REPORT ON CONTRACTOR'S PERFORMANCE
DURING
SUE 3D MARINE SEISMIC SURVEY
IN
GIPPSLAND BASIN
BY
WESTERNGECO : M/V WESTERN TRIDENT
FOR
APACHE ENERGY LTD

From 15/01/2005 to 15/02/2005

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1. INTRODUCTION

WesternGeco (WG) with their seismic vessel M/V *Western Trident* carried out the Sue marine 3D seismic acquisition program for Apache Energy Limited (Apache). RPS Energy provided independent positioning quality control for this project.

The centre of the survey was approximately 350 km from Melbourne. Acquisition area for this survey was 1067 km². Line orientation was set on a bearing of 44.566° (Grid). The sail lines were designed at intervals of 400 metres across the block to enable a 25 m cell bin width and to cover the block as a function of grid co-ordinates and parallel bearings. All sail lines were prefixed with GAP04B.

The reference point for the shot points was the CMP point so that (shot-point) 1001 represented the first full-fold SP along sail line (1008), start of line shot points were all based on this point to allow matching. WG computed a binning origin that was positioned at the SW of the block.

WG utilised their seismic vessel M/V *Western Trident* that deployed eight 4800-metre streamers and 384 channels in each digital streamer. Inter streamer separations were set at a nominal distance of 100 m, guns at 50 m separations and the shot point interval at 18.75 m. Guns were fired in a flip flop routine using two energy sources and four gun strings were attached to each source. Inner gun string separations were set at a nominal 6m.

Seismic data was recorded on the I/O MSX Recording system. The 3D survey was carried out with 8 streamers to give 16 CMP lines per sail line pass. The planned survey contained 77 sail lines.

2. EXECUTIVE SUMMARY

RPS Hydrosearch was contracted by Apache to provide navigation supervision and quality control for the Sue 3D Survey. This report analyses specific problems during this survey and provides recommendations for future work programmes.

Positioning of the vessel was by differential GPS using C & C Technologies CNAV and the FUGRO TGS MultiFix and XP systems.

Positioning of the receiver groups was by a fully integrated network consisting of 18 POSNET transponders, 144 DigiCourse 5011 compasses and 78 DigiCourse acoustic pods. RGPS transponders were attached to each of the eight tailbuoys, two headbuoy's and the outer and inner guns strings. Compasses were placed at 300 m intervals down the cable however the initial two birds and final two birds were placed at 200 m intervals. Absolute positioning of the network was by the vessels DGPS position systems and all in-sea nodes were tied into this position i.e. the Navigation Reference Point (NRP). Orientation on the vessel was provided by the C-Plath gyrocompasses and GPS. Receiver groups were placed at a nominal 12.45 m interval along the cable.

WG used their ARC Module to resolve the distances between each compass based on the least square solution. Rotation of the streamers was applied using tailbuoy rGPS positioning.

WG integrated navigation system TRINAV had been utilised online and in post-processing. Verification of the P294 and P190 was made using the independent navigation QC systems Geometis and FGPS.

Two structures, the monopods Perch and Dolphin, were undershot during this survey. The Multiwave operated vessel M/V *Pacific Titan* was used as source vessel during this operation. This operation was delayed due to equipment malfunction and no spares available.

3. CONCLUSIONS AND RECOMMENDATIONS

3.1. CONCLUSIONS

The navigation and positioning data was good throughout the survey. The data quality of the positioning systems met the criteria to within contract specifications and tolerances. The on-line navigation and onboard processing ensured that the required positioning accuracy was met for the source and receiver positions. The level of confidence in the positioning of the source and receiver positions was confirmed by the independent navigation QC systems provided.

Sea conditions were generally good with a few poor weather windows. Lines shot during the poor weather window were all acceptable.

Positioning proved reliable and there was no downtime attributed to any of the systems.

A current meter installed to the hull of the vessel was used during this survey and it did aid the online navigators to select lines to optimize coverage.

3.2. RECOMMENDATIONS

Following are a few recommendations, most of which were in effect during this survey and which should be in effect for following surveys if possible.

- **Providing confidence in DGPS positioning accuracy.**

  WG provided a number of DGPS systems as well as several independent differential corrections delivered by two different systems. This provided redundancy in case of malfunction and also positioning confidence as the systems could be checked against each other. In addition, WG provided their proprietary Integrity Monitor system at Sale, which provided online confirmation of the reliability of the DGPS systems. WG can be commended for their comprehensive GPS setup.

- **Good timing with regards to weather.**

  The weather was generally good during the period of this survey with very little weather downtime.

- **Network redundancy.**

  The four individual gun strings in each array were positioned using one rGPS pod on each string and acoustic nodes only on the two outer strings. This set-up did not provide for any backup in the case of malfunction in the rGPS units on the inner gun strings. It would have been preferable to have acoustic nodes on each gun string. However the inclusion of two front floats with rGPS and acoustic positioning did improve the redundancy of the network and is recommended during future surveys.

- **Logs**

  The quality of the online and processing navigation logs was poor with minimal input thought should be given to improving these inputs on future surveys.

- **Orientation of the Sources in the Network**

  The contractor should ensure that the orientation of the source laybacks and source ties be from the first compass of the closet streamer and not the gyro. Errors in the absolute positioning of the source would occur if the vessel was crabbing > 15° due to poor sea conditions or bad weather. The relevant compass was used during this survey.

- **Confirmation of the P190 files**

  Provision of an independent navigation QC system is recommended on future surveys. Quality control of the raw data can easily be assessed along with independent checks on the contractor's P190 data as occurred during this survey.

- **System Upgrade**

  The I/O PRO 2000 has since superseded Version 3 of the acoustic ranging system and from past experience has proven a more reliable and robust system. Future mid acoustic networks should be based on a braced a quadrilateral as was the case during this survey. However this could prove unfeasible for WG as the Q system has superseded PRO 2000 and believe all vessels will be upgraded at some time.

- **HSE Consideration**

  A major HSE bonus would be to by-pass the use of lithium batteries in compasses and to have them powered directly through the cables.

- **Velocity Database**

  During future surveys water velocities could be extracted from the US Naval website at http://128.160.23.42/gdemv/gdemv.html to verify any Sippican and TSP (temperature, salinity, pressure) dips. Velocities from this site were used during this survey as the sea conditions sometimes prevented small boat work during the survey. A TSP-dip confirmed the given values.

- **Depth Checks**

  Absolute checks on each P190 file should be implemented on future surveys to confirm that the tidal, draft and velocity corrections had been applied correctly. Independent checks were carried out for draft and velocity corrections only during this survey as tidal corrections were applied in the WG office post survey.

- **Undershooting**

  The undershooting operation, with the *Pacific Titan* as source vessel, was delayed and later acquired with some re-work needed on the final data set. This was caused by inadequate spare parts. For an expensive operation such as an undershoot, where two vessels are involved, sufficient spares should be available.

4. PERFORMANCE APPRAISAL

4.1. CALIBRATIONS AND VERIFICATIONS

Static calibrations were carried out by FUGRO TGS (AUSTRALIA) between the 11th and 12th February 2004 at the Dampier Cargo Wharf. A total station was used during the calibrations and verifications, using pre-defined geodetic control on the sand and silica wharfs relative to WGS-84 datum.

DGPS Mean Linear Misclosures

A summary of the results of the DGPS verification are as follows:

System	P2-ID	Misclosures
MultiFix		0.65 m
C-Nav1 :		0.22 m
C-Nav2 :		1.17 m
Posnet1		0.35 m
Posnet2		0.78 m
TriGPS :		0.52 m
RTKGPS :		1.19 m

Please note no further verifications have been made since this date.

rGPS

Re-radiation checks were made on the transit to the survey and are listed below:

	Lat (m)	Lon (m)
F001	0.47	-1.02
F002	-0.71	-0.01
F003	-0.10	0.58
F004	-0.50	0.06
F005	0.47	0.67
F006	-0.44	0.20
F007	-0.70	0.11
F008	-0.34	0.24
FG01	0.56	0.36
FG02	0.55	-1.30
FG03	-0.19	-0.64
FG04	0.22	0.52
FG05	0.47	0.67
FG06	-0.13	-0.57
FG07	0.42	-0.56
FG08	0.66	-0.59
FF01	-0.44	0.20
FF02	0.14	0.83

The above results are deemed acceptable.

Acoustics

DigiCourse 3

Verification of the DigiCourse pods was achieved in post processing by comparing the Observed against the nominal ranges on selected baselines in the network. In addition the verification also confirmed that the velocity of propagation computed from the TSP-dip was correct.

Streamer Compasses

DigiCourse Model 5011

No pre or post survey calibrations of the streamer compasses were performed, as the manufacturer does not recommend this is necessary. Bias checks were performed on a line-by-line basis during the survey to confirm the integrity of the compasses.

Vessel Heading: GPS Heading Sensor and Gyrocompasses

The previous static Calibration was made in each direction after turning the vessel around between the 11th and 12th February 2004 at Dampier.

The results obtained were as follows:

Gyro	C-O (°)
C-Plath 1	-0.55
C-Plath 2	0.03

The C-O differences between each direction shot were all within tolerance and the readings were considered good.

However, WG continually calibrate the gyros online and the results of the previous Malaysia survey are listed below please note these values were used on this survey.

Gyro	C-O (°)
C-Plath 1	-1.44
C-Plath 2	-0.10

Echo-sounder

A Simrad EA500 echo-sounder operating at (18 kHz and 200 kHz) was used during this survey, (please note that only the 18khz frequency was used during this survey as it proved the more reliable and TriNav only accepts the one frequency).

A lead-line verification of the draught was made prior to the survey in Fremantle, which confirmed the validity of the echo-sounder. A standard velocity correction of 1500 m/s and draught correction of 0 m was entered into the echo sounder. A TSP profile was made during this survey that was confirmed by the US Navy site. A standard draught correction of -7.4 m was used during this survey.

Depths recorded to the P190 files were all draft and velocity corrected please note the tidal corrections will be applied at the WG Kuala Lumpur office. No pitch and roll corrections were made to the final data set. Confirmation of the reduced soundings was made after each line.

4.2. DGPS SYSTEMS

Throughout the survey excellent reliability and accuracy was observed with the DGPS solution used. Comparisons were <5m for the whole survey. The following systems were made available:

Software	**Diff. corrections**	**Diff. corrections delivery**	**Supplier**
CNAV	CNAV	Inmarsat	C&C Technologies
Multifix 4	Skyfix / XP	Inmarsat/Spot	Fugro TGS
TriGPS	Skyfix SF	Inmarsat/Spot	WesternGeco
POSNET	CNAV	Inmarsat	WesternGeco

The vessel used a cocktail of available systems for positioning that were input into the Prime Estimator; a bad system was automatically or manually taken out of the solution. CNAV was made prime however XP was disabled due to instability throughout the survey.

MultiFix and the prime CNAV system were set to the 3D positioning mode for the entire survey. The final computations of the Geoid - Spheroid separations were from the inbuilt EGM96 model in the MultiFix solution.

QC of the DGPS systems was basic and included PDOP, HDOP, the Number of satellites in view and the Geodial heights. Graphs of the above were produced after each line from TriNav.

WG, providing two totally independent sources of corrections and a multitude of different processors of this data, along with a TriNav GPS integrity monitor located locally in Sale, ensured vessel positioning was always of a high standard.

The integrity monitor essentially worked as a tail buoy located in Sale where the received pseudo ranges were transmitted to the vessel, real-time, via VSAT. The location of the monitor station was known and the computed location was compared with the known location. Normally the c-o was less than 1m for this project. The Integrity monitor was not available during the period of VSat unavailability.

CNAV

Supplied by the American company, C & C Technology uses a “global” network of reference stations to track all GPS satellites in orbit around the world and send the raw GPS signal measurements back to a “Network Processing Hub” (NPH). The NPH then calculates and models in real time all of the individual GPS satellite Orbital Corrections and also the individual GPS satellite clock offset values (from the broadcast ephemeredes – IODE). These corrections are then transmitted to the mobile user via geostationary communication satellites (description taken from the C-NAV Operations Manual).

The advantage to the CNAV approach is theoretically that, since corrections are related to individual satellites and not reference stations, the user’s distance from a reference station is no longer a factor in positioning quality.

CNAV has traditionally performed very well and is in the author's opinion an excellent system. CNAV was designated the 'Primary' GPS system and virtually all the GPS statistics stored to the MultiSeis database were generated by this system. A stand-alone QC system is available from C&C Technologies to access the quality of the GPS on a line-by-line basis but was not made available for this survey.

Multifix 4

The Multifix 4 system is relatively new and on recent experience has been improved in response to some harsh criticism from various sources. XP was used in the solution except for a few sequences when the data was noisy.

TriGPS

TriGPS is a proprietary WG network solution and it performed well. Trinav utilised the Skyfix Single Frequency corrections and CNAV the XP system was disabled as outlined above.

POSNET

POSNET is a proprietary WG system and is also part of the rGPS system. This system also performed well.

4.3. IN-WATER SYSTEMS

rGPS

rGPS positioning was provided by WG's proprietary TriGps POSNET system.

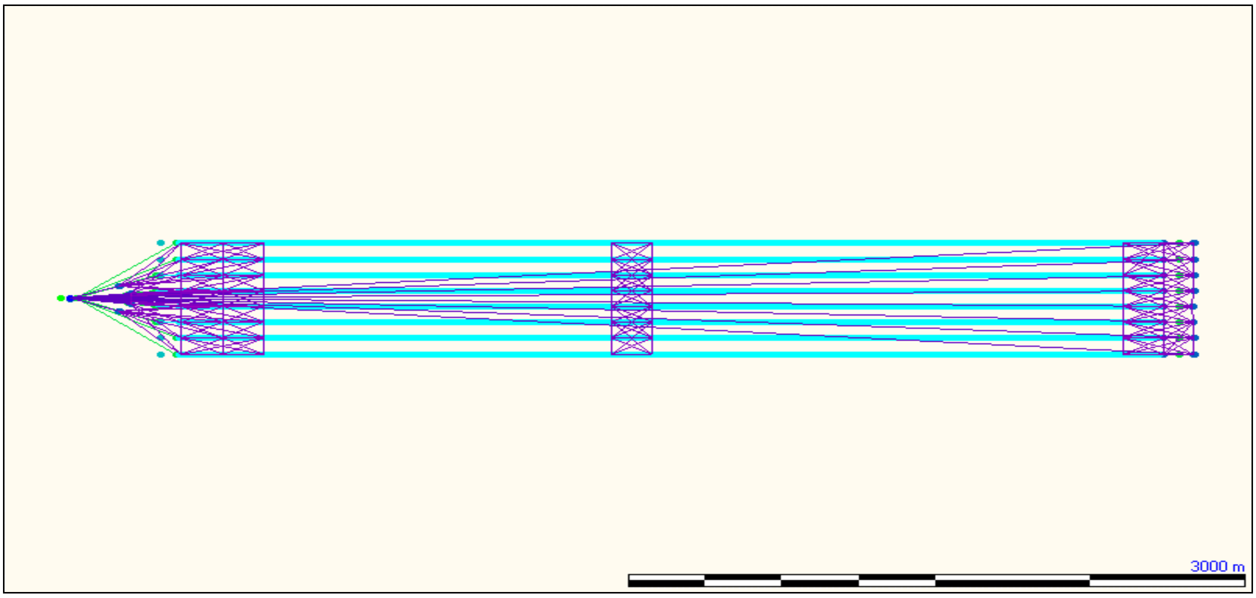
A few position jumps in individual buoy positions were observed. These jumps were small and easily detected and did not result in any shot point edits as the data was adequately interpolated. Noise levels did increase during periods of poor sea conditions but were acceptable. Individual units failed occasionally, these were replaced when weather conditions permitted workboat operations. The aforementioned outages did not affect the quality of the final dataset due to the great redundancy of units deployed.

Acoustics

The placement of the acoustic units on the streamer was fairly conventional. Each streamer carried 8 units as follows:

Network	Number of Pingers
Starboard Front Float	Positioned between streamer 3 and 4
Port Front Float	Positioned between streamer 5 and 6
Front	3 per streamer
Mid	2 per streamer
Tail	2 per streamer plus 1 tail buoy

Please refer to the diagram below:

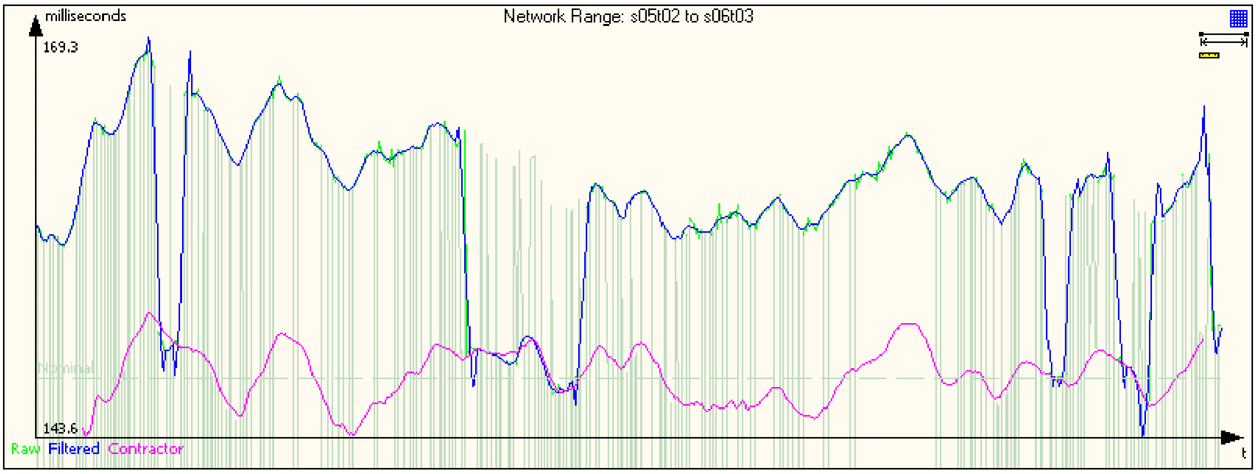


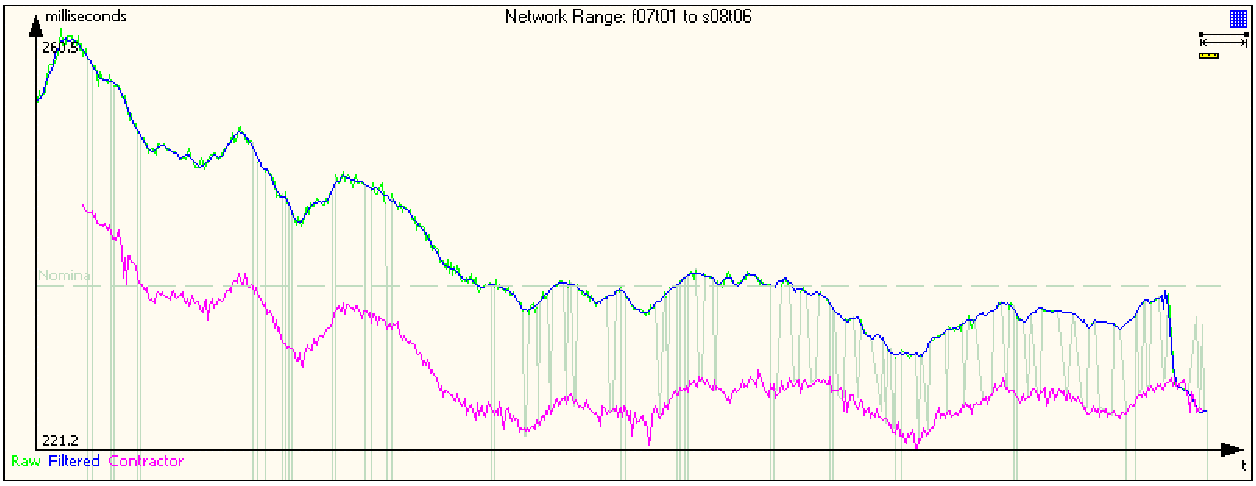
Only source sub-array 1 and 4 on each source had an acoustic unit fitted, giving 4 units in total. Additionally each string had an rGPS unit.

Acoustics performance was generally good with the majority of ranges, other than the standard inner streamer head and inner source string ranges (these being degraded by gun bubbles and prop wash). Poor weather during the survey did not unduly affect the performance of the acoustics except around the wash of the guns and prop. A few ranges that passed through the gun and prop wash that appeared good were reflections and were made passive in the network.

Seabed reflections were evident throughout the survey, but once those ranges were accessed appropriate gating values were set into the control system.

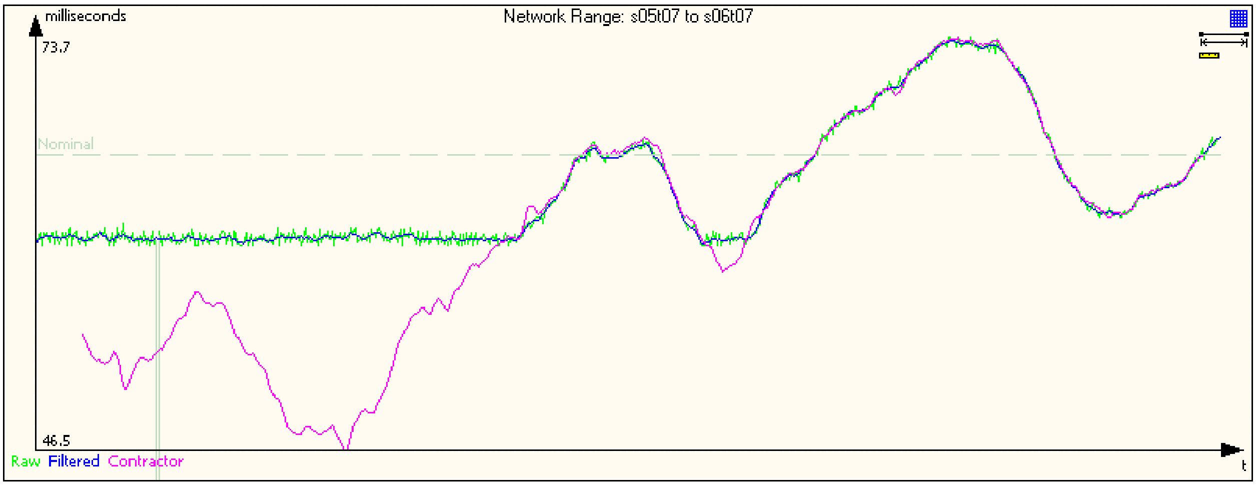
Examples of seabed reflections at the front and of the tail of the network are given below.





A limitation of DigiCourse occurs during periods of high feather and crab angle in which separations are higher and exceed the gating values input into the system.

The following plot is typical of the dataset during such periods.



Data for the speed of sound in water was collected through the US Naval site, a Valeport temperature salinity probe drop and calculation of the surface velocity via known inline acoustic ranges within the network. The latter option was seen to agree reasonably well with the values derived from the initial two methods.

The propagation velocities used during this survey were:

Sequence 1 to 3, 1516.58 m/s

Sequence 3 to 56, 1516.60 m/s

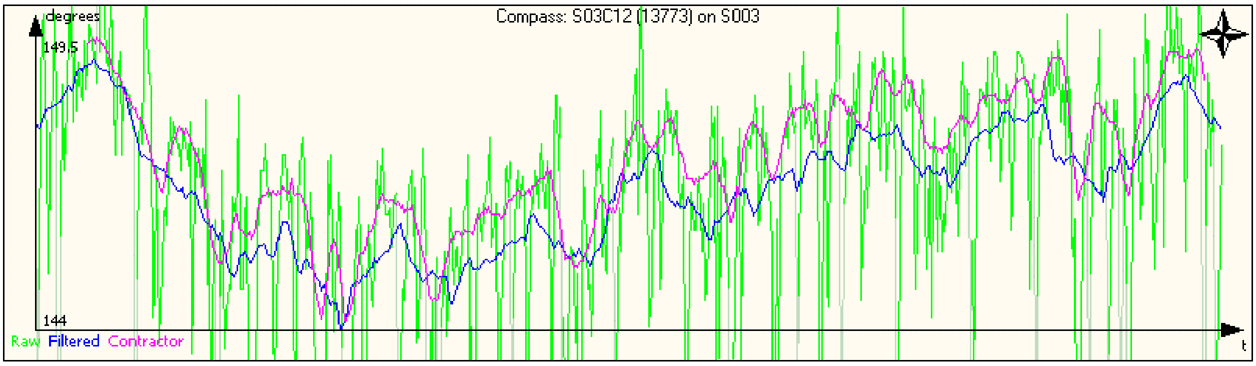
Sequence 57 to 98, 1520.93 m/s

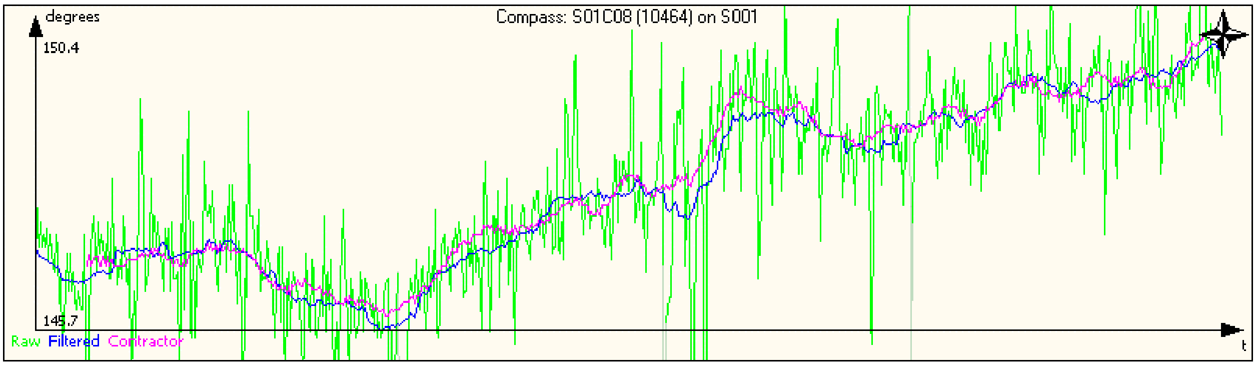
Streamer compasses

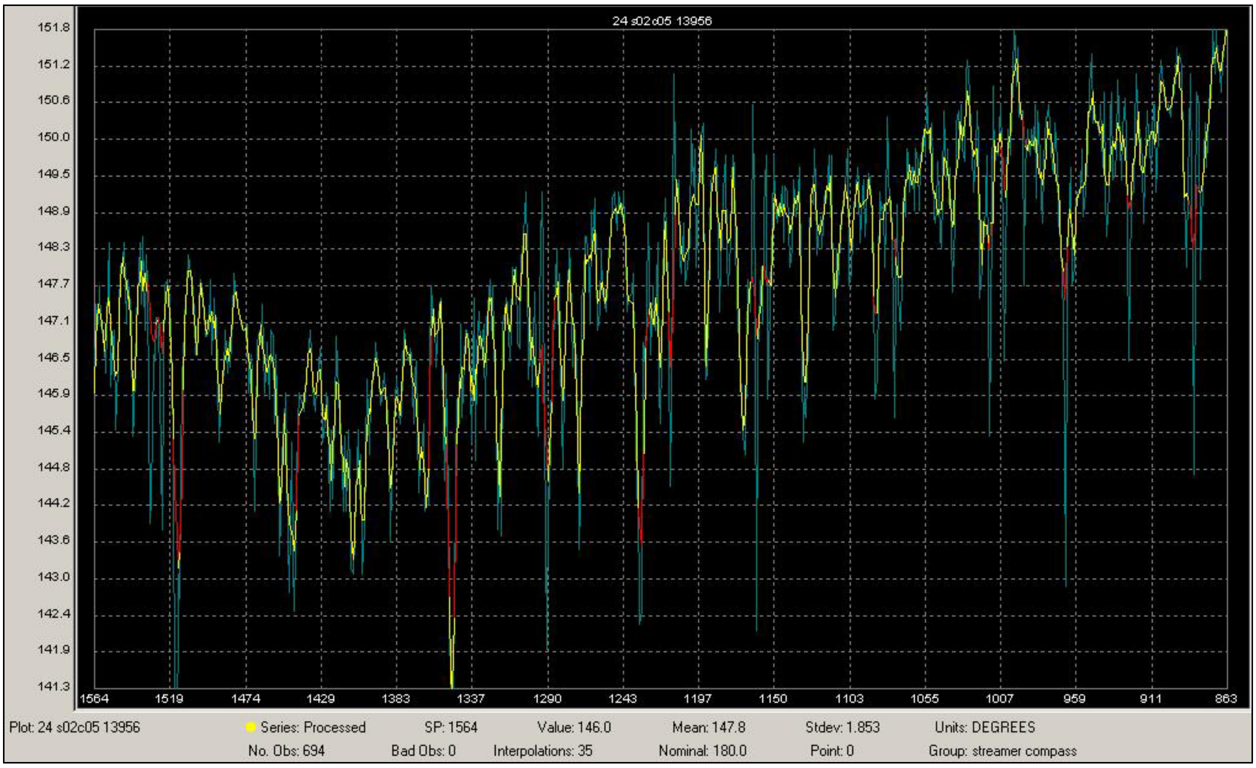
Digicourse model 5011 Digibird Compass Units were used for streamer depth measurement, depth control and magnetic heading measurement. Eighteen units were mounted on each streamer at intervals of 300 m. The initial two and final two compasses were 200 m apart.

Compass data caused the most concern during this survey due to occasionally poor sea conditions.

The following plots were typical of the data observed during this period:







It should be noted that compasses mounted on solid cables are more liable to be noisy than the oil filled alternatives.

Streamer rotations throughout the survey were low which indicated that the IGRF2000 calculated magnetic deviation (declination) was appropriate. During the periods of poor sea conditions rotation values were less stable with probably a 0.5° of uncertainty due to the poor compass data.

The Trinav processing software carries out a "dynamic calibration" of compasses on an ongoing basis and generates a compass calibration report for each line. The Navigation Representative reviewed these after each sequence.

Gyrocompasses

Two C-Plath gyros were available and designated Gyros 1 and 2.

These performed well throughout the survey. Comparisons to an rGPS baseline onboard (WG's RT Calib) agreed reasonably with the gyro data.

Echo-sounder

The echo sounder, a Simrad EA 500 with an 18 kz transducer, was set to 0 m draft correction and a fixed propagation velocity of 1500 m/s to provide raw data to P294 data records.

Water depth was corrected for draft and propagation velocity in the P190 data set. A fixed draft correction of 7.4 m was applied throughout. Data was not pitch and heave compensated. Tidal corrections were to be applied in house, post survey.

Propagation velocities used for this survey were:

Sequence 1 to 3, 1513.55 m/s

Sequence 3 to 56, 1516.72 m/s

Sequence 57 to 98, 1520.99 m/s

Water depths over the prospect area ranged from 20 to 60 metres.

4.4. ONBOARD PROCESSING

WG performed their routine onboard processing using their UNIX based fully integrated Trinav navigation system. Following processing, data were exported in UKOOA P190 format based in the GDA 94 Datum. The production of final P190 tapes was usually completed within 2 hours of the completion of line.

At the end of the processing of each line, the main QC plots were generated electronically and these plots along with the P190 and P294 were made available to the client representative via a client-networked drive.

RINAV was used to post process the navigation data and P190 and P294 files were produced after each line. Processing was made by a survey crew member, final quality control was made by the navigation shift leader or the Chief Navigator before passing on the data to the client navigation representative.

Compass azimuths and acoustic ranges around the guns proved to be the most troublesome in post processing. A number of acoustic ranges were made inactive throughout the survey including the crossed brace astern of the guns due to excessive noise. As mentioned above the compass data quality was good during the period of calm seas. Inclusion of the headbuoy's at the front of the network did strengthen the network and gave added redundancy.

Statistics extracted from TRINAV each line did indicate that the positioning specifications were being met despite the problems caused by the sea conditions during this survey. And in conclusion TRINAV was an excellent navigation post processing system that has proven reliable and robust over the years. However, as with all systems it was dependent on operator input. The inclusion of an independent navigation QC system confirming the processing during this survey proved valuable.

Good procedures and QC of the data before handing over to the client representative resulted in none of the usual book keeping errors such as incorrect shot numbers in data files. However the processing and online logs had minimal inputs and could be improved in the future.

External Positioning Quality Control

Positioning was considered acceptable after carrying out the following QC procedures:

1) Import of the PAC file into the project database and subsequent analysis of this.
2) Analysis of the contractor QC files/plots.
3) Import and verification of the P190 data set.
4) Graphical and numeric QC of the P190 data using Geometis.
5) Processing of P294 data and comparison of resulting "System" data with contractor P190.
6) Inspection of P294 and P190 configuration.
7) P190 and P294 file and header checks.
8) Data frequency, detecting missing data.
9) Vessel, tail buoy, source, receiver and cmp position and spacing.
10) Acoustic, compass, gyro, echo sounder and GPS data inspection.
11) Source sequencing.
12) Reverse engineering of contractor P190 to produce raw data comparisons.

13) Compass heading and depth bias checks.
14) Real-time vessel, streamer (individual receiver locations) source and observation modelling.
15) Check of water depth correction in P190 data.

Post-processed QC statistics were obtained from the contractors PAC file and relevant statistics were extracted and graphed to plot trends in the data.

4.5. SURVEY PERSONNEL

The author was very happy with both the processing and the processing navigators (generally the Chief Navigator and shift leader) and happy with their attitude. They were receptive to suggestions and requests, providing anything asked for in good time. They also performed a very good QC of the data giving very little to be desired as there were very few sequences returned for reprocessing.

APPENDICES

Appendix 1

Positioning Parameters

Positioning Parameters

Geodetic Parameters

Work Datum

Name:	GDA 94
Spheroid:	GRS 80
Semi major axis:	6378137.0 m
Inverse flattening (1/f):	298.257222

Datum transformation Parameters from WGS84 to Local Datum (BursaWolfe Convention)

dx:	0.0 m
dy:	0.0 m
dz:	0.0 m
rx:	0.0 arcs
ry:	0.0 arcs
rz:	0.0 arcs
Scale:	0.0 ppm

Projection parameters

Projection type:	UTM
Zone:	55S
Central meridian:	147° 0’ 0.0” E
Scale factor:	0.9996
False easting:	500,000 m
False northing:	10,000,000 m
Latitude of origin:	0° 0’ 0.0” N

Test Point Conversion:

Latitude WGS 84:	38° 26’ 22.872” S
Longitude in WGS 84:	147° 23’ 48.329” E
Northing in WGS 84:	5,745,324.46
Easting in WGS 84:	534,625.36
Latitude in local datum:	38° 26’ 22.872 S
Longitude in local datum:	147° 23’ 48.329” E
Northing in local datum:	5,745,324.46
Easting in local datum:	534,625.36

Magnetic Variation and Geoidal Height

Location latitude:	38° 26’ 22.871” S
Location longitude:	147° 23’ 48.330” E
Source of variation data:	IGRF2000
Geoidal height data:	EGM96
Date of computation:	16th January 2005
Magnetic variation:	12.89°
Geoidal height:	3.67m

Primary navigation system

Computation system:	Cnav
RTCM system:	Global Monitoring
Delivery method:	Inmarsat
Supplier:	C&C Technologies

Secondary navigation system

Computation system:	Multifix 4
RTCM system:	Global Monitoring
Delivery method:	Inmarsat/Spotbeam
Supplier:	Fugro

Tertiary navigation system

Computation system:	Trinav GPS 2.6
RTCM system:	Skyfix
Delivery method:	Inmarsat
Supplier:	Fugro

Streamer and source positioning

Source rGPS	POSNET
Tailbuoy rGPS	POSNET
Supplier	WesternGeco
Acoustic	DigiCOURSE 3
Compasses	DigiCOURSE 5011

Navigation processing

Processing system:	Trinav 2.6
Binning system:	Trinav 2.6

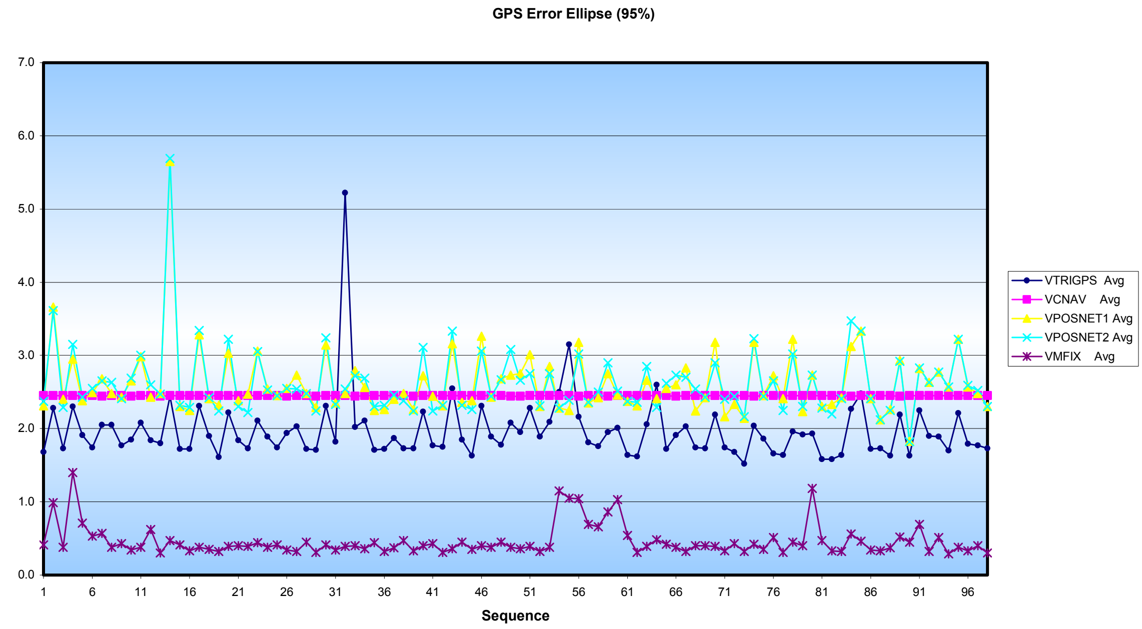
Other equipment

Echosounder:	Simrad EA500
Draft:	7.4m
Gyro, primary:	C-Plath
Error:	-1.44°
Gyro, secondary:	C-Plath
Error:	-0.10°
Current meter:	Nortek ADCP 500kHz

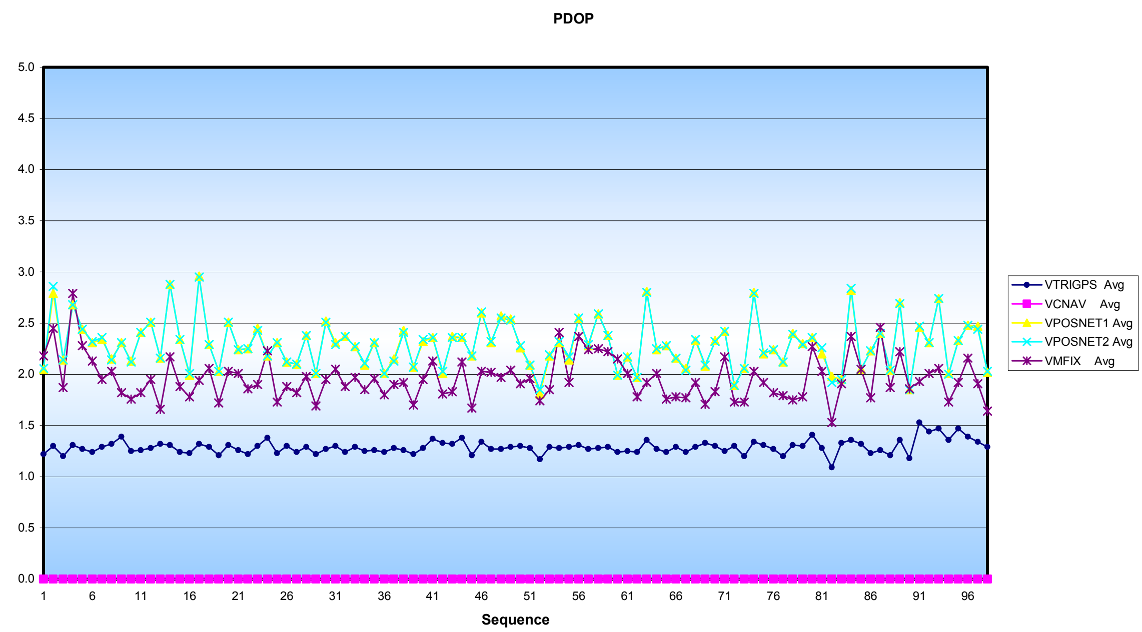
Appendix 2

Positioning Statistics

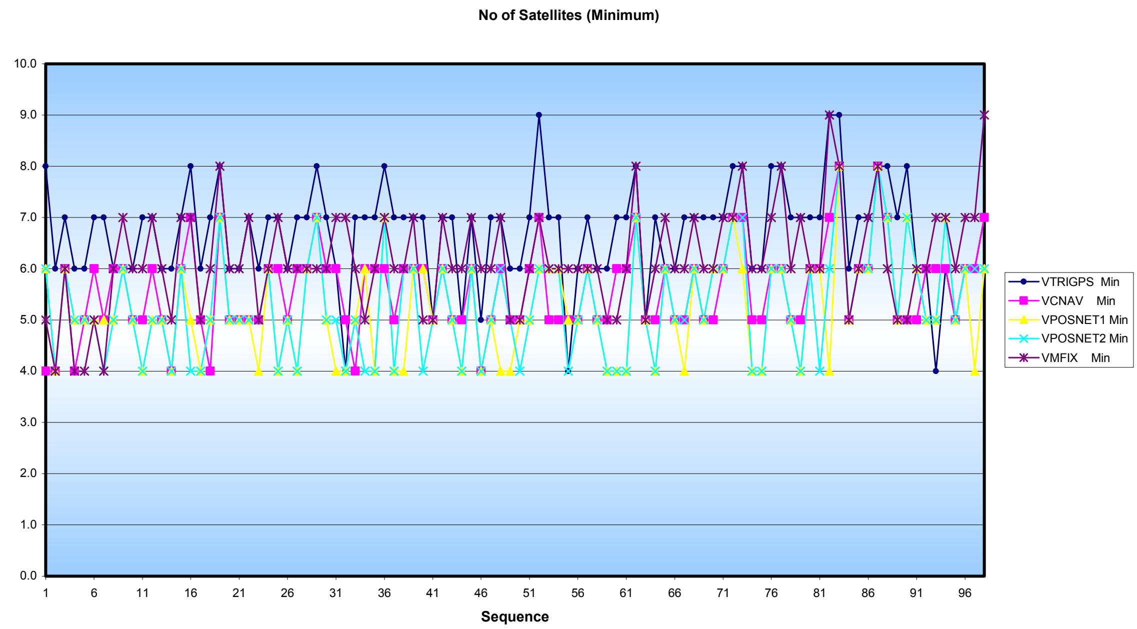
POSITIONING STATISTICS



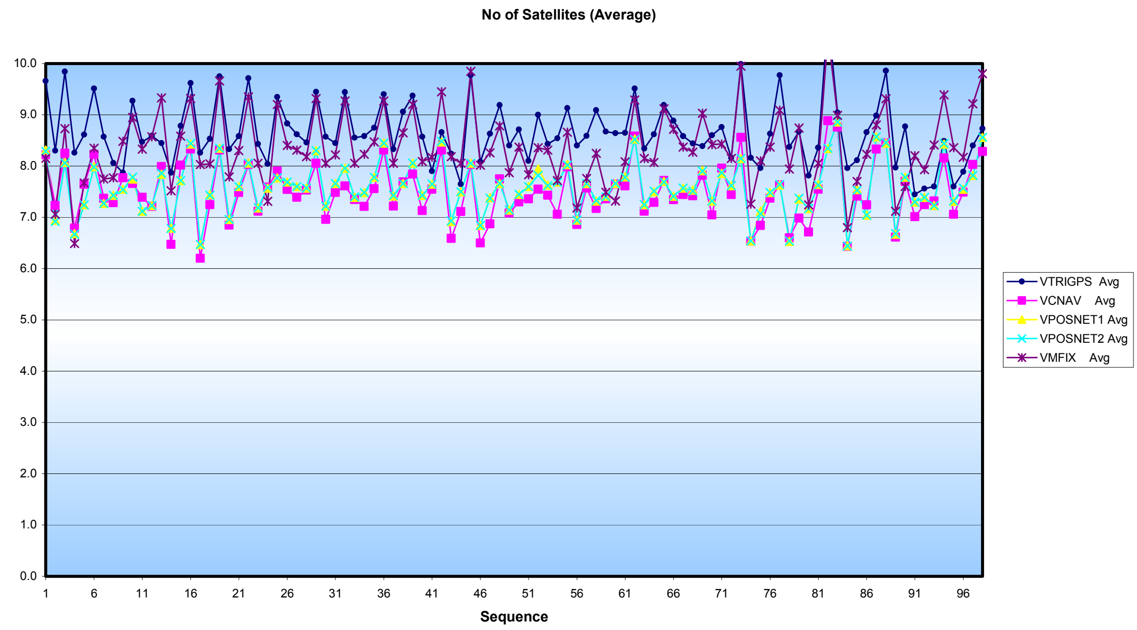
The four DGPS systems worked good with only minor occasional drop outs.



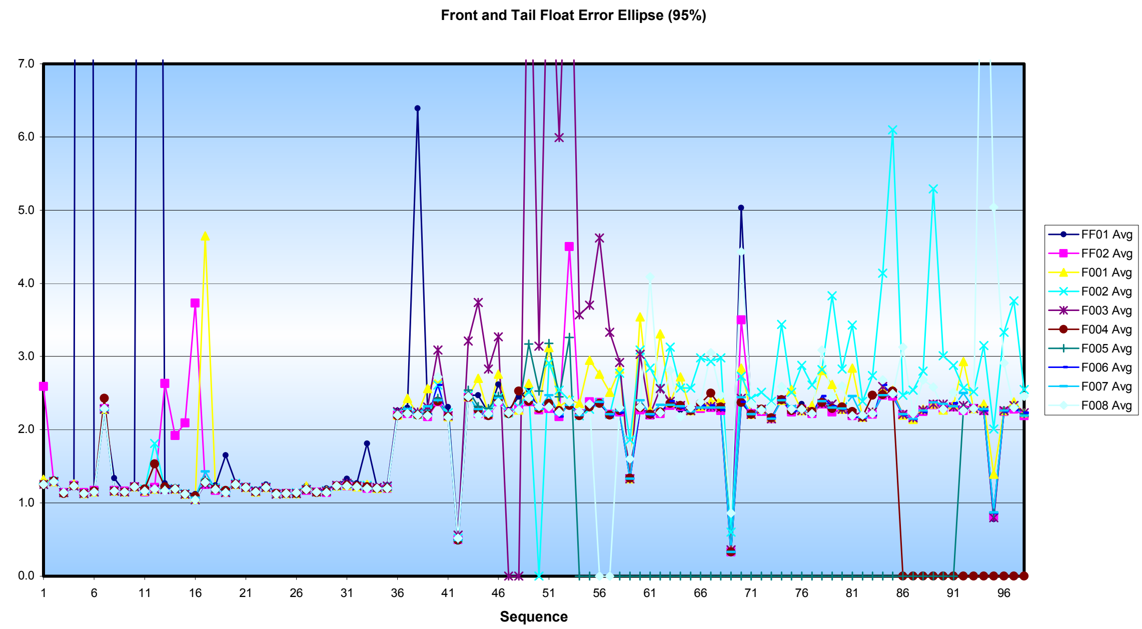
PDOP was good for all systems during the survey.



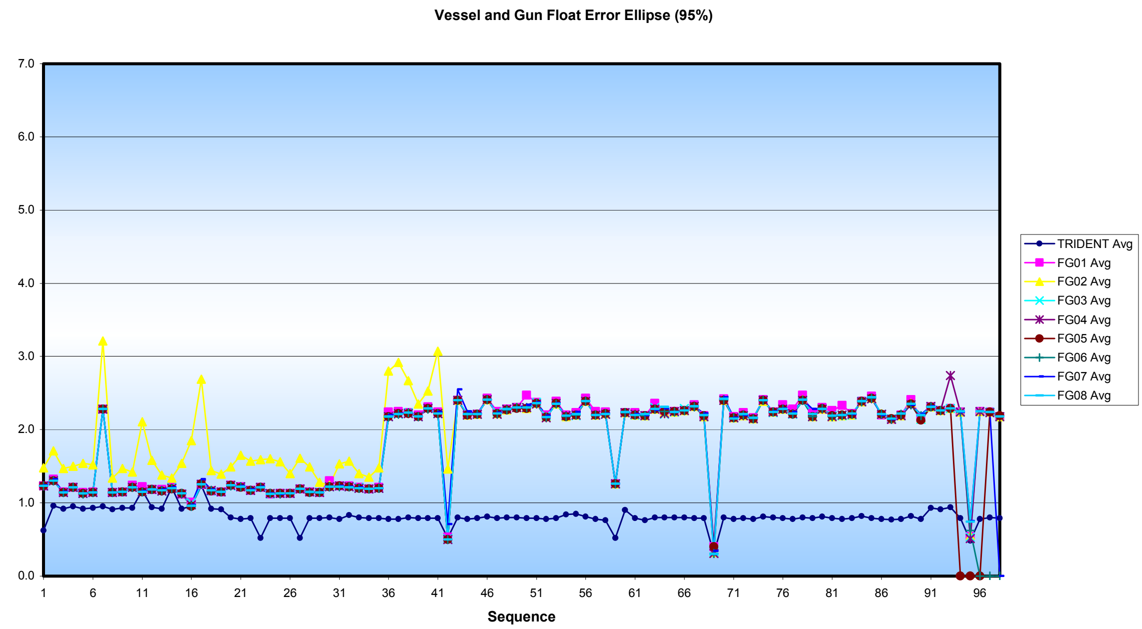
Occasionally during a line the number of satellites dropped down to less than 6 satellites.



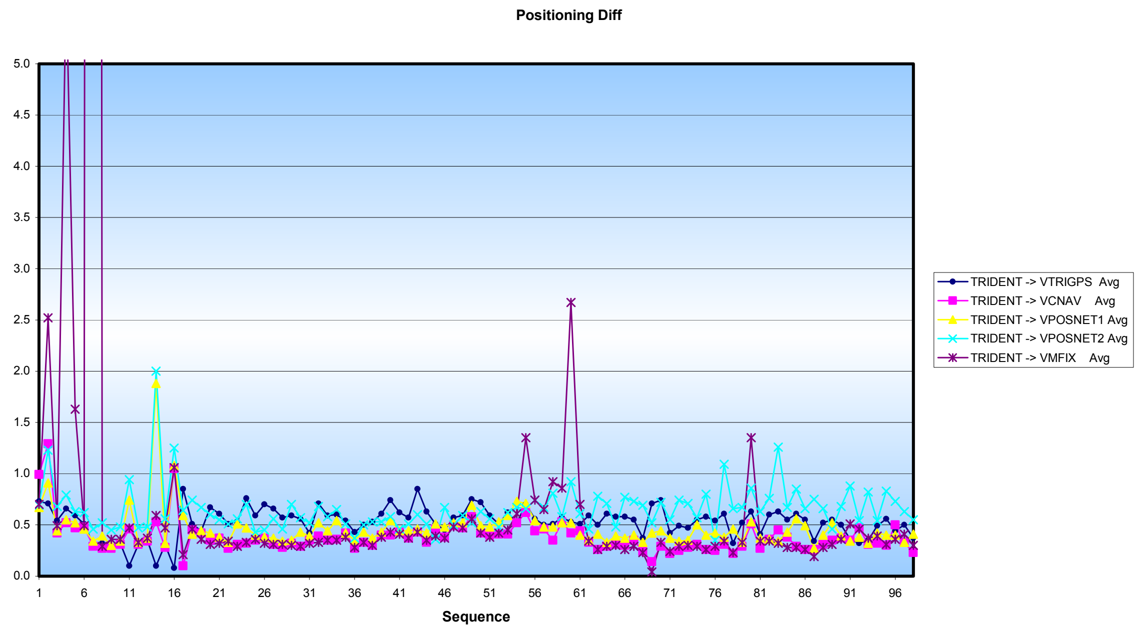
Average number of satellites in use was always over 6.



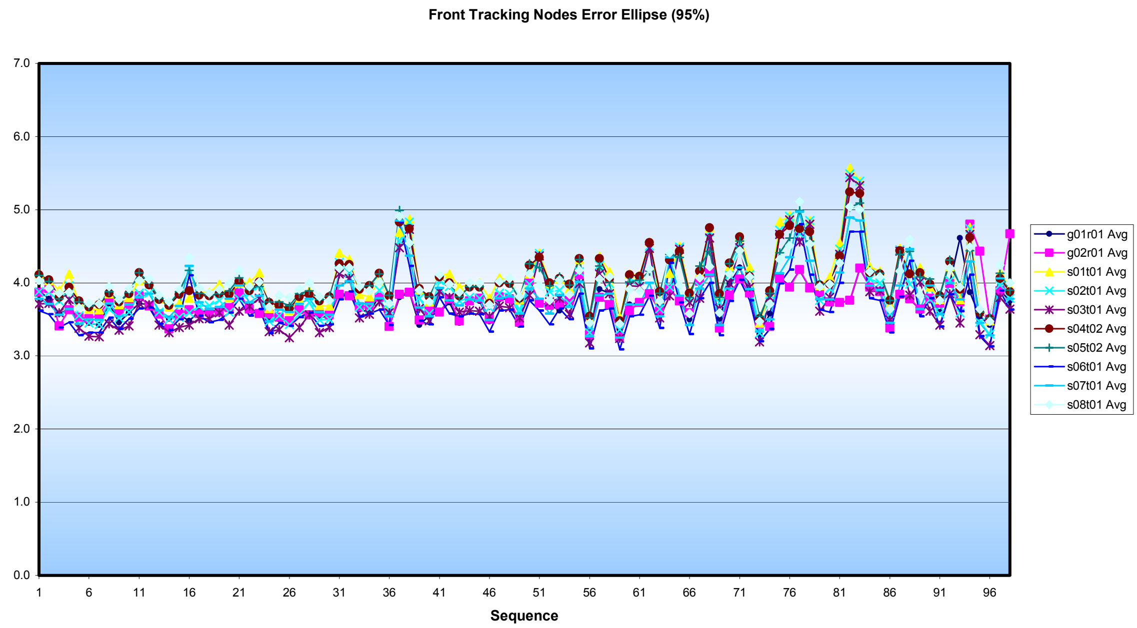
Error ellipses for front and tail floats were steady under 3 except for individual floats with occasional noisy data. A configuration change sequence 36 slightly increased the error ellipses.



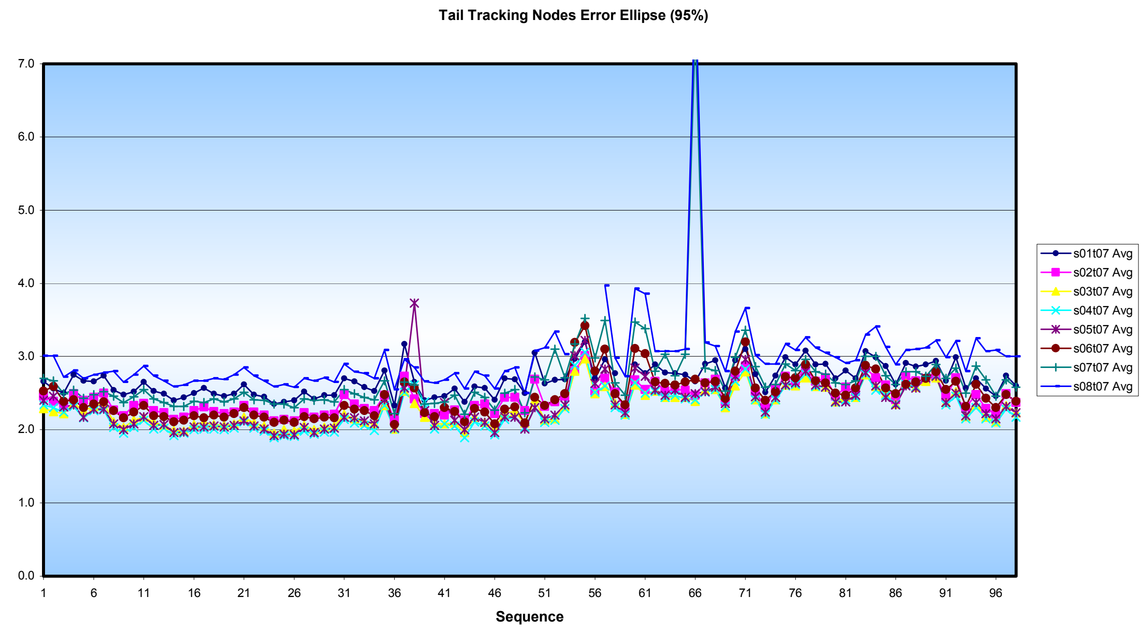
Vessel and gun float error ellipses were also steady under 3.



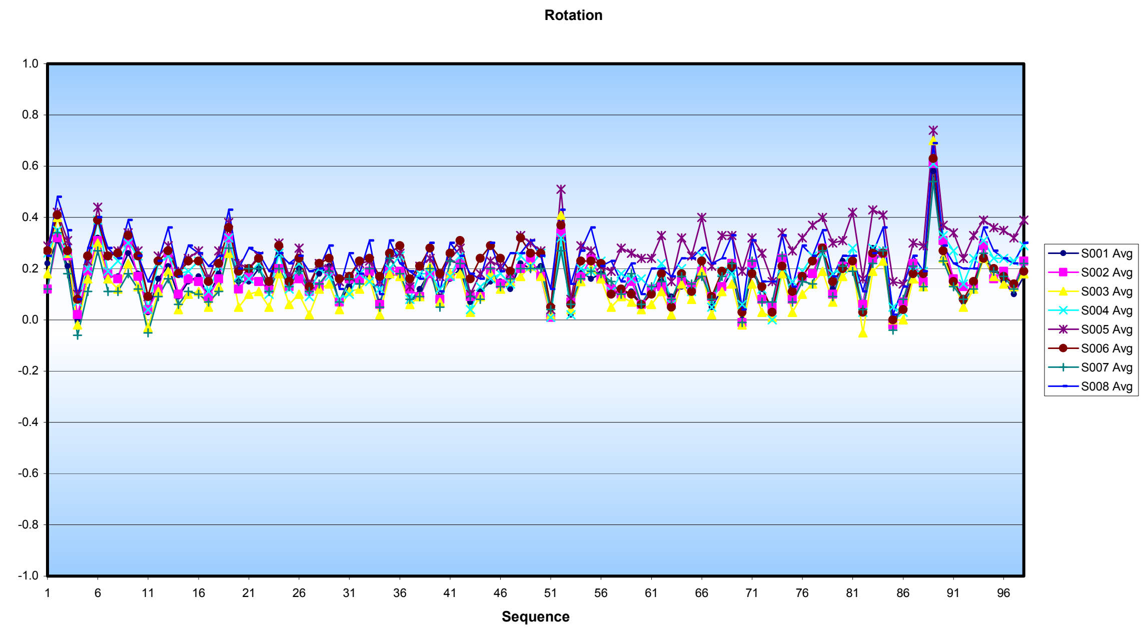
The differences between the different DGPS systems were normally under 1 m. The Multifix XP solution initially had some problems but was good from sequence 9.



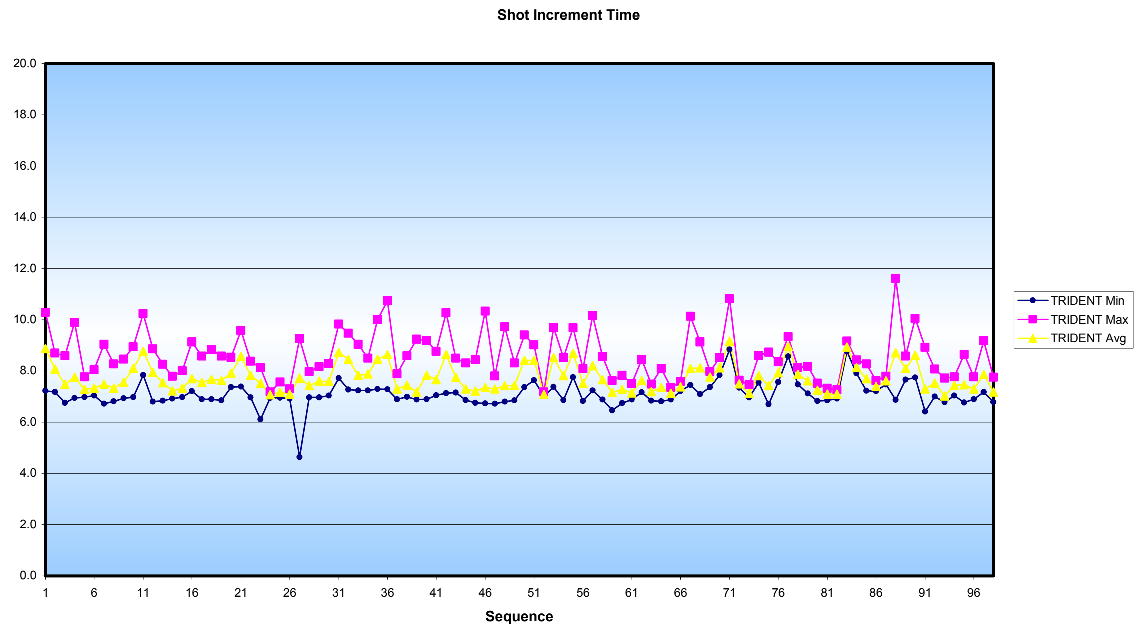
Error elipses for the front end nodes were normally under 4 while the weather was good.



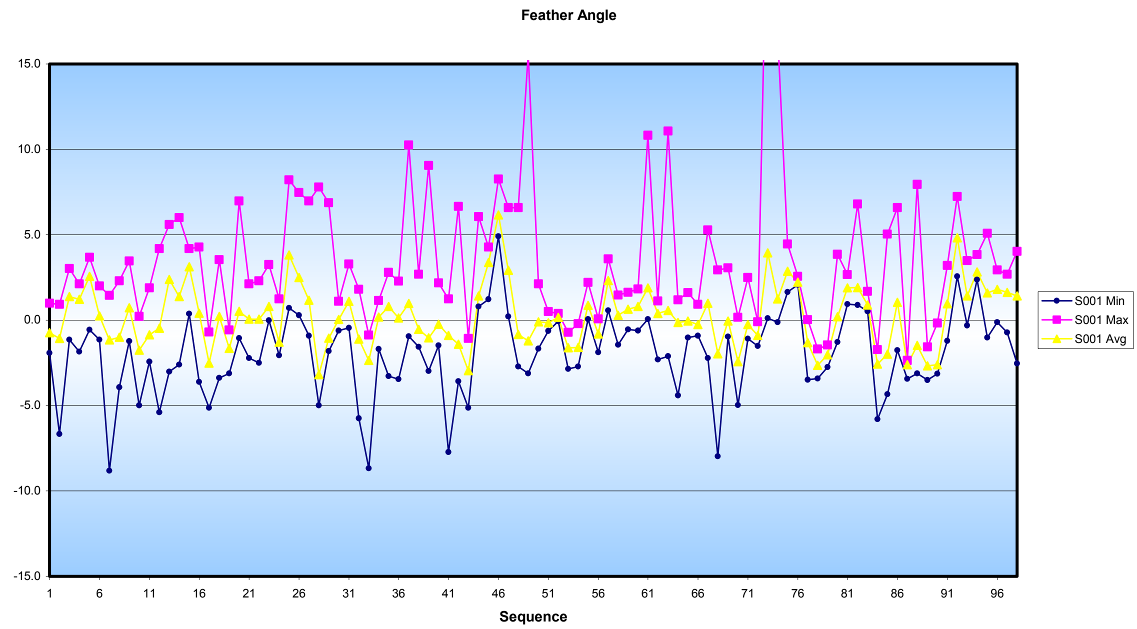
The error ellipses for the tail end were normally under 3 during good weather.



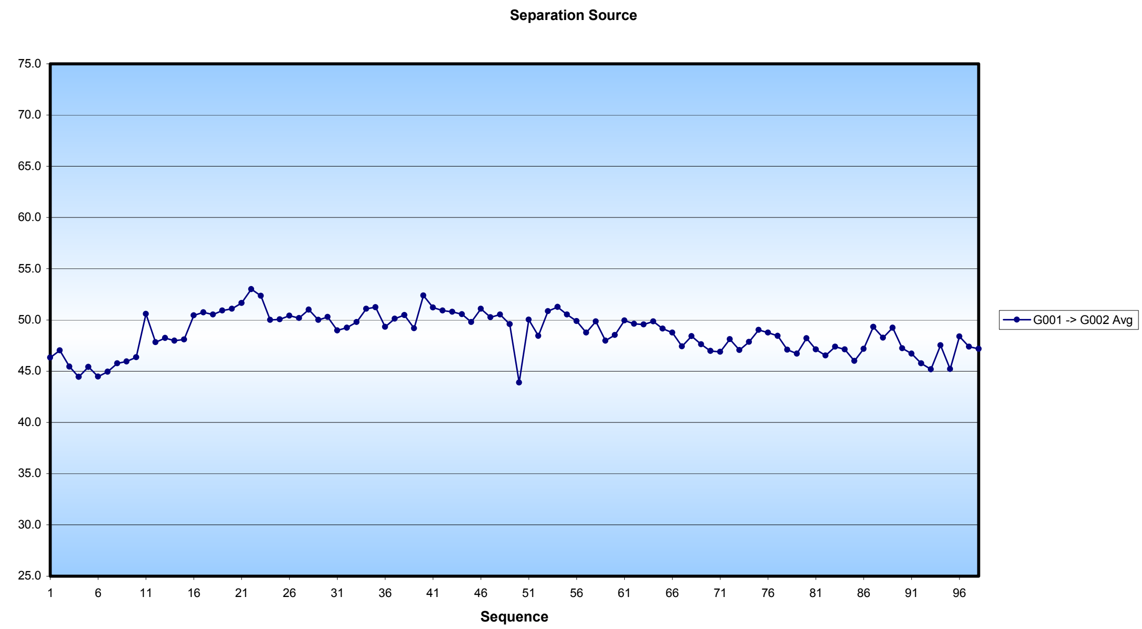
The rotation was steady around 0.2°. This confirmed that the computed magnetic declination of 12.89° was correct. The spike at sequence 89 was caused by bad weather affecting surface position of the tail floats.



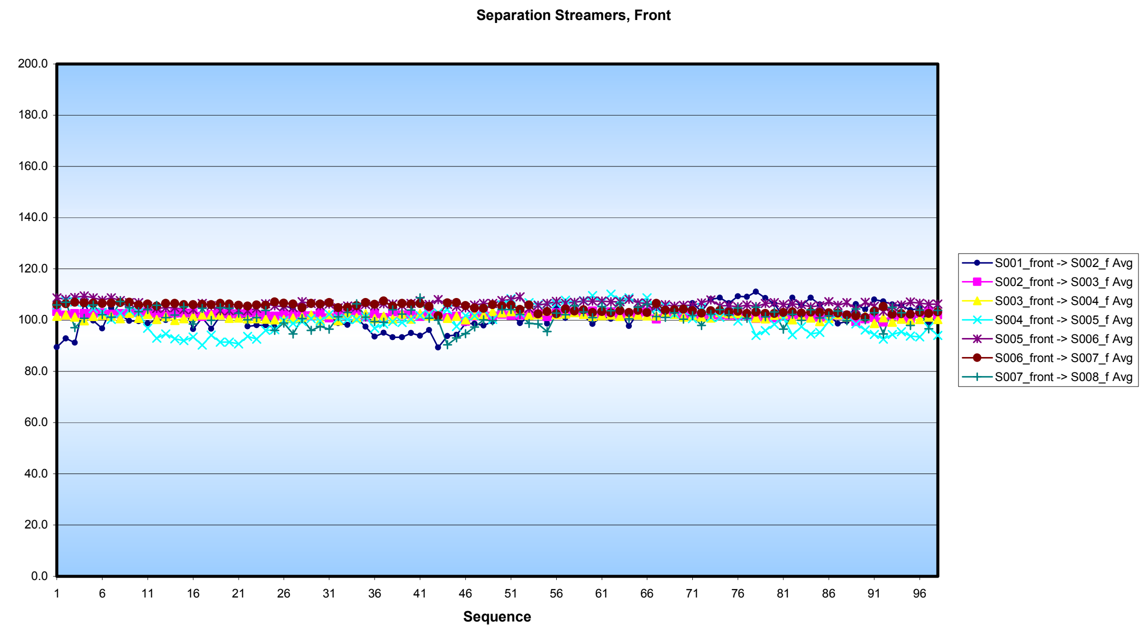
The shotpoint interval was generally around 8s corresponding to a vessel speed of 4.34 kts.



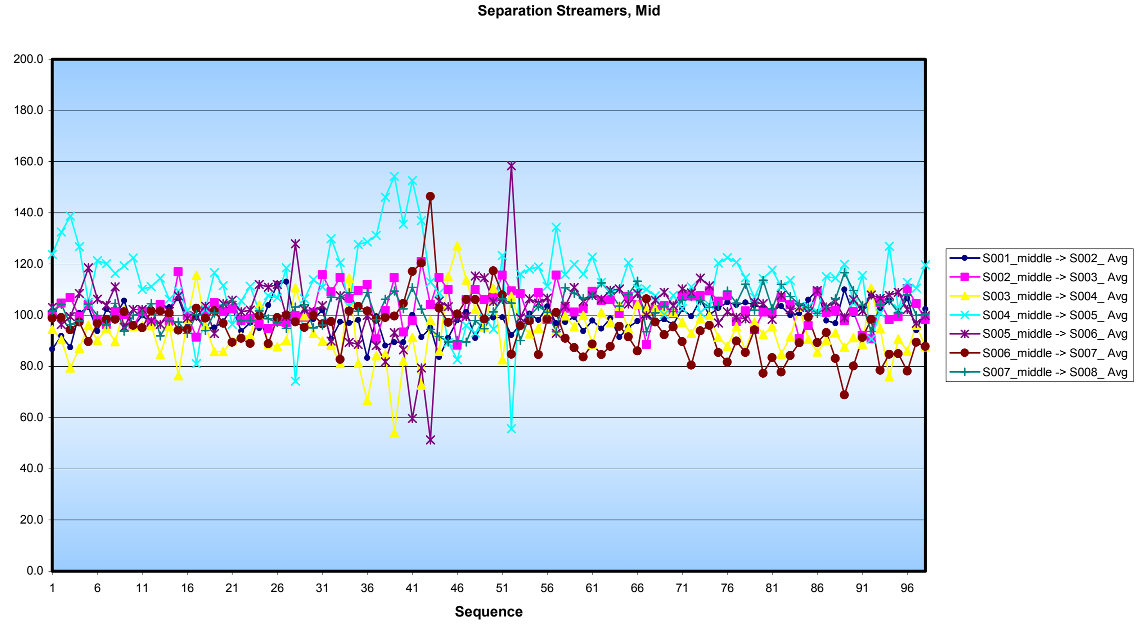
The feathering angles were generally small, averaging around 3°. The min and max values are somewhat distorted as some of the lines were stopped or started with a bend in the streamers due to obstructions or shallow water.



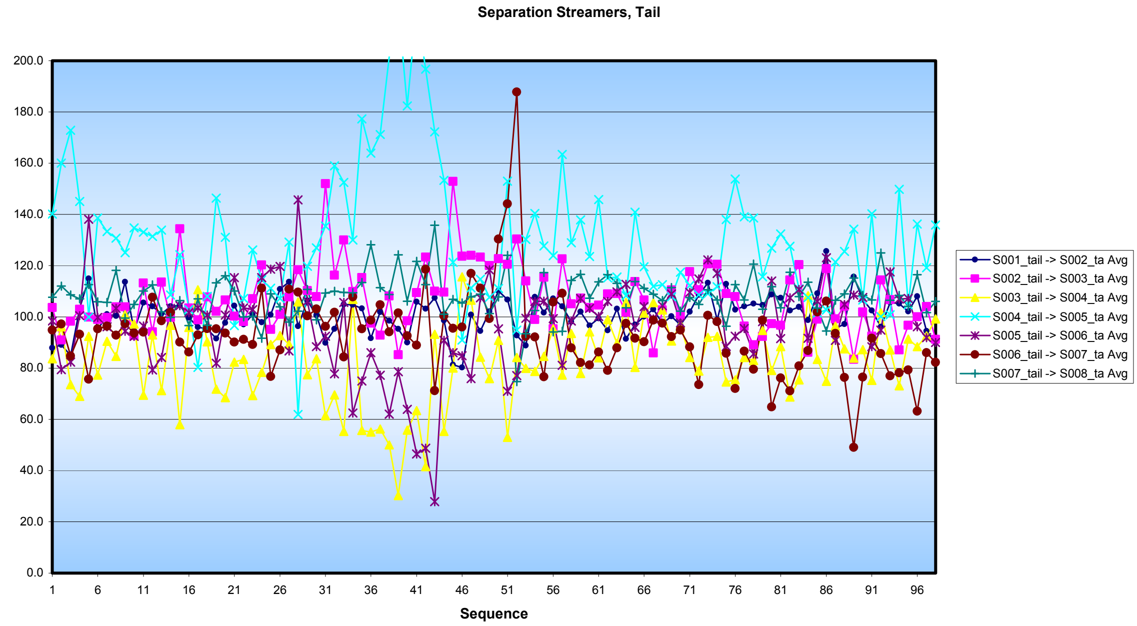
The separation between starboard and port energy sources was steady around 50 m.



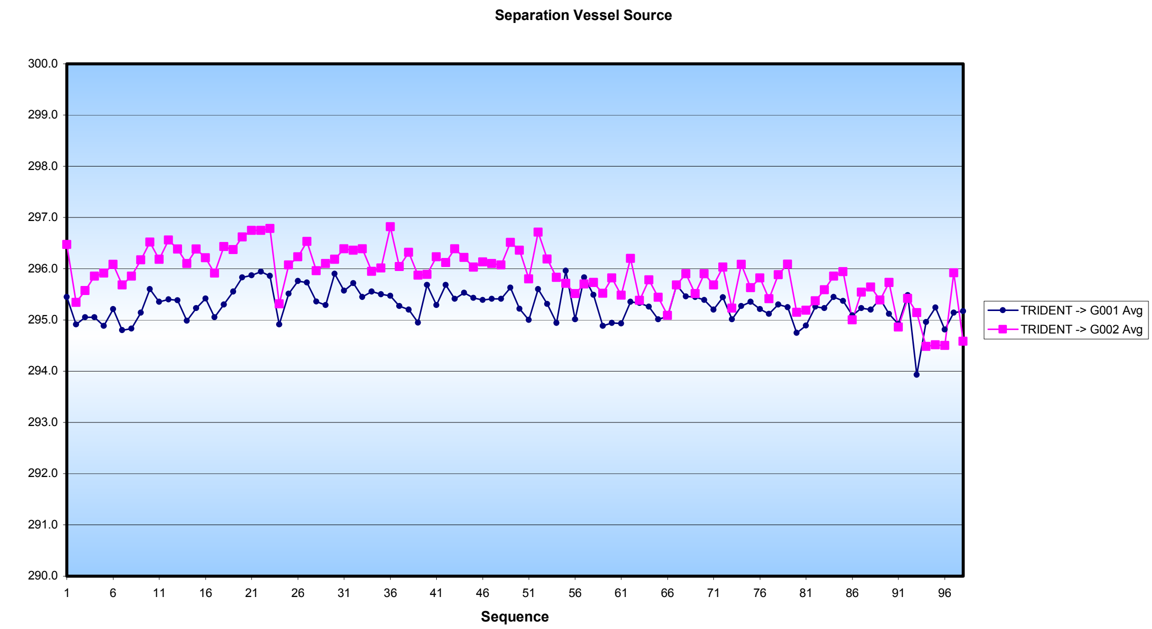
Front end streamer separations were steady around 100m.



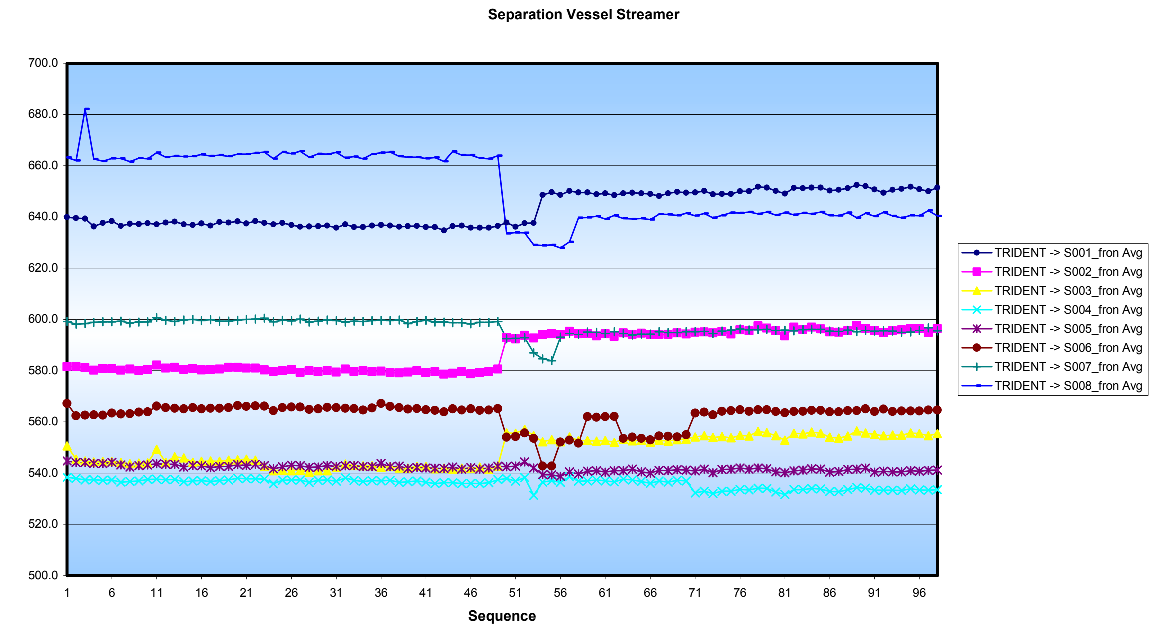
Mid streamer separations were also good around 100 m. There was as usual some variations, especially between the centre streamers (4 and 5).



Tail separations were also around 100 m. Most of the variations were again between the centre streamers. The variation in separations did normally not cause any loss of coverage.



Vessel to source inline separation was around 295 m for this survey.

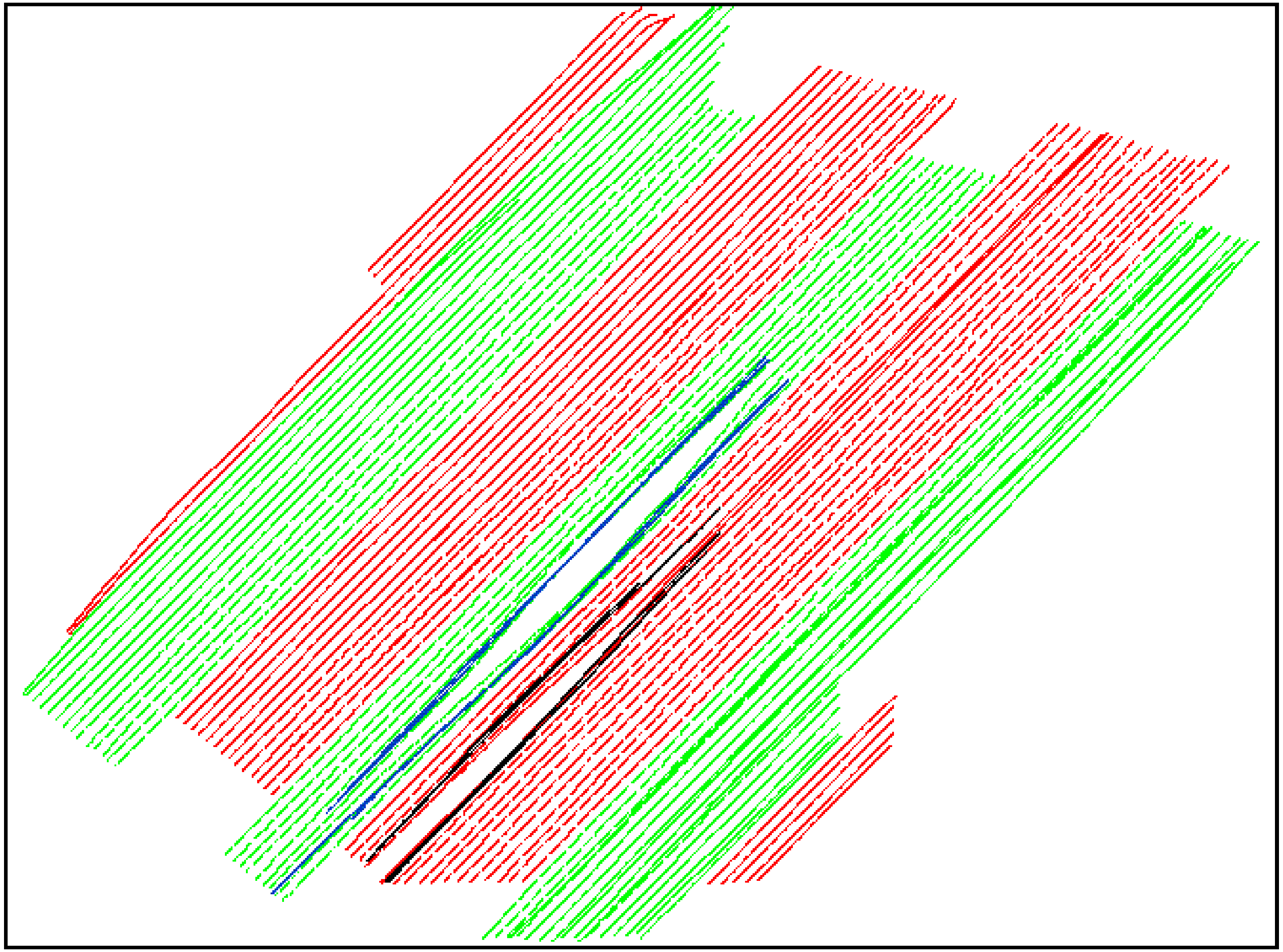


The inline separations between the vessel and the streamer heads were adjusted slightly around crew change to even out the differences in separation between starboard and port side.

Appendix 3

Post Plot Map

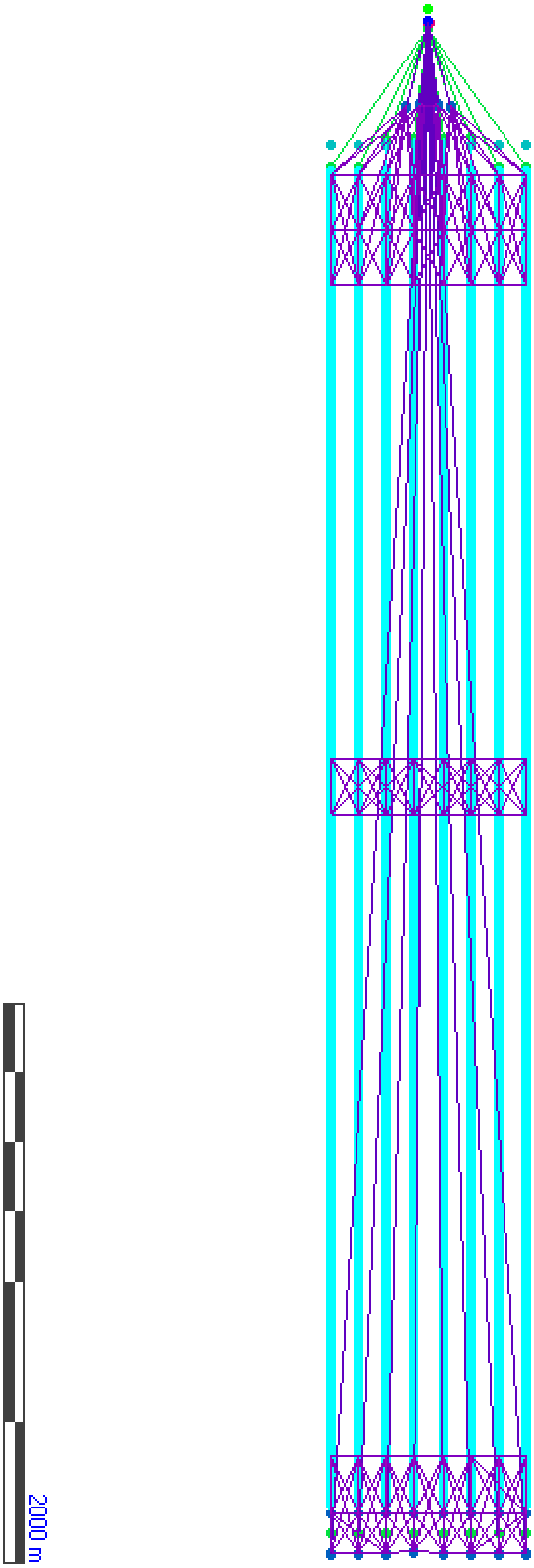
Post Plot Map Sue 3D



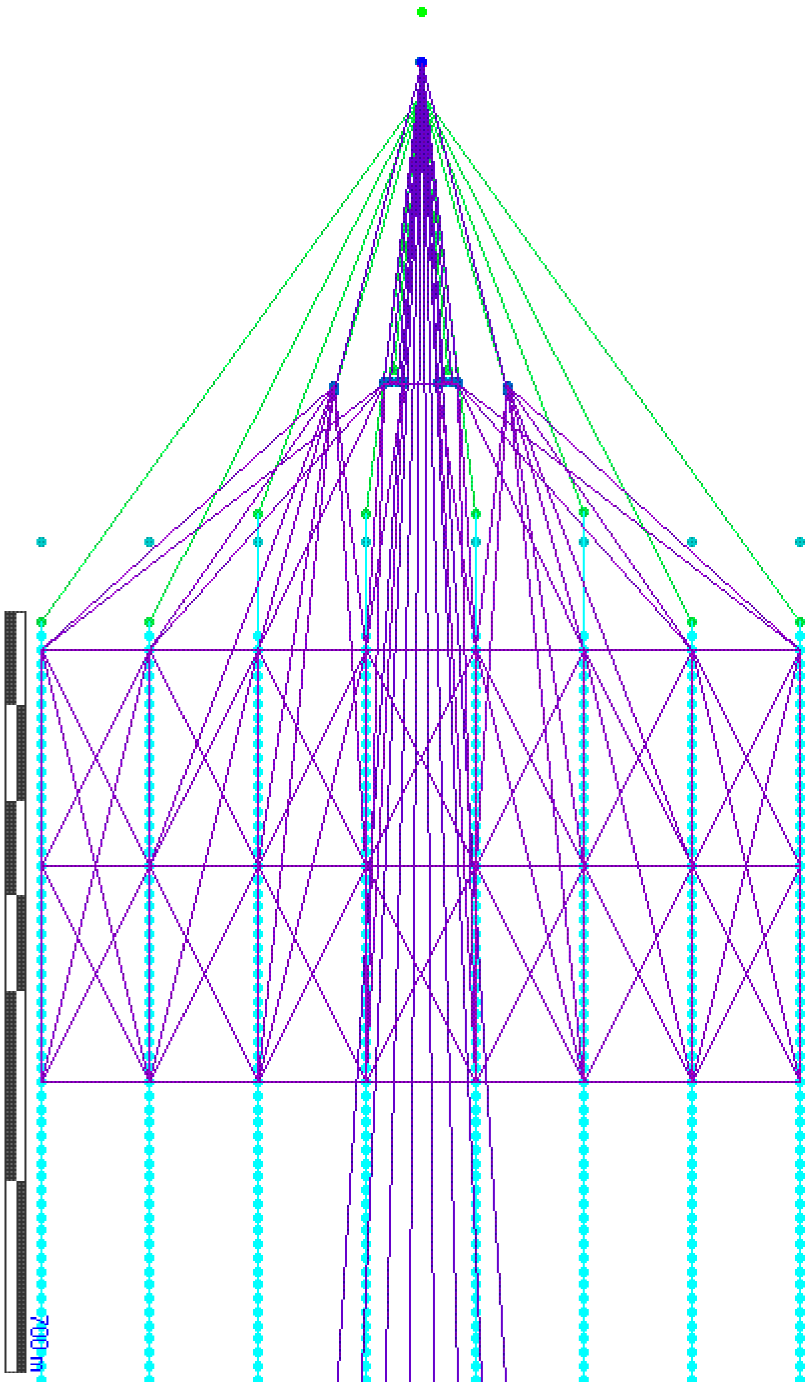
Appendix 4

Network Diagrams

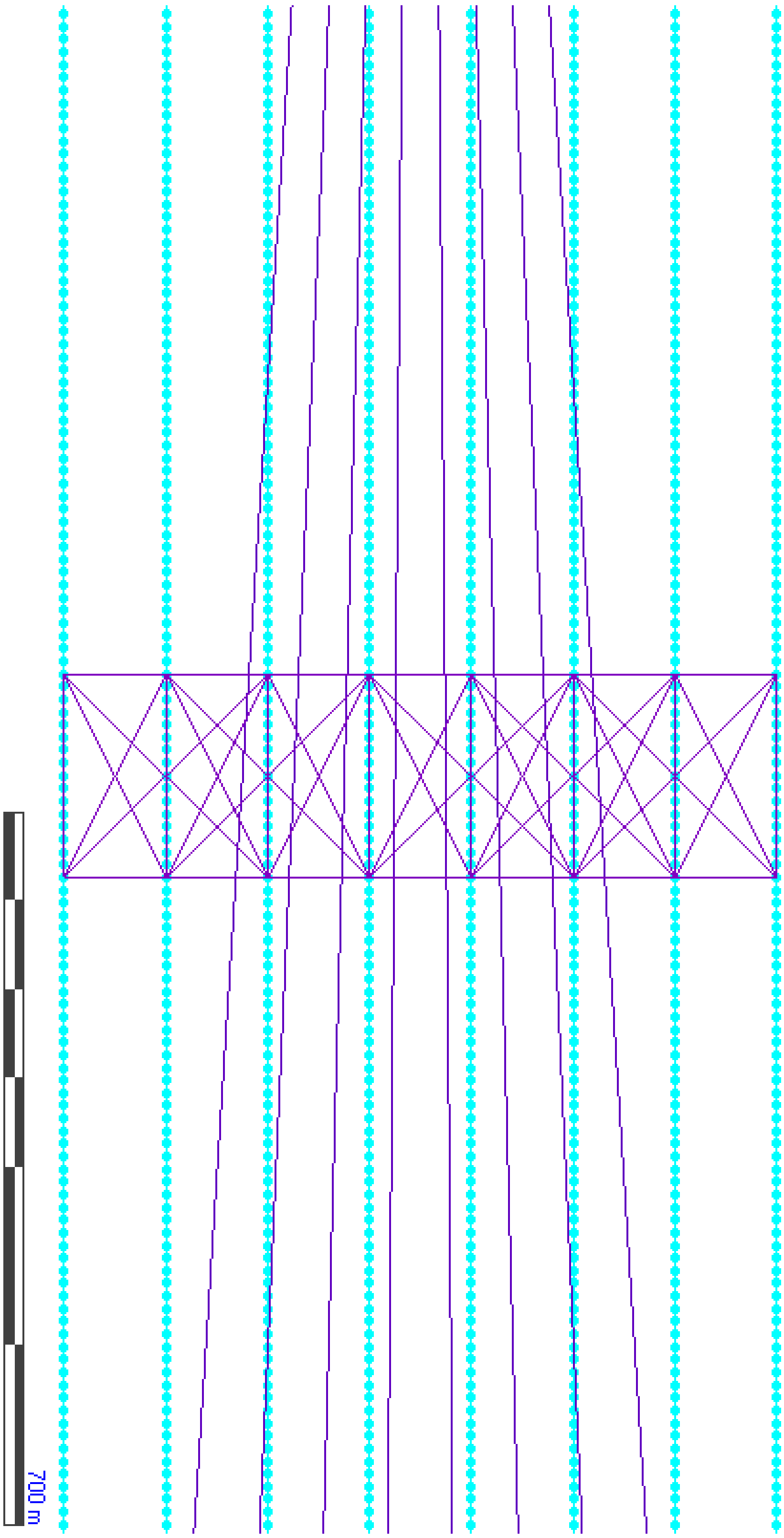
Full Network



Front Network



Mid Network



Tail Network