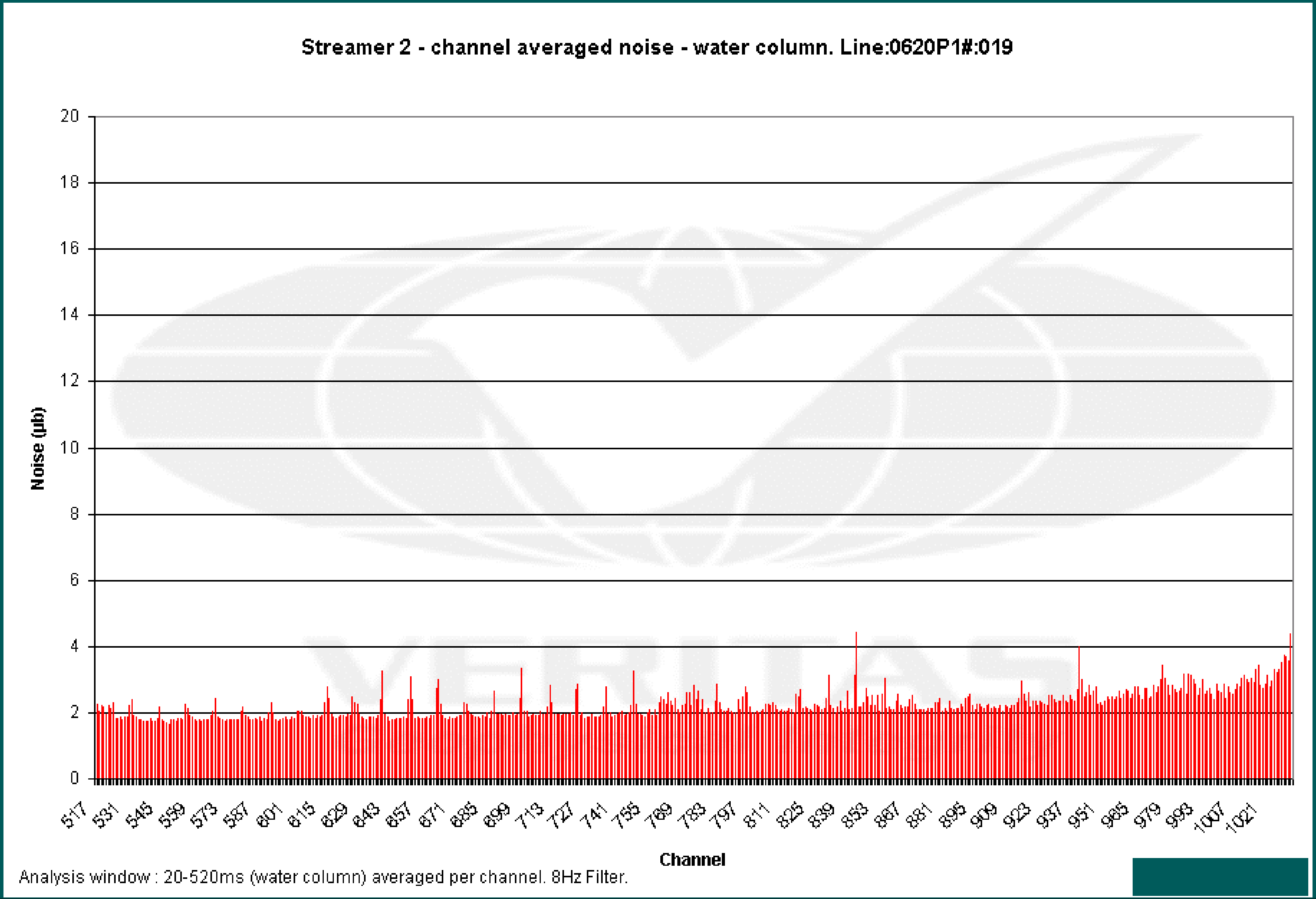
How Much Fill is Required?

- Fill requirements are obvious related to the survey objectives, geologic setting, the frequency bandwidth of the seismic data, spatial sampling requirements, and so forth, so it impossible to make blanket statements concerning fill requirements
- Fold decimation studies conducted on 2D data during the survey pre-planning stage can play a vital role in establishing objective offset distribution and fill requirements
- Onboard seismic processing can obviously play a major role here if 3D bin stacks, rather than just bin attribute plots, are available to guide fill decisions
- Fill can always be reduced by bin expansion (overlapping or flex), but this expansion can attenuate high frequency components of dipping events during stacking

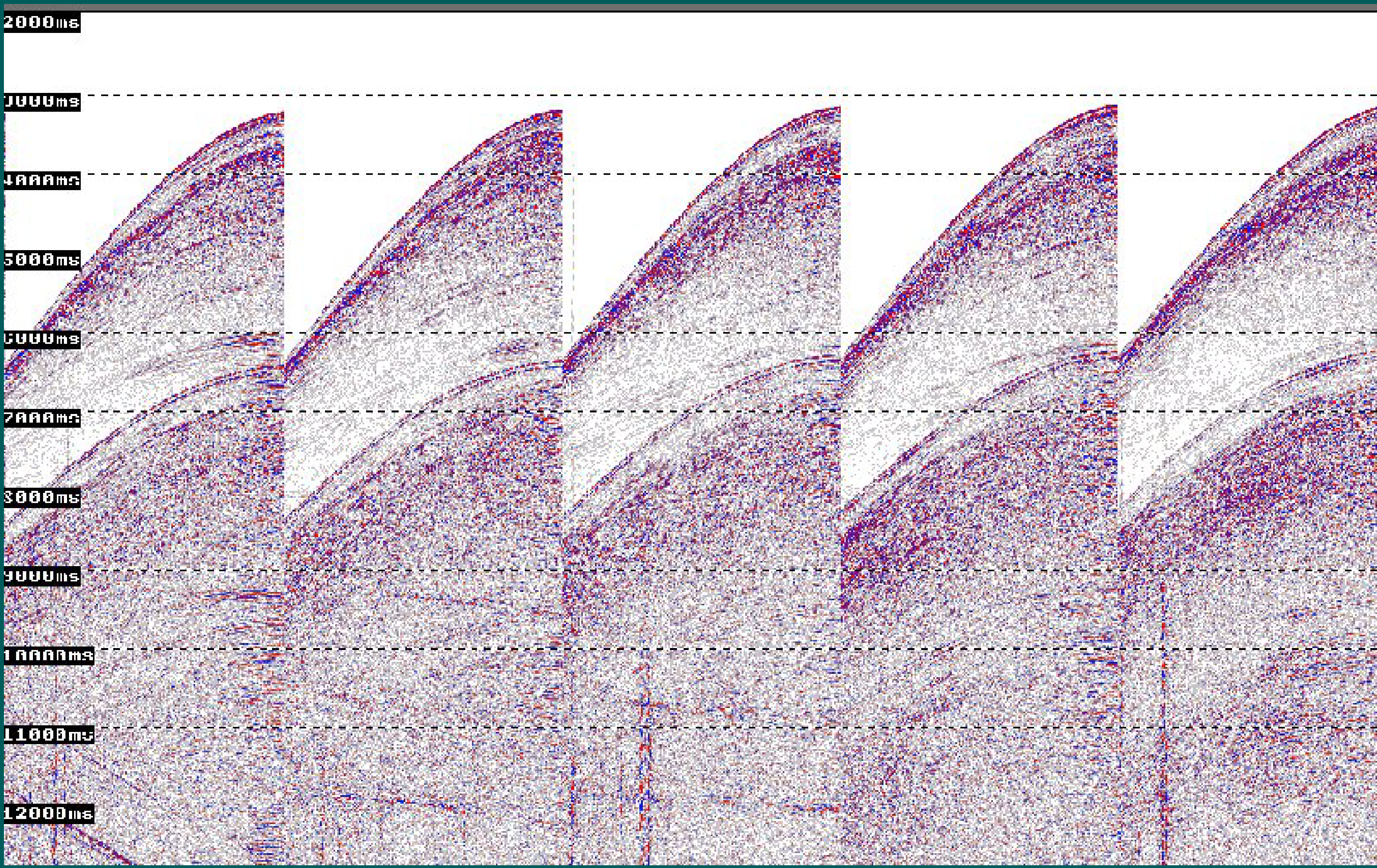
Marine Survey QC

- Assurance and verification of seismic survey coverage
- Assurance and verification of seismic data quality.
- Assurance and verification of positioning data quality.

RMS Evaluation – SOL / EOL

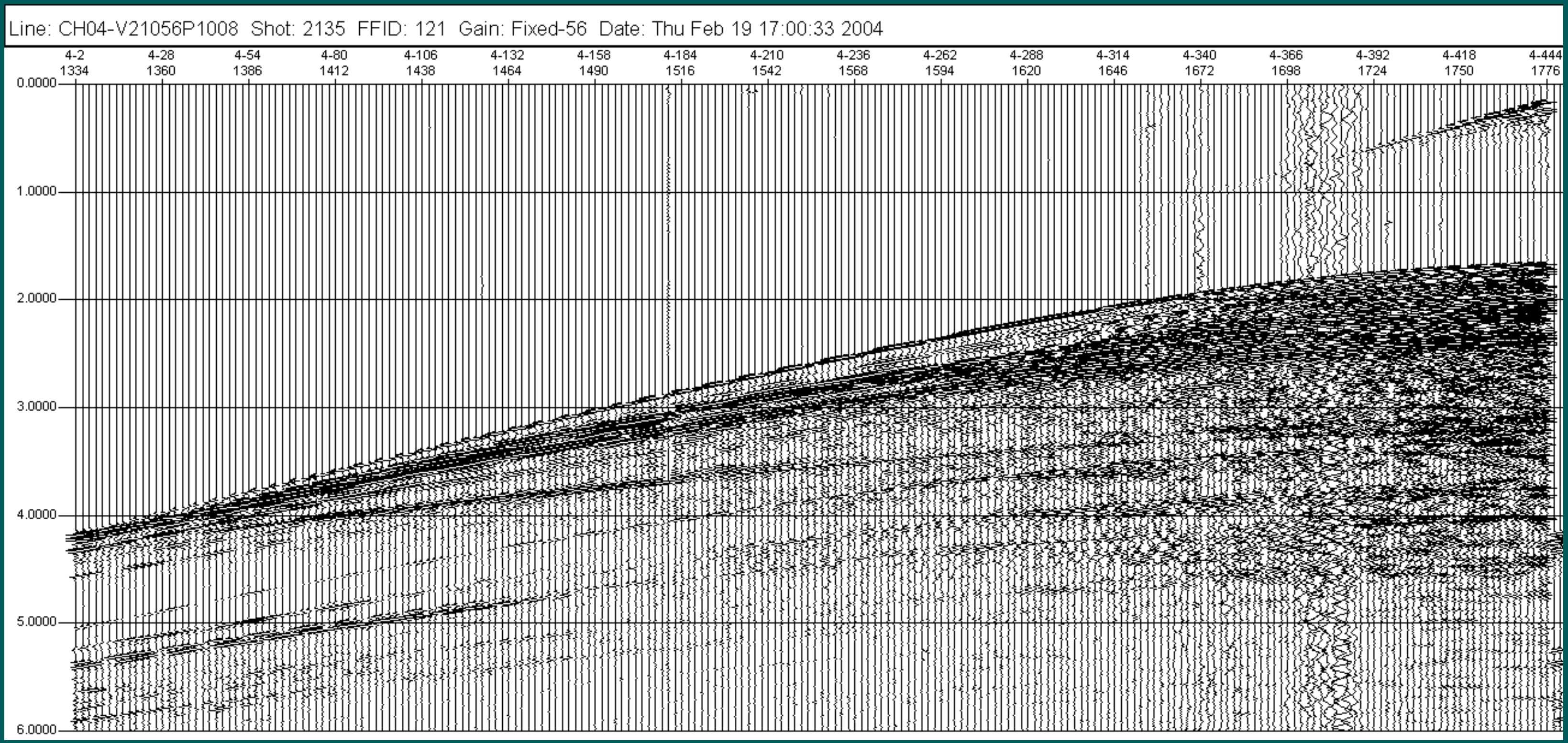


Raw Shots – Noise Evaluation



Shot Gather Availability

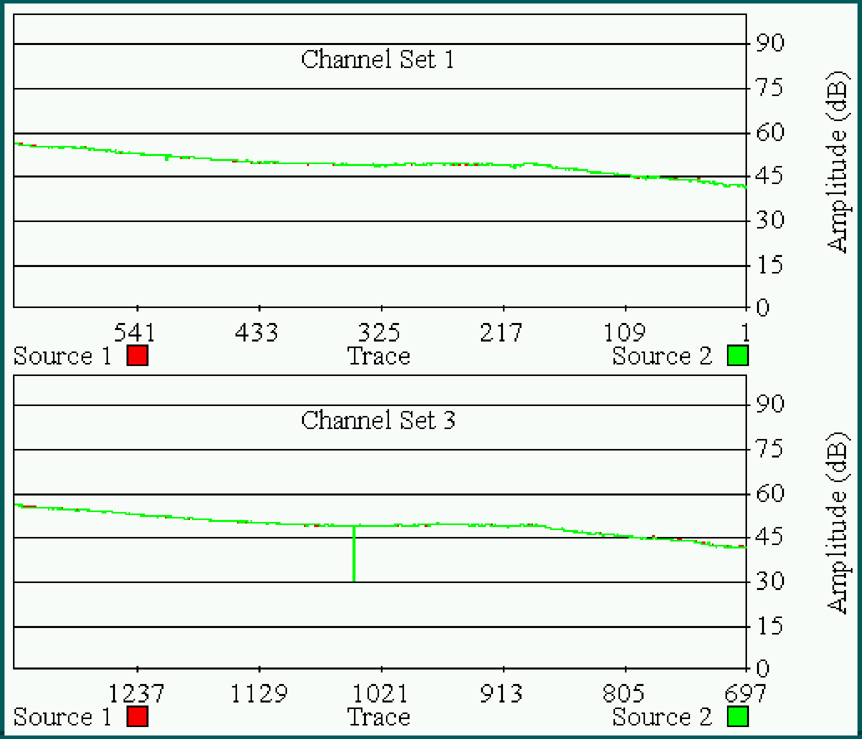
- Images stored to disk and accessed by QC View
- View 2 streamers for each image combing every 9th shot.
- Utility and Images are freely available to all on the ship's



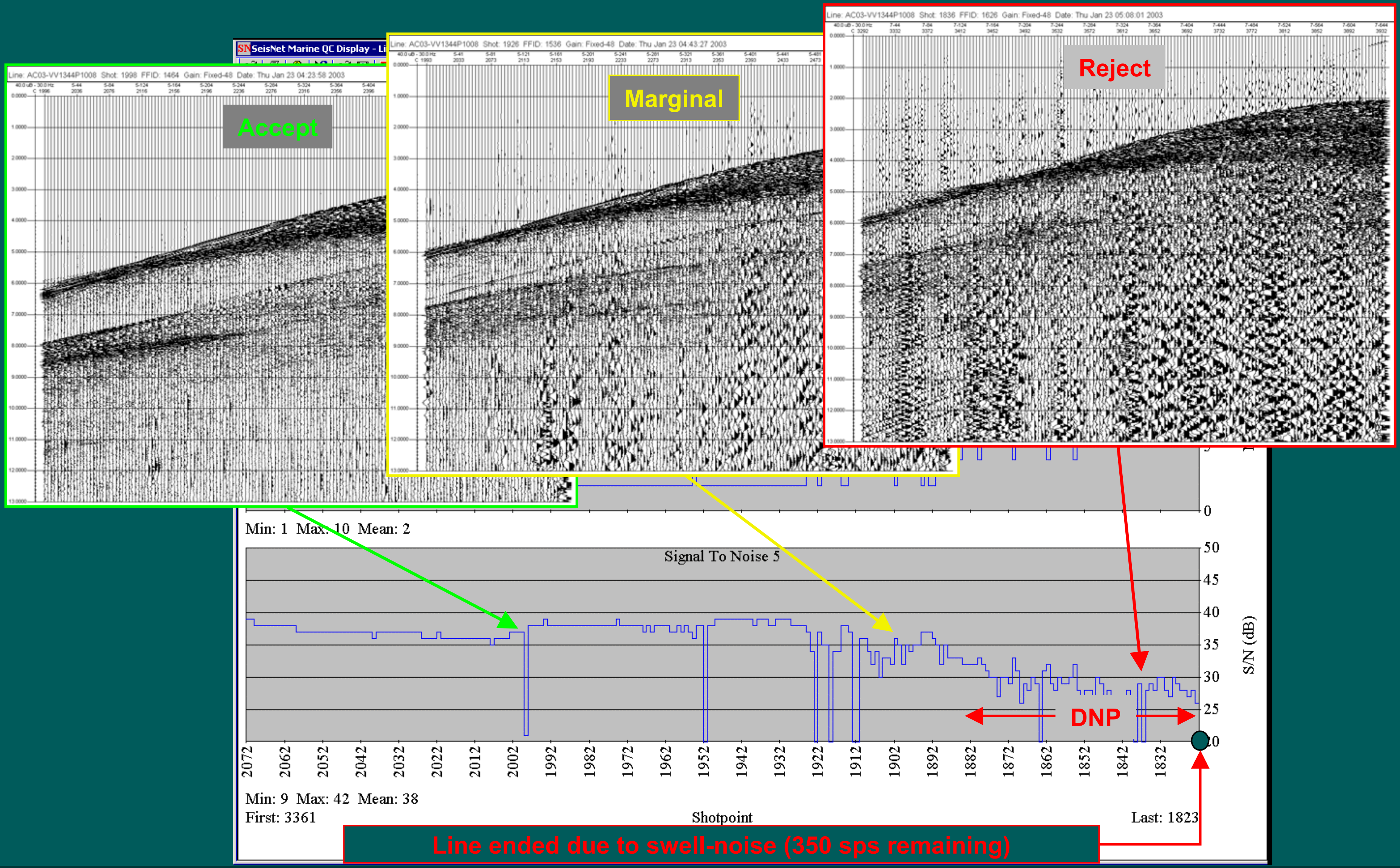
Lauch QC View

Real-Time Seismic QC

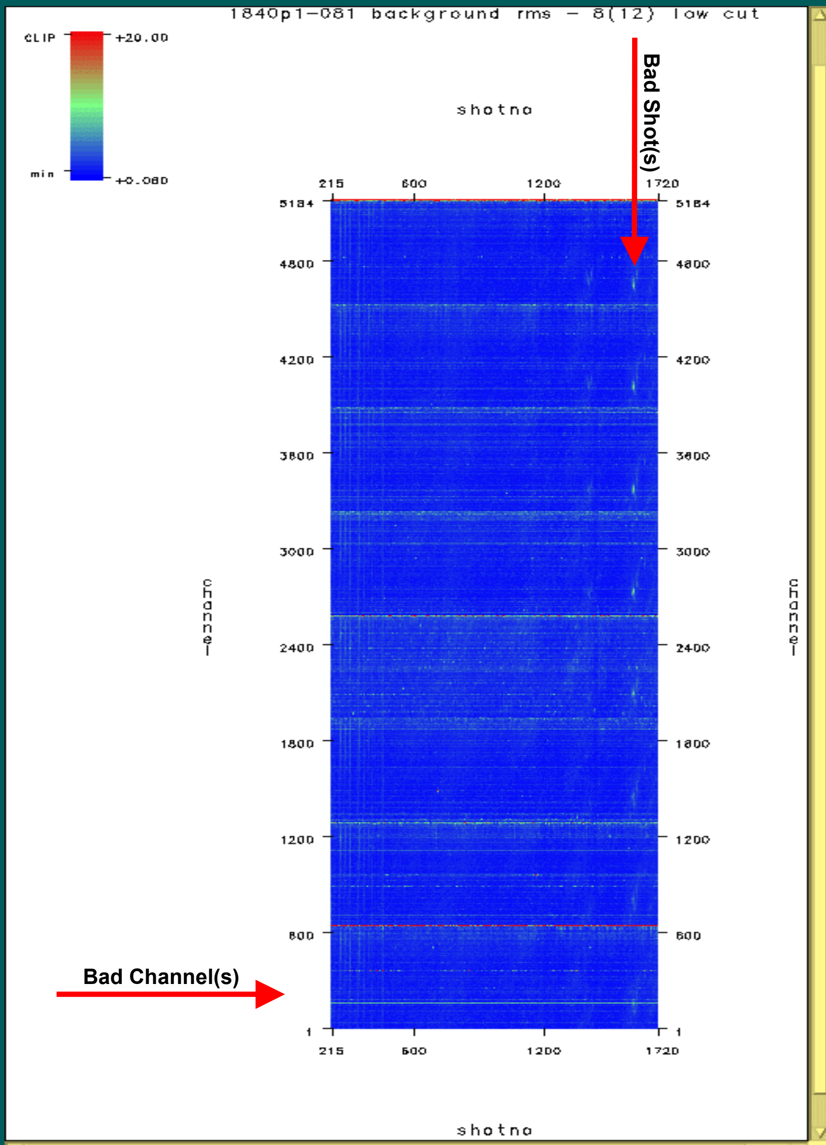
- **Seismic QC**
  - rms for all channels at each shot
  - Signal window rms calculated
  - Noise window rms calculated
  - Display S/N ratio
- **System QC**
  - Calculate rms at each channel for the water bottom
  - Average rms for each shot
  - For each streamer display all traces



Real-Time Seismic QC

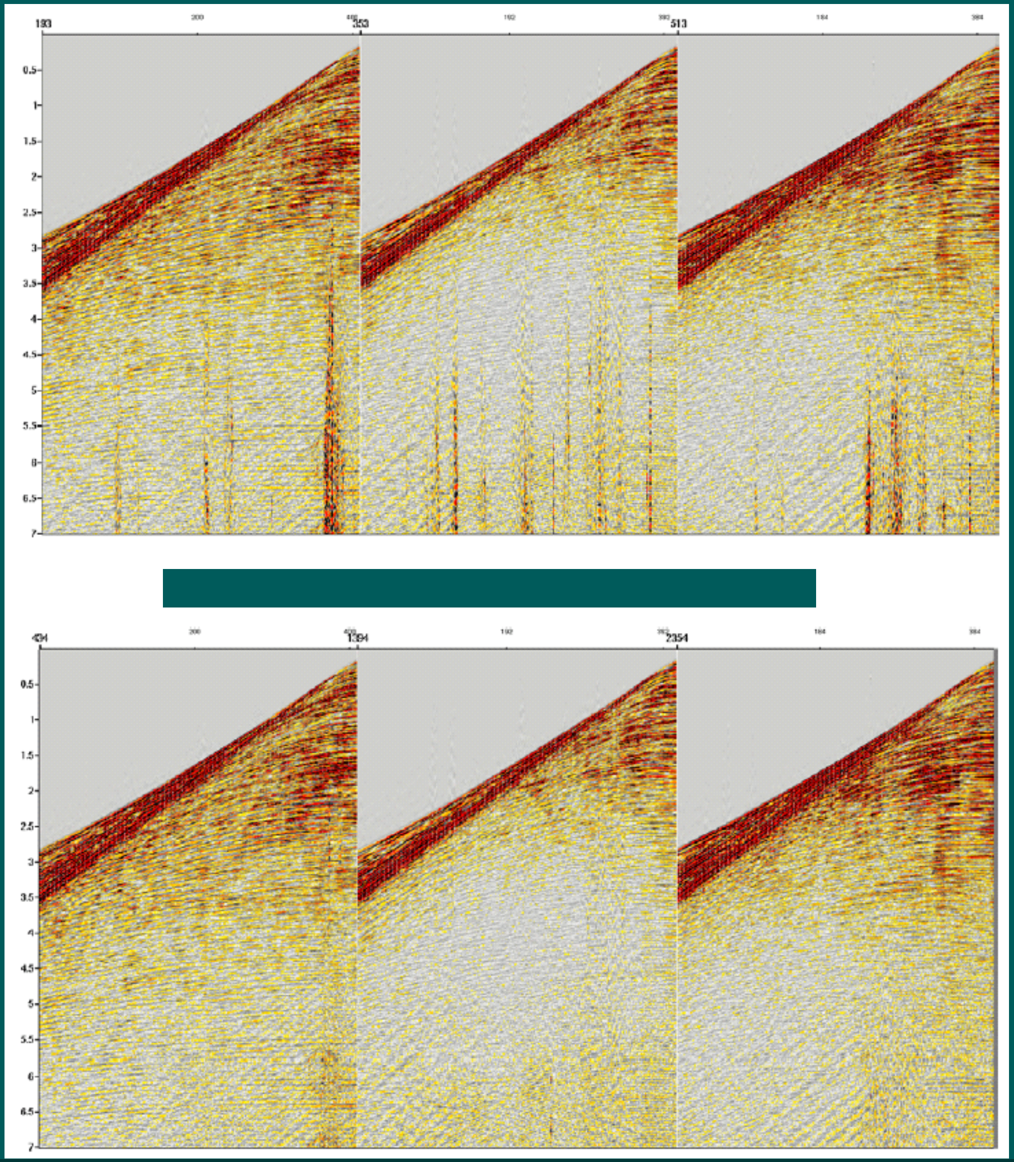


RMS Arial Color Grid



- **Purposes**
  - Detect noisy and bad traces
  - Detect bad shots
  - Trending in swell and SI
  - Streamer-to-streamer comparisons
  - Available for any configured window (target or noise)

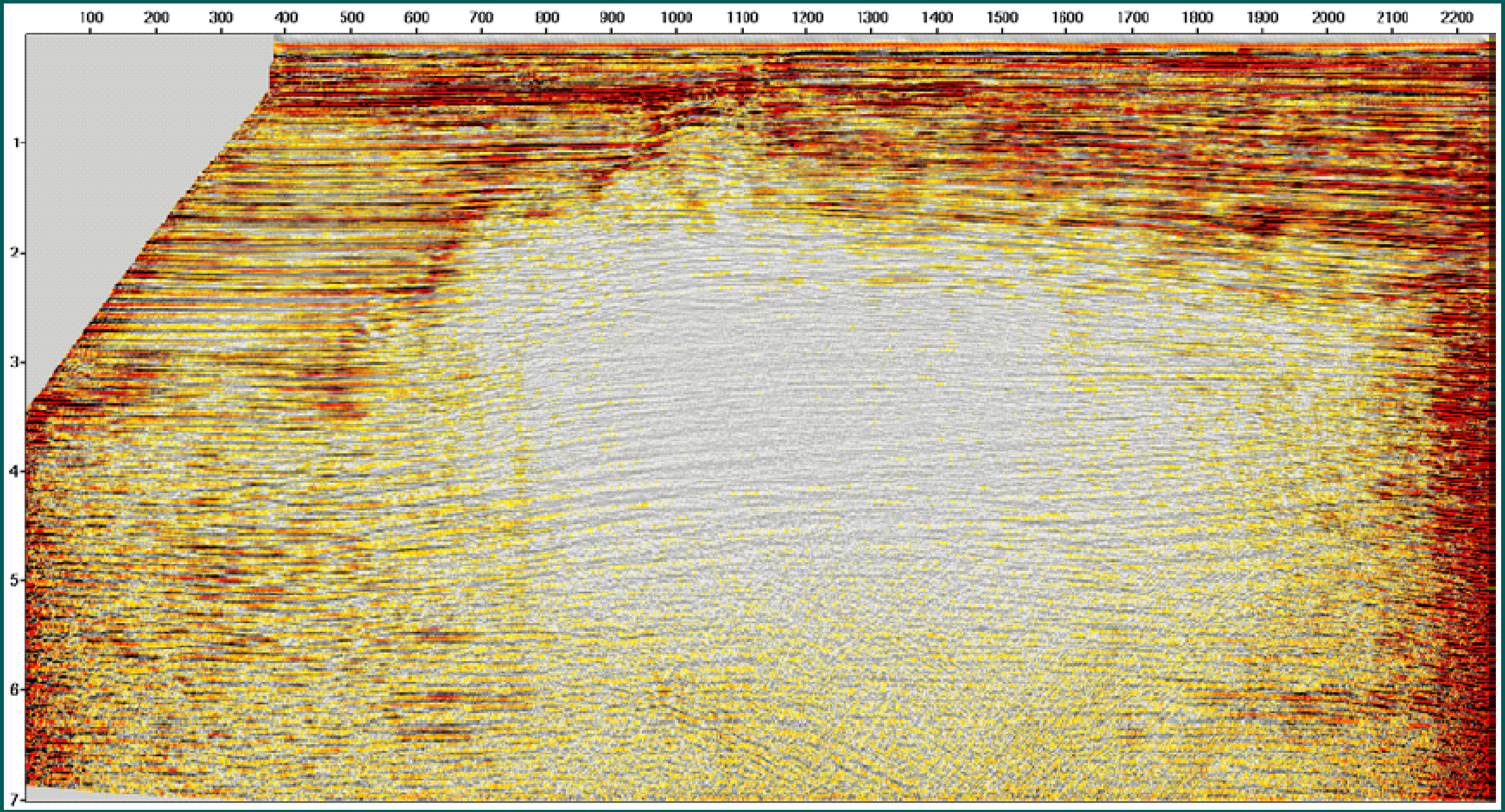
Noise Attenuation Testing



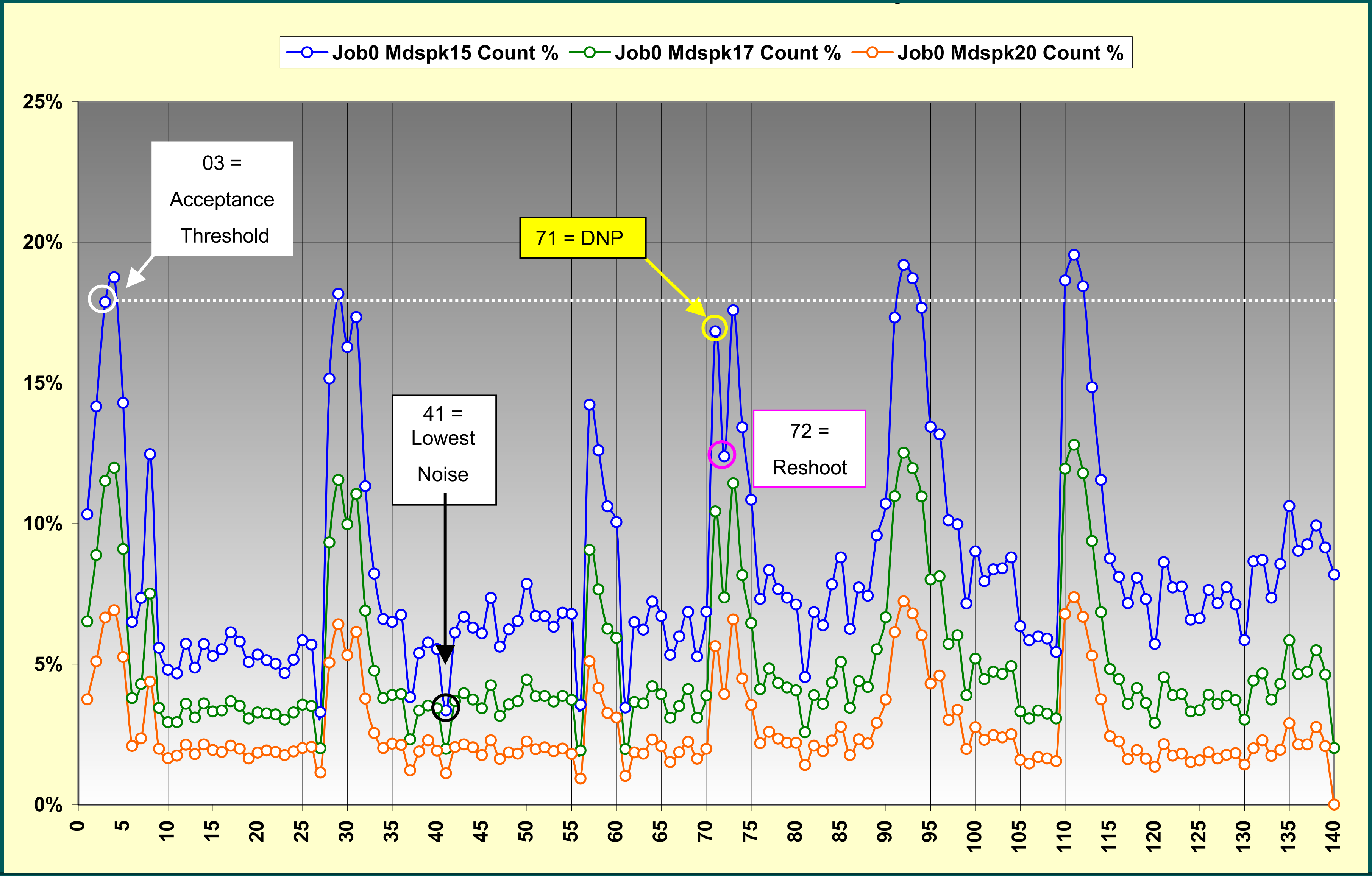
Before

After

Brute Stack w/wo noise attenuation



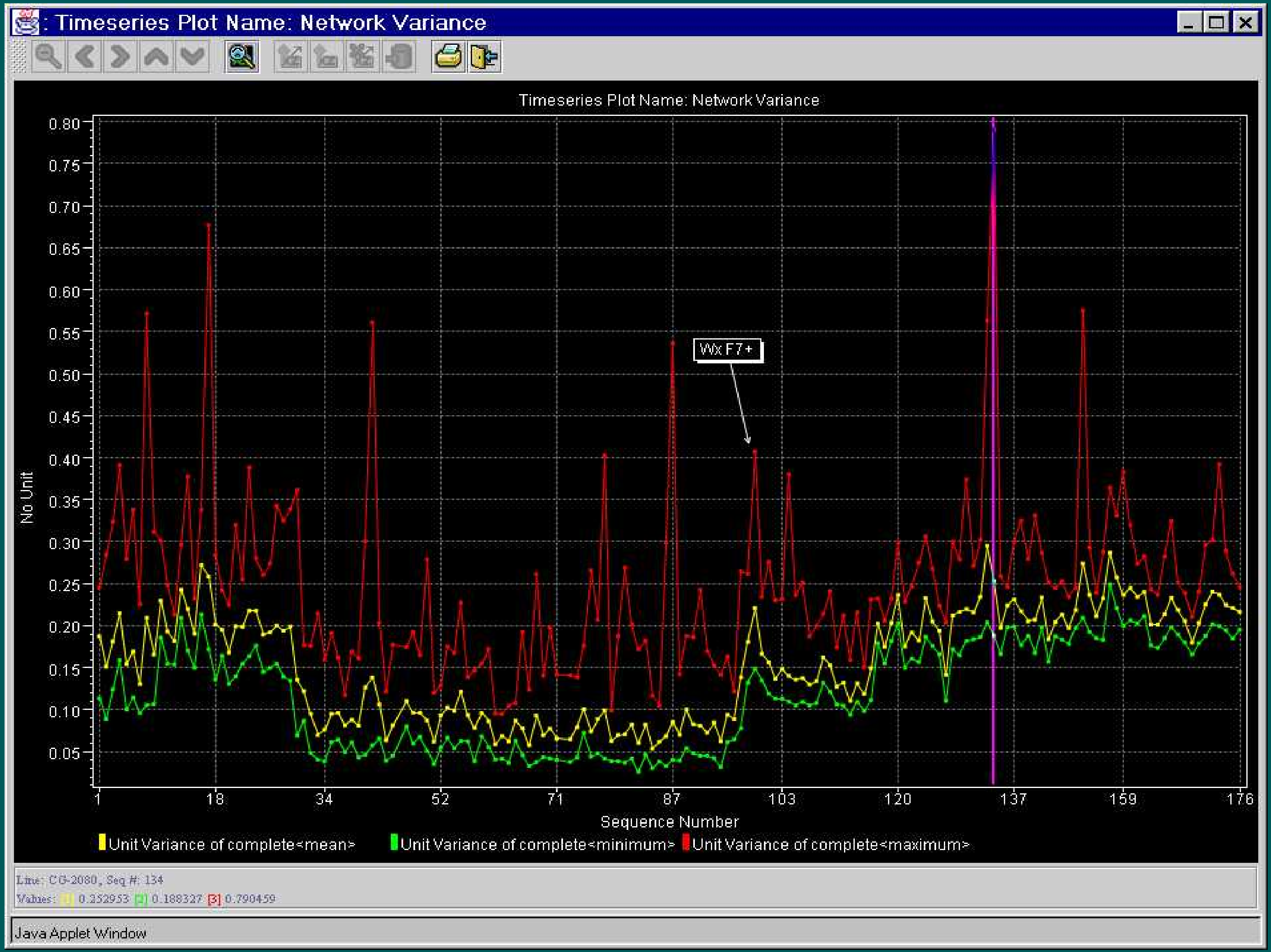
Swell noise evaluation



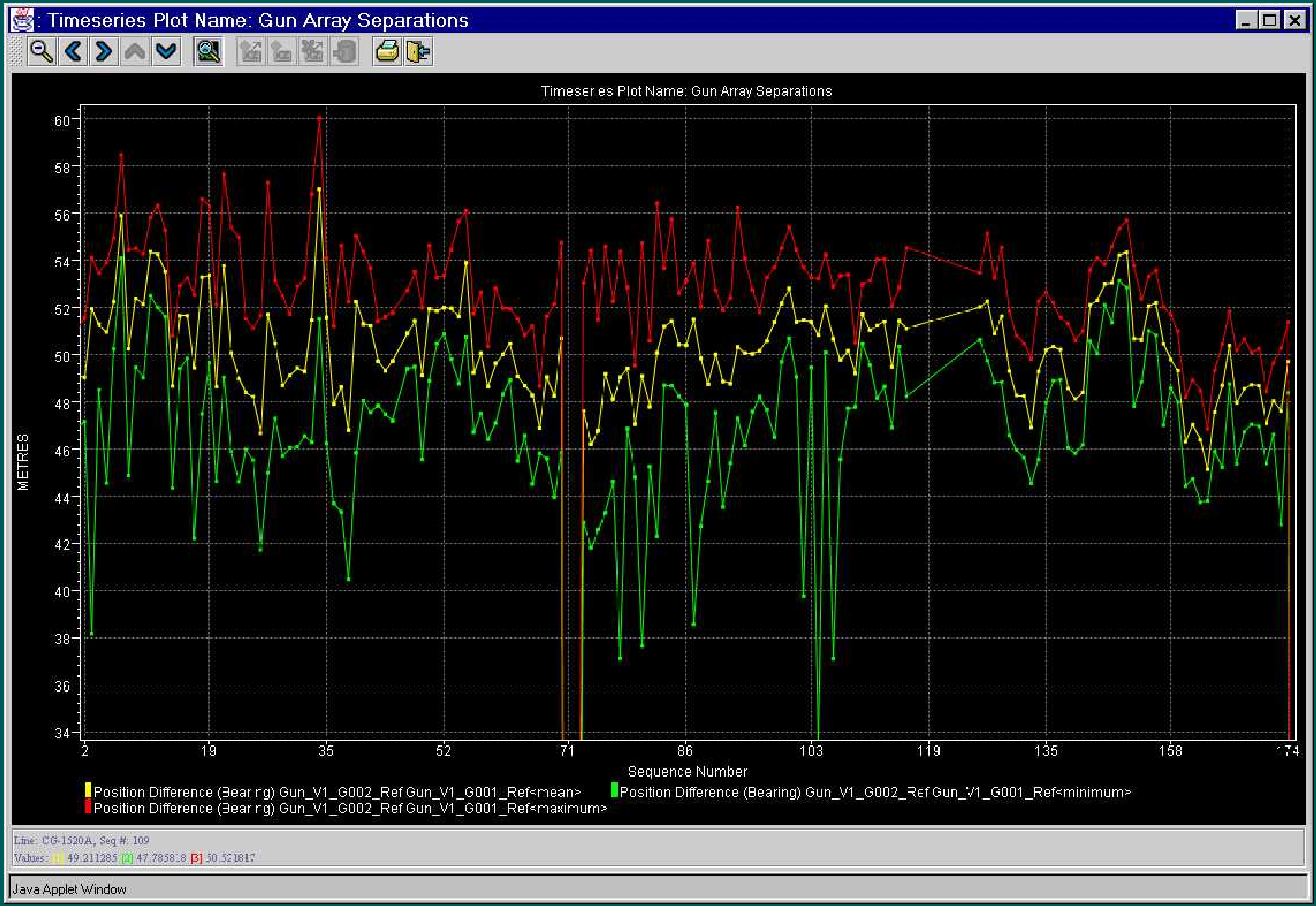
Marine Survey QC

- Assurance and verification of seismic survey coverage
- Assurance and verification of seismic data quality.
- Assurance and verification of positioning data quality.

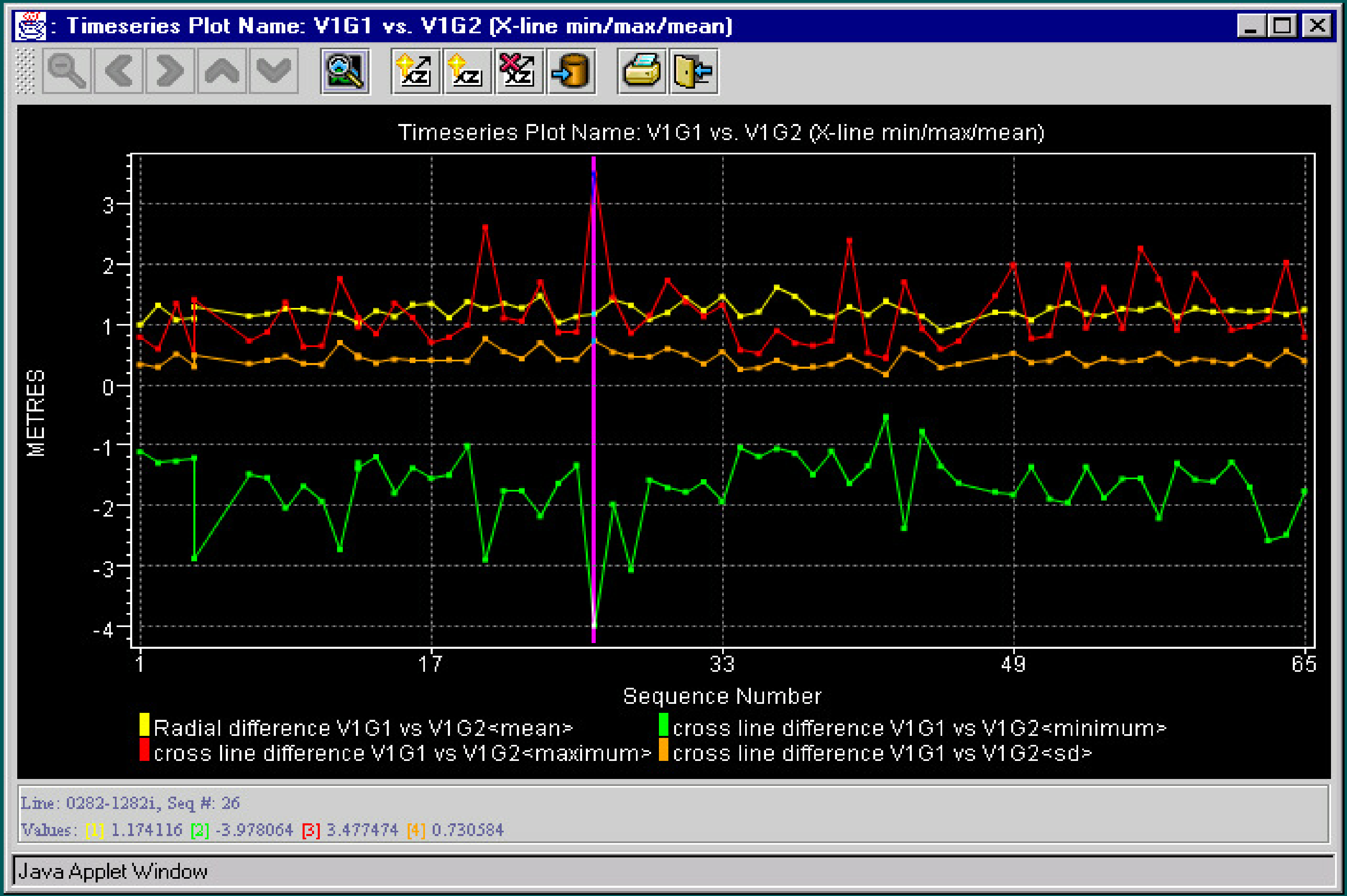
Time Series Plot - Quality Factor



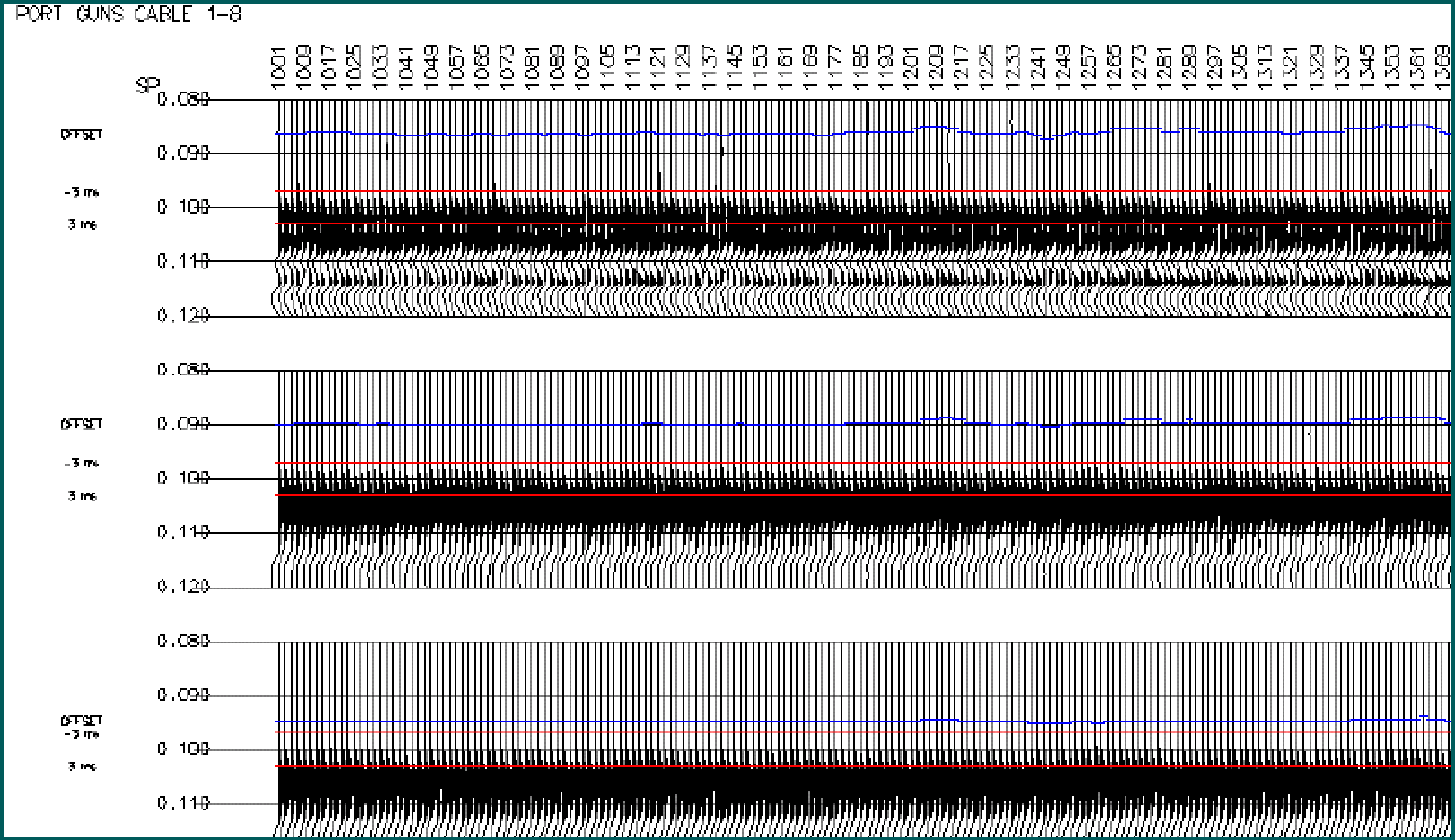
Time Series Plot - Gun Separations



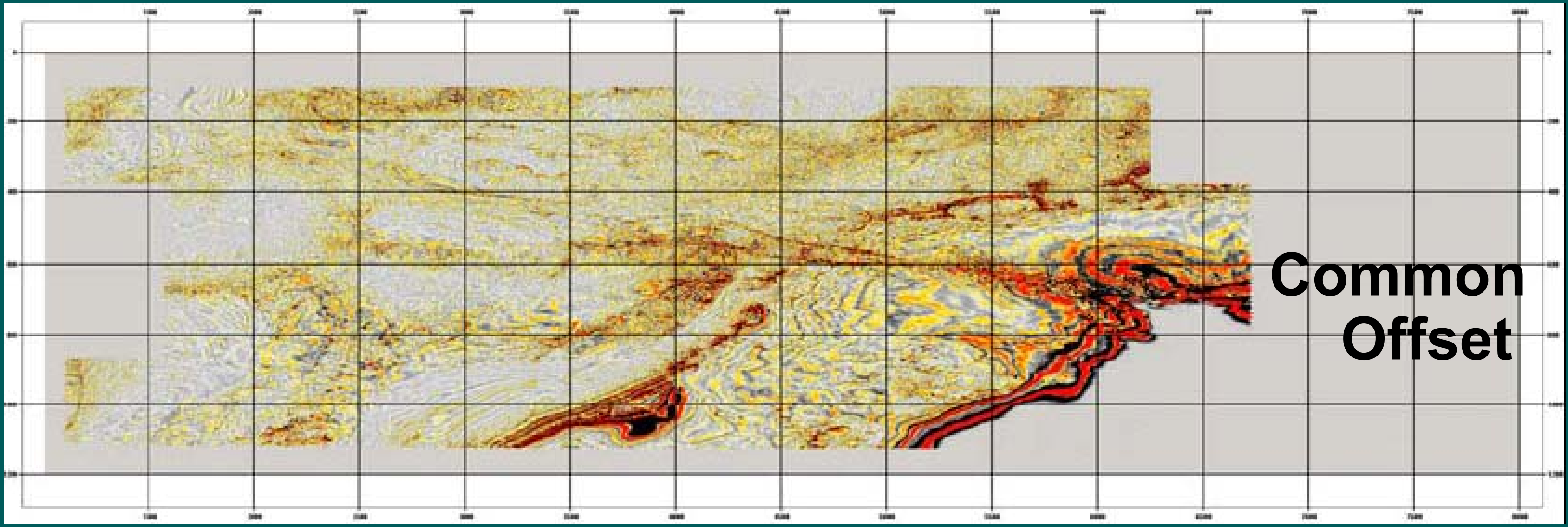
Time Series Plot - Positional Difference

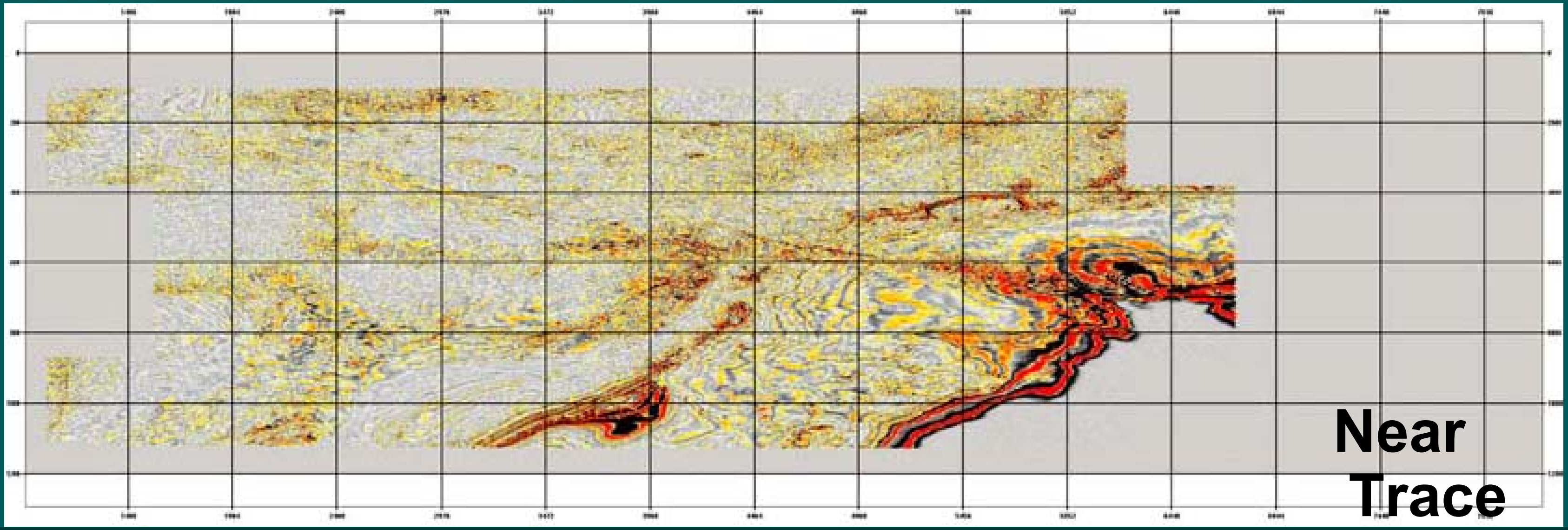


Nav LMO


PORT GUNS CABLE 1-8
SP
1001 1009 1017 1025 1033 1041 1049 1057 1065 1073 1081 1089 1097 1105 1113 1121 1129 1137 1145 1153 1161 1169 1177 1185 1193 1201 1209 1217 1225 1233 1241 1249 1257 1265 1273 1281 1289 1297 1305 1313 1321 1329 1337 1345 1353 1361 1369
OFFSET
-3 ms
3 ms
0.080
0.090
0.100
0.110
0.120

Offset Cubes

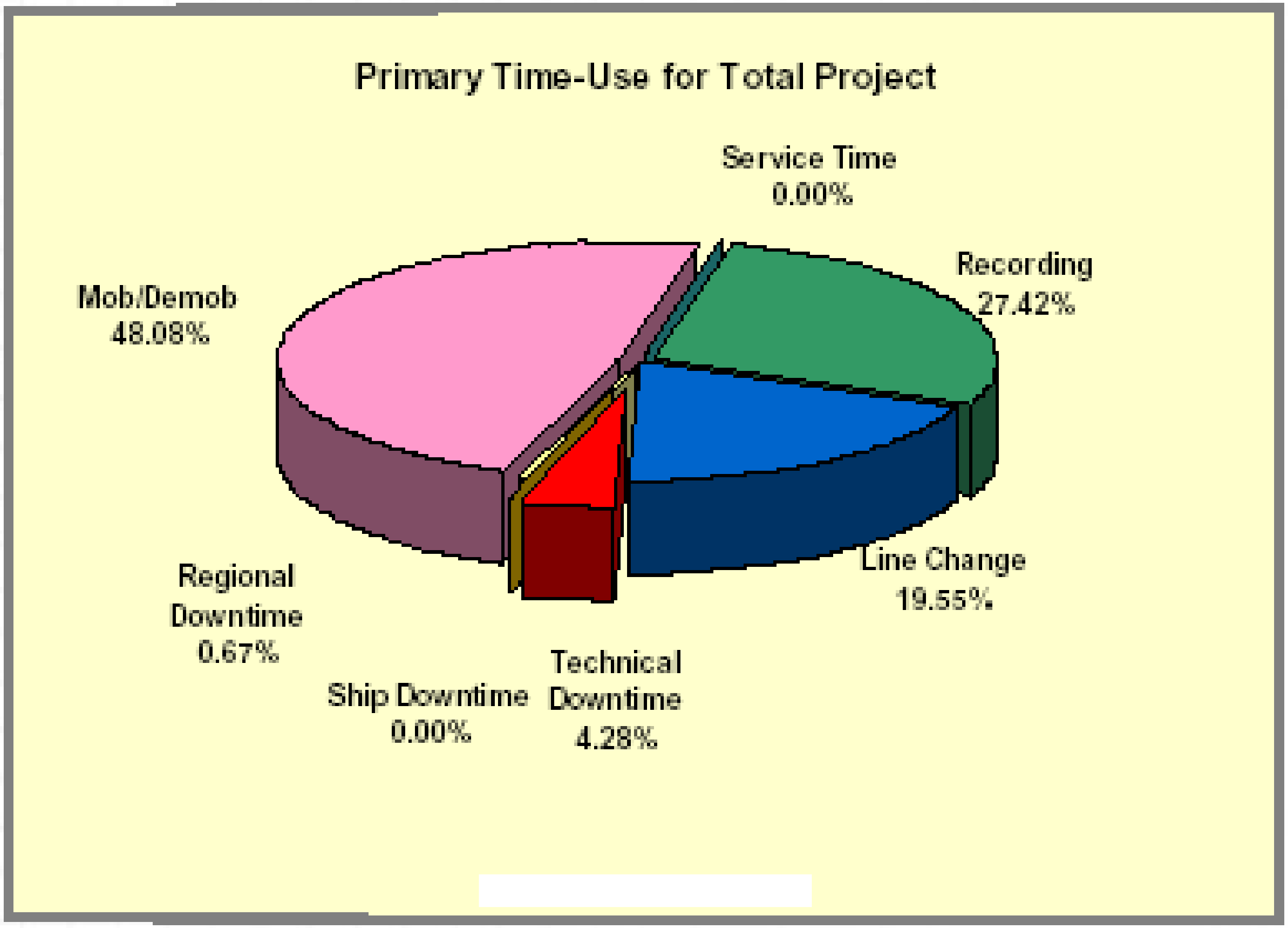




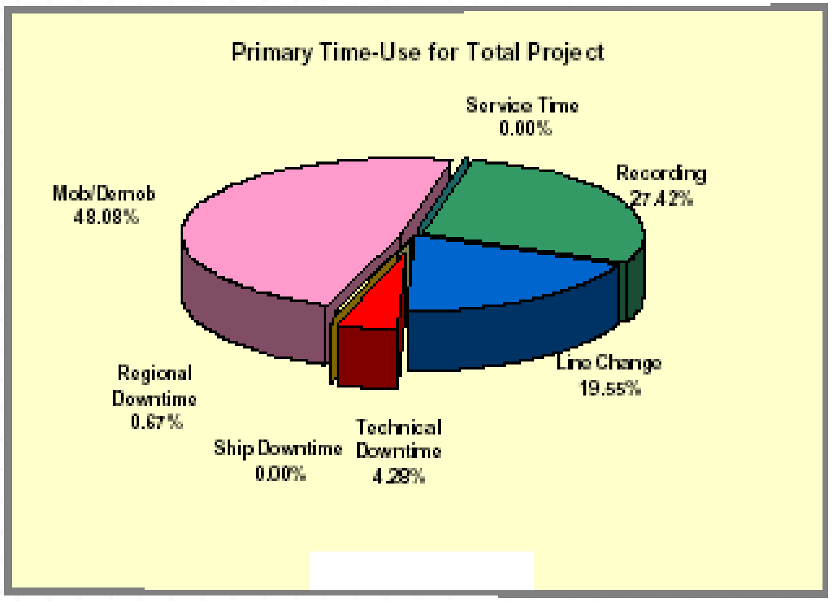
Fundamental Equation of Seismic Data Acquisition

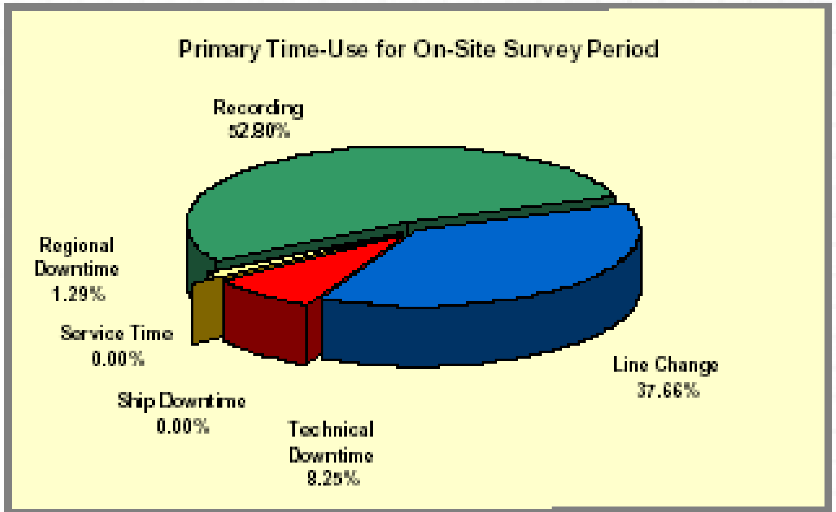
TIME = 

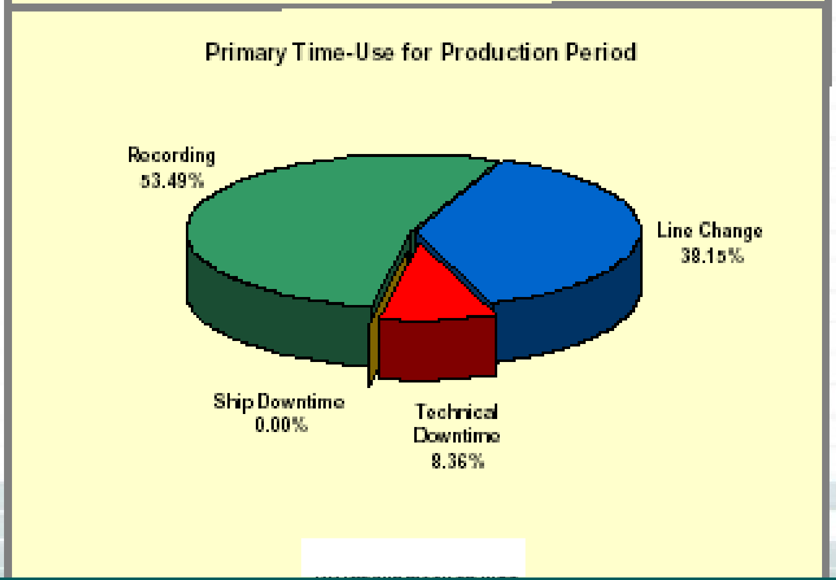
Project Time Analysis



Project Time Analysis





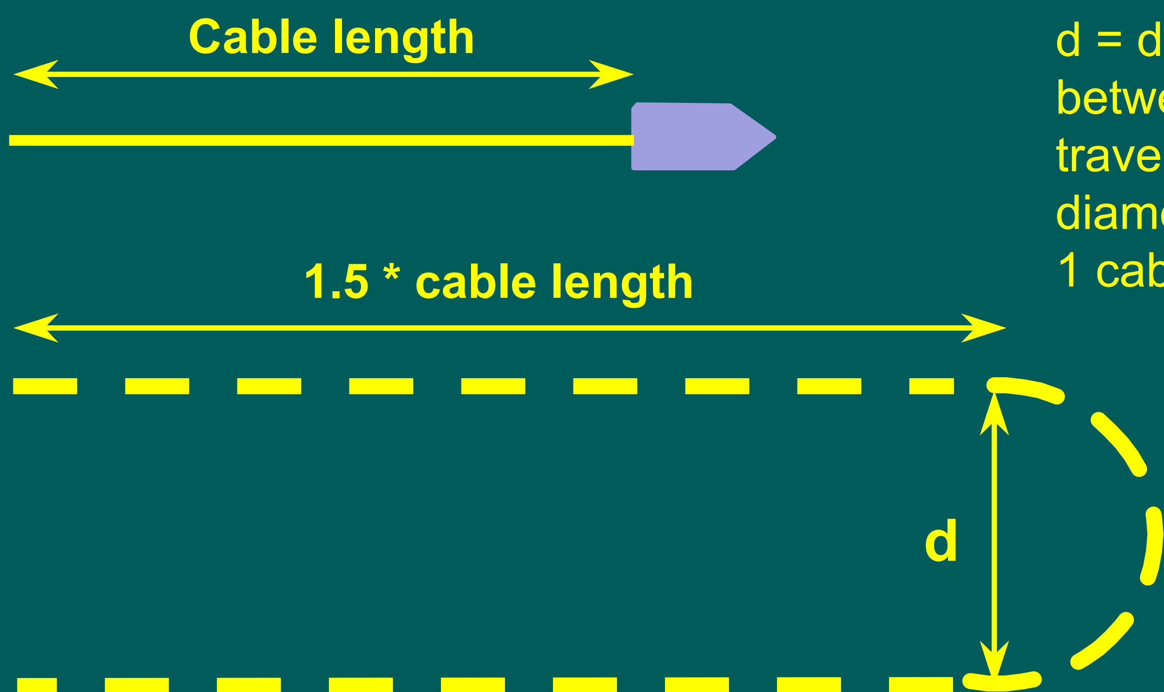


Parameters and Computations for a Cost Estimate Spreadsheet

- **Area to be covered**
  - Average line length
  - Survey width
- **Spatial sampling**
  - Line spacing
    - Number of lines
  - Detector group interval
  - Shot interval
    - CMP interval
    - Fold of coverage
  - Cable length
    - Number of groups
    - Taper length
    - Line change distance
- **Temporal sampling**
  - Sampling interval
  - Record length
- **Acquisition time**
  - Vessel speed
  - Number of vessel passes * average line length
  - Number of vessel passes * line change distance
  - Estimated crew productivity
  - % of fill
- **Economic risk**
  - Amount and cost of equipment deployed
  - Difficulty of prospect (obstructions, shipping lanes, bathymetry, fishing activity)

Line Change (Traditional)

Traditionally, lines changes had been effected to result in a "straight" streamer when entering the survey grid



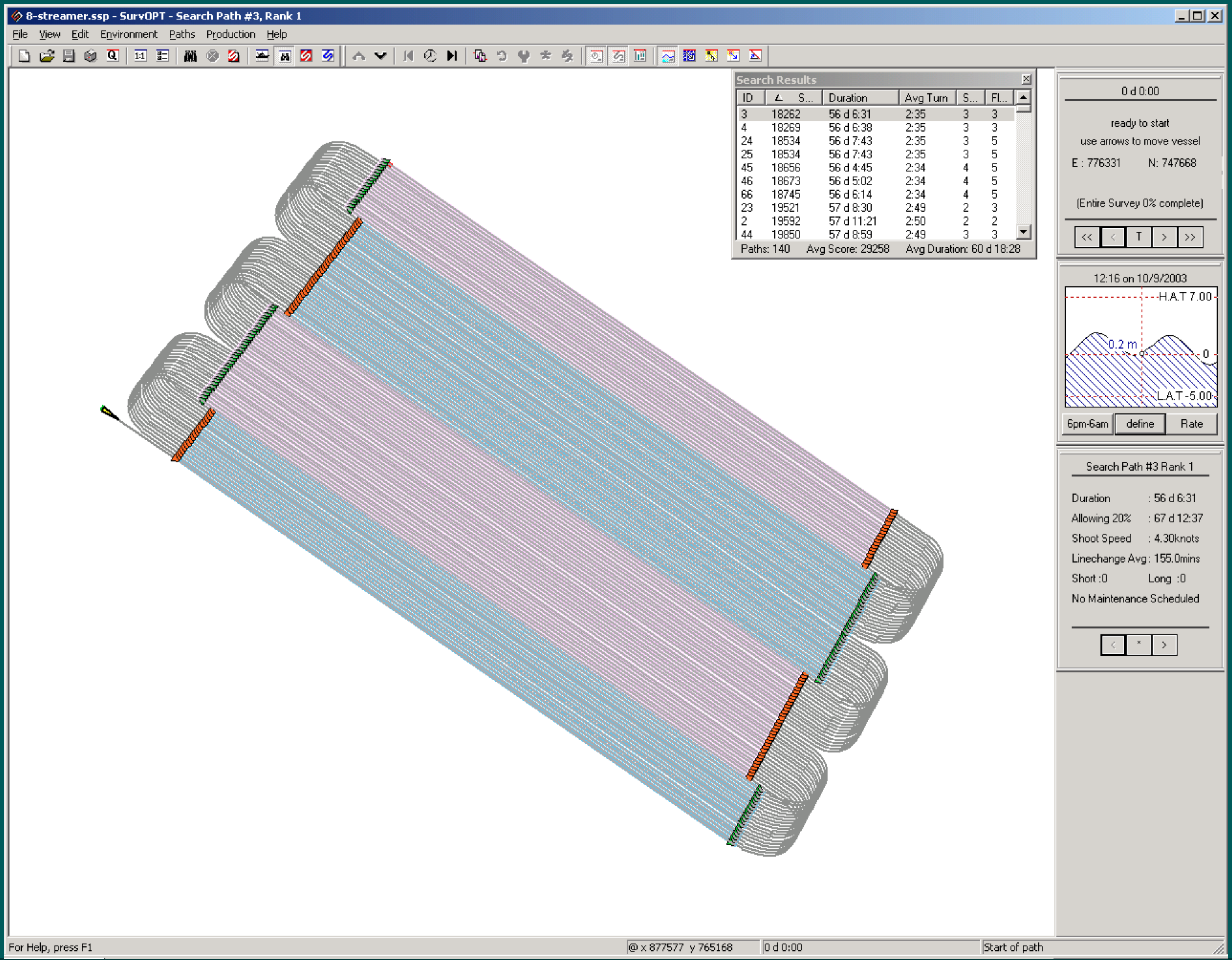
d = diameter of vessel turn between successive traverses; minimum turn diameter is approximately 1 cable length

Note: As the number of cables & spread width increases, so does d_{min}

Line change distance = 2 * (cable length * 1.5) + (π * d / 2)

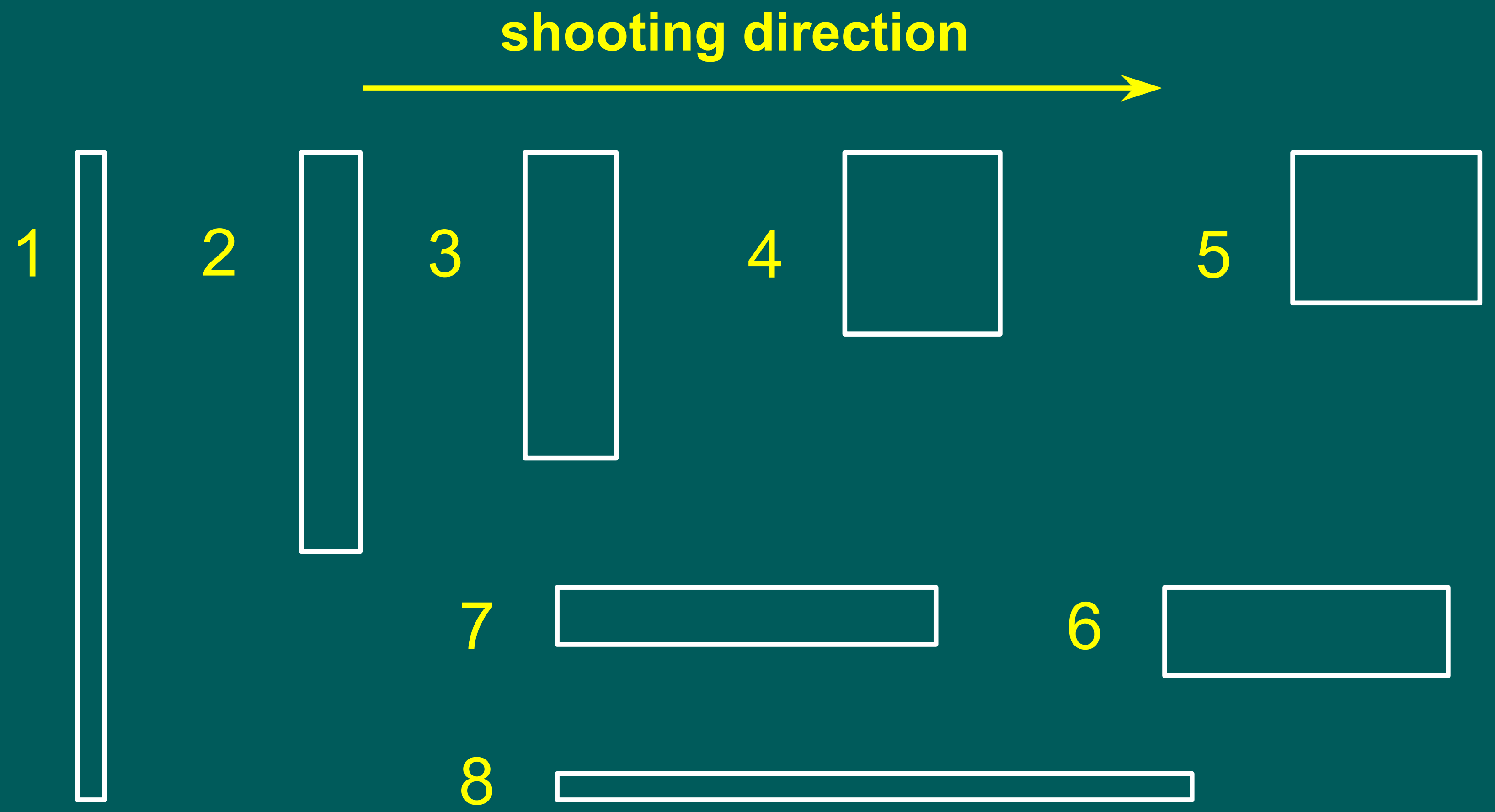
Line change time = line change distance / vessel speed

Race Tracks


8-streamer.ssp - SurvOPT - Search Path #3, Rank 1
File View Edit Environment Paths Production Help
Search Results
ID S... Duration Avg Turn S... Fl...
3 18262 56 d 6:31 2:35 3 3
4 18269 56 d 6:38 2:35 3 3
24 18534 56 d 7:43 2:35 3 5
25 18534 56 d 7:43 2:35 3 5
45 18656 56 d 4:45 2:34 4 5
46 18673 56 d 5:02 2:34 4 5
66 18745 56 d 6:14 2:34 4 5
23 19521 57 d 8:30 2:49 2 3
2 19592 57 d 11:21 2:50 2 2
44 19850 57 d 8:59 2:49 3 3
Paths: 140 Avg Score: 29258 Avg Duration: 60 d 18:28
0 d 0:00
ready to start
use arrows to move vessel
E : 776331 N: 747668
(Entire Survey 0% complete)
12:16 on 10/9/2003
H.A.T 7.00
0.2 m
0
L.A.T -5.00
6pm-6am define Rate
Search Path #3 Rank 1
Duration : 56 d 6:31
Allowing 20% : 67 d 12:37
Shoot Speed : 4.30knots
Linechange Avg : 155.0mins
Short :0 Long :0
No Maintenance Scheduled
For Help, press F1
@ x 877577 y 765168
0 d 0:00
Start of path

Economic Impact of Survey Shape
30 OCS Block Survey

1 OCS Block = 3 mile x 3 mile =4.83 km x 4.83 km = 23.3 sq km



Economic Impact of Survey Shape
Survey Duration and Cost

Shooting speed = 5 miles/hour
Line change time = 2.5 hours
Migration aperture = 3500 feet

Survey Shape	Number of Lines	Shooting Time	Shooting + Line Change	Survey Duration	Normalized Cost
1 x 30	2939	1.2 Hrs	3.7 Hrs	449 days	$ 1,000,000
2 x 15	1491	1.8 Hrs	4.3 Hrs	265 days	$ 590,000
3 x 10	1008	2.4 Hrs	4.9 Hrs	204 days	$ 454,000
5 x 6	622	3.6 Hrs	6.1 Hrs	157 days	$ 350,000
6 x 5	525	4.2 Hrs	6.7 Hrs	146 days	$ 325,000
10 x 3	332	6.6 Hrs	9.1 Hrs	125 days	$ 278,000
15 x 2	236	9.6 Hrs	12.1 Hrs	119 days	$ 265,000
30 x 1	139	18.6 Hrs	21.1 Hrs	122 days	$ 272,000

Operational Considerations = Economics

- Water Depth
- Sea State
- Surf, currents, tides, river mouths, estuaries
- Obstructions
- Hazards
- Ship Traffic
- Distance to Port
- Environmental

Shooting Direction
Operational Considerations

- **Surface obstructions**
  - The alignment of surface facilities and other obstructions along certain directions can have a major impact on survey costs, in that the narrower the obstructed zone which needs to be undershot, the less time consuming and less expensive the survey. For this reason, surveys are often designed with the inline (shooting) direction determined by favorable alignment of platforms and other surface facilities rather than by geophysical considerations
- **Shallow water**
  - Shallow water within the operational area of the survey (i.e., Including the region where the vessel turns) can have a major influence on survey direction, particularly if a significant portion of the survey is inaccessible such that deadheading would be required
- **Shipping lanes**
  - Crossing shipping lanes with several millions of dollars worth of streamer equipment is considered "sub-optimal" by most contractors

Impact of Survey Orientation

- From an economic viewpoint, we wish to have the shooting direction of the survey be along the longest extent of the survey

- From a geophysical viewpoint

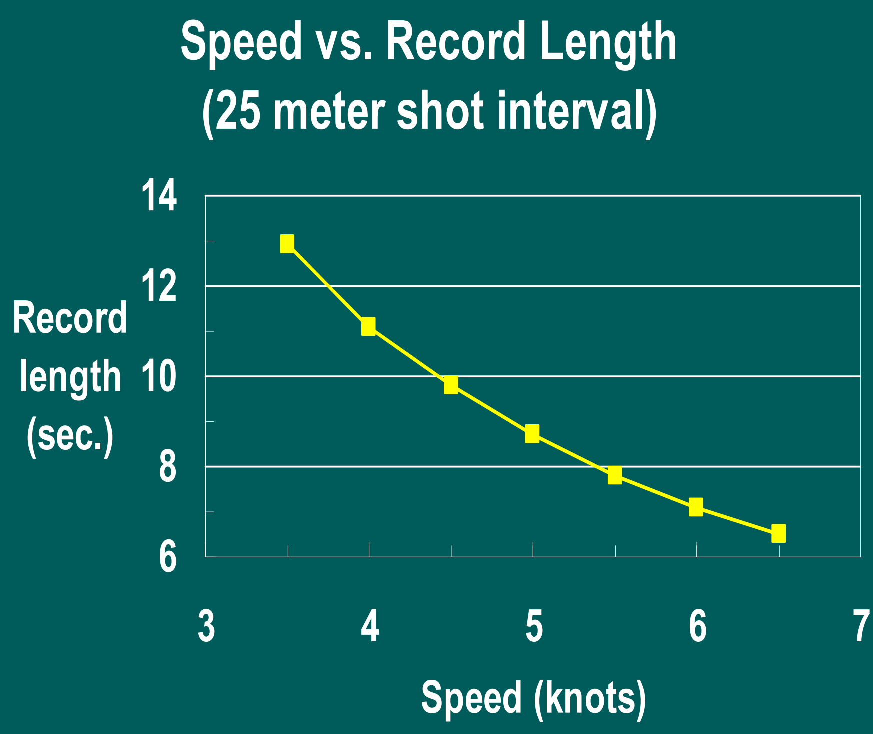
  - Spatial sampling considerations generally favor the shooting direction being in the dip direction, since this is direction in which finer spatial sampling is easily achieved

  - Dip shooting minimizes impact of image aperture.

Real world situations sometimes put these factors at odds with another

Economic Impact of Geophysical Parameters:
Record Length, Shot Interval & Fold

- The multiple source and multiple streamer configurations currently used to acquire marine 3D surveys depend upon vessel speed through the water to keep acquisition elements (i.e., source arrays and streamer cables) separated
- The minimum stable speed for most separation devices (paravanes) is about 3 knots, or 1.5 meters/second
- Decreasing vessel ground speed from 5 knots to 4 knots increases survey time and cost by 25%



Survey Duration Estimate (1)

- Survey Parameters

• Full fold area length	40 kilometers
• Full fold area width	20 kilometers
• CMP Line spacing	25 meters
• Streamer length	6000 meters
• Shooting speed	2.3 m/s (~4.5 kts)

- Computed Values

• Number of lines	800
• Line length	43.0 kilometers
• Line change distance	15.4 kilometers

Survey Duration Estimate (2)

- Acquisition Configuration

  - **4 streamers / 2 sources = 8 cmp lines per traverse**
  - **Number of traverses = 800 lines / 8 lines per traverse**

    = 100 traverses

- Zero Risk Duration Estimate

  - **100 traverses * (43.0 + 15.4 kilometers) = 5,840 kilometers**
  - **5,840,000 meters / 2.3 meters per second**

    = 2,539,130 seconds

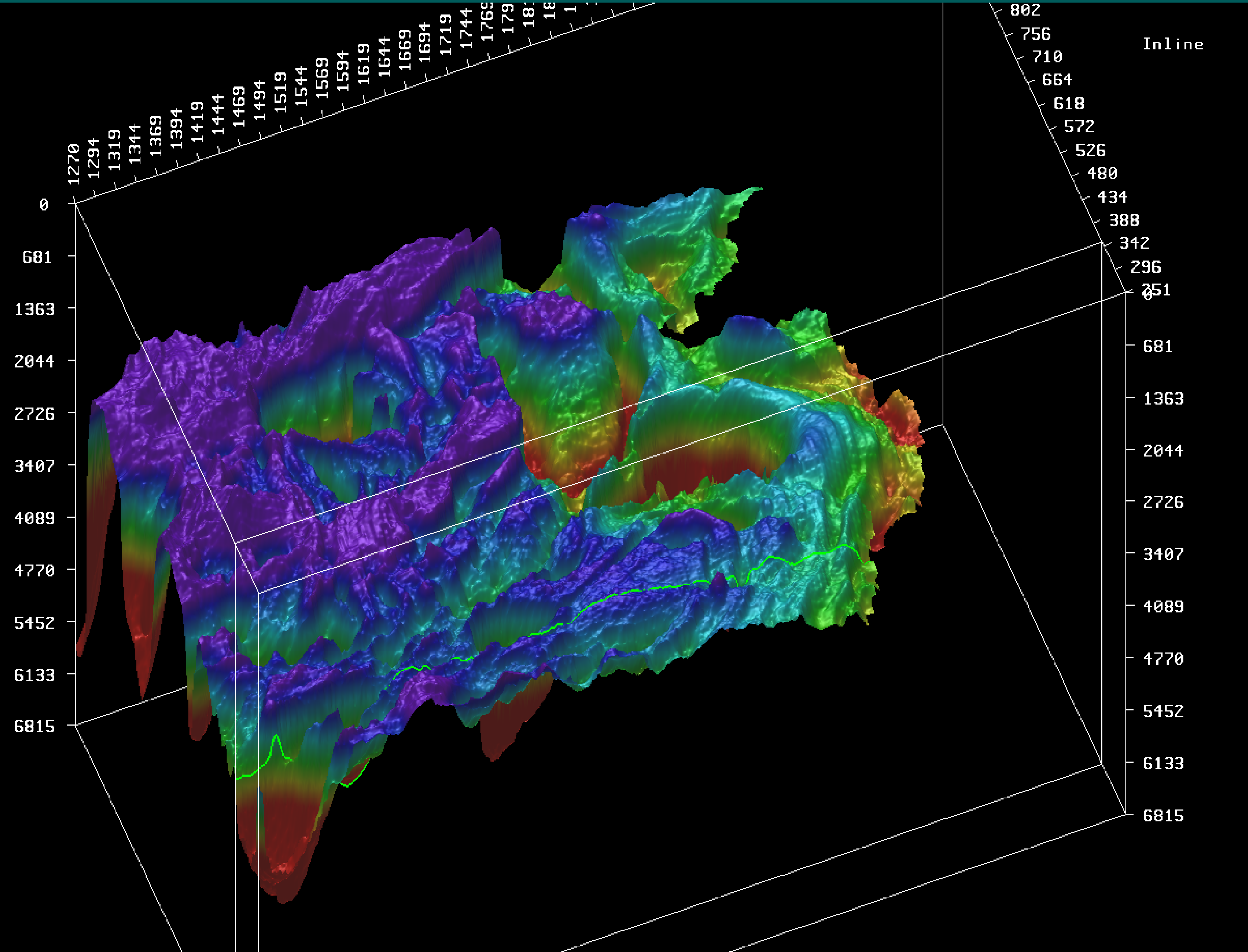
    = 705 hours

    = 29.4 days

Survey Duration Estimate (3)

- In-Fill
  - Assume 30%
  - 29.4 days * 1.3 = 38.2 days
- Risk
  - Assume 30% downtime (instruments, weather, etc.)
  - Hence 70% uptime (shooting + line change)
  - 38.2 days / 0.7 = 54.6 days
- Ideal vs. Real
  - Ideal: 30 days (no fill, zero downtime)
  - Reality: 55 days (30% fill, 30% downtime)

Top of Salt



Inline
802
756
710
664
618
572
526
480
434
388
342
296
251
1270
1294
1319
1344
1369
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1719
1744
0
681
1363
2044
2726
3407
4089
4770
5452
6133
6815


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