REPORT AND ANALYSIS OF TEST DATA FROM 1998 TRAWL POSITIONING GEAR TRIALS IN THE PUGET SOUND DABOB BAY, WASHINGTON

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1. INTRODUCTION

The National Marine Fisheries Service - Alaska Fisheries Science Center (NMFS-AFSC) recently contracted Racal Pelagos, Inc. (RPI) to coordinate testing of various ultra short baseline (USBL) systems in a bottom trawl environment. The overall purpose of the test was to determine which USBL system performs best in conditions that approximate those in Bristol Bay, Alaska, where future tests will occur in 2000. During the future testing, AFSC will need to accurately track bottom fishing trawls in order to assess their impact upon the sea floor biology in Alaska.

The trials were conducted in Dabob Bay, Washington, in May 1998. The main objective of these trials was to determine an accurate and reliable system to track a fishing trawl. Three USBL vendors were invited and agreed to participate in the trials. Nautronix Ltd. (Nautronix) provided their ATS II system, Simrad Subsea A/S (Simrad) provided their ITI system, and Ocean Research Equipment, Inc. (ORE) submitted their Trackpoint II Plus system. A local ORE distributor, MECCO, Inc. (MECCO), provided and operated the Trackpoint II Plus system.

The U.S. Navy's fixed, underwater tracking range in Dabob Bay, operated by the Naval Undersea Warfare Center (NUWC) Division – Keyport, Washington, was also used in these trials. The range was used to provide simultaneous sub-sea positioning of the fishing trawl and to serve as a benchmark for system evaluations. The U.S. Navy also provided surface navigation support for the fishing vessel during these trials.

The vessel selected by AFSC to conduct these trawls was the F/V VESTERAALEN. It is 124 feet long, has a beam of 32 feet, and a draft of 18 feet. The F/V VESTERAALEN has a single, fixed-pitch propeller with a nozzle. By design, the vessel is like most in-shore trawlers and has, in fact, operated in Alaska in the past. The tests were conducted using NMFS otter trawls, typically used in Alaskan waters.

A trial schedule was developed that would provide each vendor with three days to mobilize and test their systems. Each vendor's equipment was attached to the fishing trawl, along with the U.S. Navy tracking gear. Both the U.S. Navy and the USBL vendor collected simultaneous trawl position data as determined by their respective equipment, with the trawl being dragged on the bottom along a predetermined track.

The main objective of these trials was to assess the accuracy of each vendor's equipment. This was accomplished using a statistical comparison between each vendor's data and the U.S. Navy's data that were observed simultaneously. This report details the results of these trials and summarizes the comparison results. It also contains details of the equipment and the methodologies used to collect and analyze the data. As a result of the data analysis, conclusions were drawn and recommendations have been included in this report.

2. U. S. NAVY UNDERWATER RANGE TRACKING

The U.S. Navy's underwater tracking system consisted of several arrays of transducers, situated in a straight line, approximately 2000 yards apart. Submarine cables connected the arrays to a computer center on shore at Zelatched Point. Data were logged at the computer center throughout the trials.

Each array consisted of four passive transducers; three forming a horizontal right triangle and the fourth positioned vertically above the base point. The base lines were 30 feet long. The positional accuracy of each beacon was 10 feet in each direction (X,Y,Z). A pinger, operating at 75 kHz, was attached to the trawl and set to ping at a rate of four seconds. The pinger was synchronized to UTC every 30 to 60 minutes using a portable time standard.

The velocity of sound was determined through conductivity, temperature, and depth (CTD) casts that were made once or twice per day using a Seabird SBE 19. This information was made available to the vendors for use in the calibration of their USBL systems.

The U.S. Navy's shore-based computer center was also synchronized to UTC time and observed the time of arrival of each ping at each transducer in the fixed, underwater tracking array. A position for each ping could then be determined, since the epoch of each ping is known and the velocity of sound was observed. The position was computed and logged at the computer center on shore. These positions were also transmitted over a radio frequency (RF) link to the vessel.

Since the U.S. Navy system consists of several arrays of transducers it is possible to obtain more than one beacon fix for the same point in time. When this occurred, both U.S. Navy beacon positions were used in the data analysis.

3. ULTRA SHORT BASELINE (USBL) EQUIPMENT TESTED

The information below provides a brief description of each of the three USBL systems used in these trials. Although every effort has been made to preserve accuracy of data, this information is not intended to be a substitute for the manufacturer's manuals and the reader is directed to the manufacturer for complete details.

3.1 THE NAUTRONIX ATS II

Nautronix provided their ATS II USBL system. It consisted of a master control unit, an omni-directional transducer head, a vertical reference unit, and a high-powered beacon. Spare beacons were also provided. These beacons also provided depth data using a telemetry string.

The following dimensions are approximate:

Control Unit:
- Height: 35.5 cm
- Width: 48.4 cm
- Depth: 42.4 cm
- Weight: 32.0 kg

Hydrophone Assembly
- Length: 61.0 cm
- Diameter: 22.5 cm
- Weight: 38.0 kg

High-Powered Beacons
- Model ABH243 - Omni-directional, Depth, Telemetry
- Length: 80.0 cm
- Diameter: 8.0 cm
- Weight: 7.2 kg in air, 3 kg in water
- Power: 192 dB re. 1 μ Pa @ 1m
- Battery: NiCd
- Depth rating: 2000m
- Frequency:
  - interrogation - 15.02 kHz
  - reply chirp centered at - 16.50 kHz

The beacons were provided with a protective rubber sheath.

3.1.1 ATS II Configuration

The head of the ATS II system was calibrated at the dock in a static mode. This was accomplished through a comparison of calculated beacon positions with those measured locally. A beacon was lowered fore, aft, and port of the transducer and observations were compared on the control unit with the measured offsets. Pitch and roll corrections were also determined and applied for the hydrophone and for the vertical reference unit.

The control unit was interfaced to the hydrophone, vertical reference unit, gyro (digital input), and integrated navigation software, WinFrog. WinFrog was used to combine the vessel position, gyro, and USBL data to produce the latitude and longitude of the beacon. The speed of sound, determined by vendor personnel from the U.S. Navy's CTD data, was entered into the control unit. All raw data were logged.

3.2 THE SIMRAD ITI

Simrad provided their Integrated Trawl Instrumentation (ITI) for these trials. It consisted of a control and display unit, a transducer head, and three net-mounted sensors. Each net sensor can be used to measure a range and bearing. Additionally, one or two other options can be selected from a list of approximately 12 features and added to the sensor when ordering. The three net sensors provided for the trial could measure depth, height, or catch in addition to the standard range and bearing. The transducer head had three transducers and covered an area of 100° horizontally and 40° vertically down from the horizontal.

The following dimensions are approximate:

Display Unit:

- Height: 35.4 cm
- Width: 41.0 cm
- Depth: 45.5 cm
- Weight: 27.0 kg

Transceiver Assembly:

- Height: 40.0 cm
- Width: 40.0 cm
- Depth: 30.0 cm
- Weight: 26.0 kg

Triple Hydrophone:

- Weight: 35.0 kg

Sensors:

- Models (3) Depth, Catch, Height
- Weight: 9.0 kg in air, 3 kg in water
- Power: 20.0 watts
- Battery: NiCd
- Depth Rating: 2000m
- Frequency: 27 kHz to 33 kHz

3.2.1 ITI Configuration

No head alignment calibration was conducted on the Simrad ITI.

The monitor and control units were interfaced to the hydrophone, gyro (analog input), NMEA vessel position, and the Electronic Chart Company's data-logging program, Globe. WinFrog was used to output the NMEA position of the hydrophone to the control unit using the U.S. Navy's antenna position, because the ITI does not allow for antenna/hydrophone offsets. The ITI does not accept a sound velocity entry, but rather uses an operator-entered water temperature to determine its own velocity. Water temperatures were obtained from the CTD data.

Prior to conducting official trawl tests, some test data were collected. These data contained the trawl position in NMEA GLL format, but lacked time. Furthermore, coordinates were recorded to only two decimal points of a minute of longitude and latitude. This represents a resolution of approximately 20 meters and caused problems in subsequent data processing. These problems could not be corrected in the field, but have since been addressed by the manufacturer.

3.3 THE ORE TRACKPOINT II PLUS

ORE provided their Trackpoint II Plus system, consisting of a command and display module, a vertical reference unit, an omni-directional transducer head, and a high-powered beacon. Spare beacons were also provided. These beacons also provided depth data, using a telemetry string.

The following dimensions are approximate:

Control Unit Dimensions:
- Height: 26.7 cm
- Width: 43.0 cm
- Depth: 51.0 cm
- Weight: 25.0 kg

Hydrophone Assembly:
- Length: 63.0 cm
- Diameter: 7.0 cm
- Weight: 12.0 kg

High-Powered Beacons
- Model 4350A - Omni-directional, Depth, Telemetry
- Length: 58.0 cm
- Diameter: 9.8 cm
- Weight: 7.5 kg in air, 4 kg in water
- Power: 203 dB re. 1 µPa @ 1m
- Battery: NiCd
- Depth Rating: 3000 m
- Frequency: 22 kHz to 30 kHz, 27 kHz used

3.3.1 Trackpoint II Plus Configuration

The transducer head was calibrated at the dock in a static mode by a comparison of calculated beacon positions with those measured locally. The calibration was conducted by lowering a beacon fore, aft, and port of the transducer and comparing the observations on the control unit with the measured offsets. Pitch and roll corrections were also determined and applied for the hydrophone and the vertical reference unit.

The control unit was interfaced to the hydrophone, vertical reference unit, gyro (analog input), flux gate compass (backup), and integrated navigation software, Hypack. Hypack combined the vessel position and north corrected USBL data to produce a latitude and longitude of the beacon. A velocity of sound, determined by vendor personnel from the U.S. Navy's CTD data, was entered into the control unit.

3.4 BEACON DEPTH DETERMINATION

All three vendors used pressure sensors to determine the depth of their beacons. This depth was sent to the vessel via telemetry at each interrogation epoch. This method of depth determination is more accurate than using the observed vertical angle and distance to solve for the depth. This independently determined depth then becomes a restraint when determining the horizontal coordinates of the beacon, thus improving the stability and positional accuracy of the beacon.

4. TRAWL AND TRAWL MENSURATION GEAR

The information below describes the research trawl and the trawl mensuration gear provided by the NMFS-AFSC. These items are standard gear and will be used in the upcoming experimental study of bottom trawl impacts on seafloor habitat.

4.1 83/112 EASTERN BOTTOM TRAWL

The NMFS-AFSC standard 83/112 Eastern bottom trawl was used for this study (RACEBASE gear code 44 - See Figure 1). This bottom trawl has been used for groundfish surveys in the eastern Bering Sea since 1982. Specific details concerning materials and dimensions are described below. The standard trawl was modified to improve capture efficiency and retention of smaller organisms, according to the research plan for the trawling impact study. These modifications (RACEBASE accessories code 122) included adding a tickler chain (half-inch, grade 30, polished proof coil chain), a hula skirt covering the footrope setback, and a 1.5” fine-mesh liner covering the entire bottom body, both bottom wings, and complete coverage of the intermediate and cod end.

4.2 83/112 EASTERN BOTTOM TRAWL SPECIFICATIONS

Netting: Nylon, pre-shrunk, and dyed green.

Headrope: the line running along the top forward edge of the net.

- Length: 83.9 feet
- Diameter: ½”
- Composition: 6 x 19 galvanized wire rope, wrapped with 5/l6” polypropylene rope.

Footrope: the line running along the bottom forward edge of a net. A total of l72 feet of 5/l6" galvanized chain is hung along the footrope by attaching every tenth link to the footrope at 8" intervals. The lower edges of the wings and throat are attached to the loops of chain formed as a result of the above attachment.

- Length: 111.9 feet long
- Diameter: ½”
- Composition: 6 x 19 galvanized wire rope, wrapped with 5/16” polypropylene rope, and completely covered with split pieces of heavy rubber hose.

Breastlines: A wrapped wire rope running along the forward edges of the top, bottom, or side panels of a net, usually attached to a bridle at one end and a ribline at the other end. The upper and lower sections are joined with a “hammer-lock.”

- Length: 11.3 feet - upper
10.5 feet - lower
- Composition: ½” diameter galvanized wire rope, wrapped with ¼” polypropylene rope.

Riblines: Lines running longitudinally in the net and codend, which provide strength and shape to the net, consisting of ¾" diameter braided nylon, or equivalent, extending the length of the first intermediate.

Flotation: Seventeen, 8-inch aluminum floats along each wing add buoyancy to the headrope. Another seven, equally-spaced floats are located at the front center of the trawl between the wings (bosom); consisting of three, l6-inch aluminum floats, one in each corner and one in the middle, plus four 8-inch aluminum floats. Total = 4l floats.

Codend liner: A cylinder ¼" # l8 nylon web at the end of a net in which the fish are collected and held.

Chafing gear: Generally, a panel of web (with hula attached) that is laced to the codend to protect it from abrasion.

Sideseams: Seam joining the upper and lower wing panels and body panels.

Bridles: Single 30-fathom lengths of 5/16" galvanized wires connecting the front of the net and the doors.

Doors: A large steel or alloy structure attached to each main wire (in front of the net) to spread the net horizontally by means of hydrodynamic and friction forces. The 83/112 uses 6' x 9' V-doors, weighing 2,000 pounds each.

4.3 MENSURATION GEAR

Auxiliary gear was attached to the trawl according to standard practice. Scanmar acoustic net mensuration gear provided real-time information on net width and height, operating at 42.631 kHz (C2 spread), 42.024 kHz (C5 spread), 41.417 kHz (C2 height), and/or 41.690 kHz (C5 height) with a power rating of 185-186 dB reference 1 ìpa at 1 meter. A mechanical bottom contact sensor was attached to the footrope to identify on-bottom/off-bottom locations for determination of area swept by the trawl. A micro-bathythermograph was also attached to the trawl to record actual water temperature profiles.

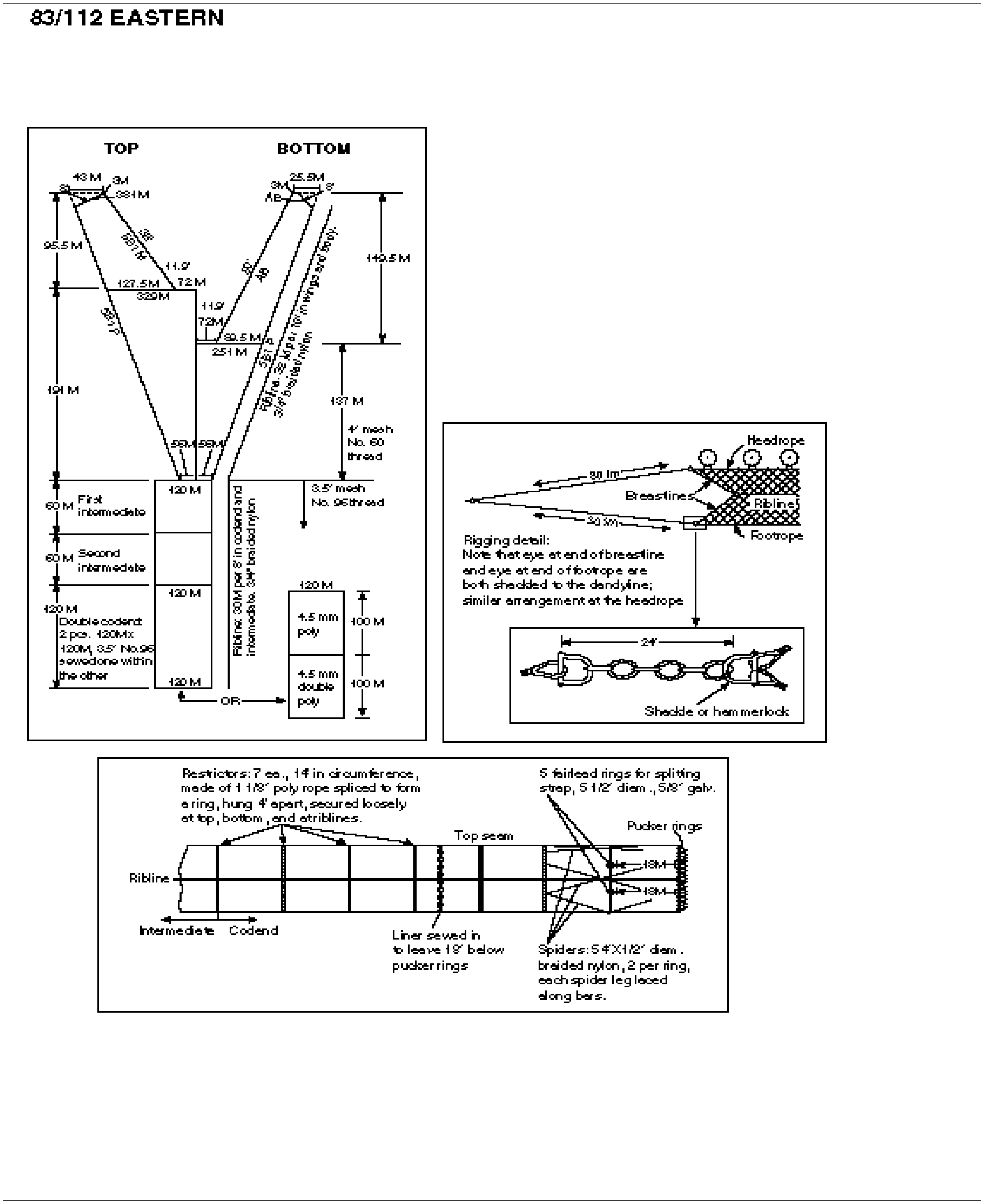


Figure 1 - 83/112 Eastern Bottom Trawl

5. SHIP NAVIGATION

The U.S. Navy also provided a shipboard DGPS system and differential corrections during these trials. To supplement this UHF differential correction source, RTCM (as it is termed by the Radio Telecommunication Committee Marine) Coast Guard differential corrections were available from Coast Guard beacon 274. Due to the fact that the U.S. Navy corrections were not initially received at the vessel, Coast Guard corrections were used for the entire test, which did not degrade the accuracy of the navigation. The RTCM data were input into a GPS receiver which, in turn, output differentially corrected positions to a personal computer (PC) running a navigation software package called PC Range Graphics (PCRG), supplied by the U.S. Navy. PCRG provided the navigational data necessary for the helmsman to steer the vessel along the desired track. It also showed the trawl track, as determined by the U.S. Navy's 75kHz pinger. The U.S. Navy also provided two-way radios, which permitted communication between the vessel and the range personnel on the beach. These personnel were responsible for controlling the range and logged the range data. The accuracy of a differentially corrected position, as provided by the U.S. Navy, was 3 meters.

Differentially corrected positions (NMEA GGA messages) and UTC time stamps (NMEA ZDA messages) were output from the GPS receiver to each vendor's equipment in the equipment room. In addition, the stepper output from the Sperry MK37 gyro was sent from the bridge to a Lehmkuhl digital gyro repeater located in the equipment room. The purpose of this repeater was to convert the gyro data to a serial message that could be easily read by PC hardware. A Lehmkuhl LR40 repeater was initially installed, but it kept losing synchronization with the gyro and was later replaced with the newer Lehmkuhl LR60 repeater, provided by the U.S. Navy.

6. HYDROPHONE MOUNT

A single hydrophone pole, to be used by all vendors, was designed and fabricated for the purpose of these trials. The final design was such that the hydrophone was situated two meters below the hull of the vessel. The pole was actually comprised of two sections, each constructed from schedule 80 steel. The top section was eight inches in diameter, pivoted approximately two meters from the top, and extended to the bottom of the hull. The bottom section was four inches in diameter and two meters long. Three bottom sections were constructed to accommodate each vendor's hydrophone. Additionally, a semi-circular brace was welded to the hull of the vessel, just below the water line. A flange, which permitted the bolting of the pole to the gunnel, was located at the top of the pole. A faring, constructed of an ultra-high molecular weight (UHMW) polymer, was placed around the pole.

The pole was bolted at the pivot point and no guy wire was used in the case of the first two vendors, Nautronix and Simrad. By the time the third vendor used the pole, it was found to knock steadily against the brace below the water line when travelling at 3 knots. Although the knocking occurred intermittently before, it was not considered serious enough by the first two vendors to warrant action. In the case of the third vendor, a guy wire was run forward and rubber was installed to make the pole fit snuggly into the brace. This eliminated all noticeable vibration.

See Appendix D for Hydrophone Pole Design Drawings.

7. BEACON LOCATION AND ATTACHMENT TO THE TRAWL

As mentioned previously, two sets of beacons were attached to the trawl during every trial run. The U.S. Navy's, 75kHz beacon was always fixed to the trawl, while each vendor would also attach their beacon to the trawl during only their portion of the trials. The locations of all beacons used in these trials are indicated in Figure 2. The Nautronix beacon was moved after Trawl 2 from 4.6m aft of the U.S. Navy beacon to 5.2m aft. The Trackpoint II beacons were moved after Trawl 29 from 1.8 meters on either side of the U.S. Navy beacon to 4.6 meters on either side.

The U.S. Navy beacon was mounted on a nylon board, such that its transducer projected horizontally towards the fixed acoustic range. The assembly was inserted into a pocket of net material, which was then sewn onto the top of the net. Additional nylon cord was used to tighten the pocket, which kept the assembly from twisting.

The ATS II and Trackpoint II beacons are both cylindrical in shape. These were laid flat on top of the net with the transducer element pointing towards the vessel. A piece of netting was sewn tightly over the beacon to form a pocket. The ITI beacons are roughly rectangular in shape and are designed to attach to a trawl. These were attached to the head rope with shackles.

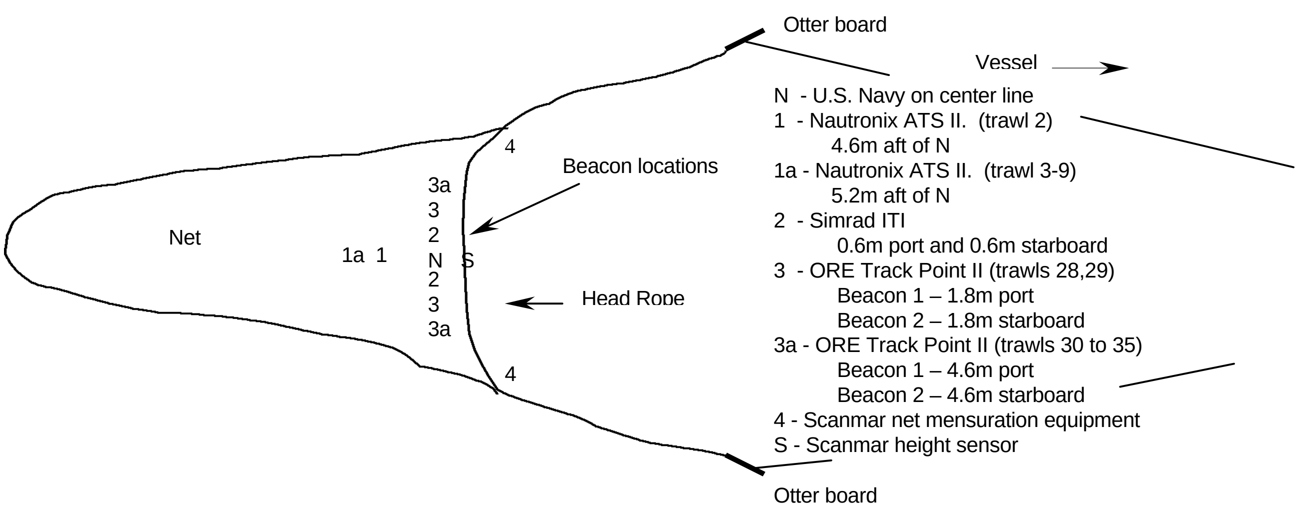


Figure 2 – Net Showing Beacon Locations

Both Nautronix and ORE moved their respective beacons after initial test runs to see if this improved tracking, there was no apparent change. At the end of the first day, U.S. Navy personnel also tilted their beacon to improve performance. The second ORE beacon was placed on the net in case the first failed.

8. GYRO CALIBRATION

A gyro calibration was conducted at the pier, prior to the commencement of any trawls. The gyro was calibrated by comparing observed gyro readings with the known azimuth of the dock. This calibration was later confirmed using the U.S. Navy's DGPS system. Two points along the dock, 11.4m apart, were chosen as the baseline. The perpendicular distances from these points to the centerline of the vessel were measured at the same time the gyro was observed. A gyro correction of -4.7° was calculated. The first and second vendor applied this correction during their trawls, while the third vendor used a value of -0.5°. This value (-0.5°) was determined by comparing the observed vessel track and observed gyro heading, while the vessel steamed from the dock to the underwater tracking range. Despite the fact that the correction of -4.7° was confirmed on three separate days, a value of -0.9° was calculated on the fourth day. At the time, it was thought that this value was erroneous and was caused by a rapidly changing vessel heading, due to currents around the dock.

The use of a repeater did not effect the calibration value, as it was the gyro that was calibrated not the repeater. After calibration, the repeater was adjusted to read the same heading as the gyro. The correction was applied to the USBL equipment; the gyro itself was not adjusted.

9. SELECTION OF THE TRAWL LOCATION

Two areas were initially selected as potential trawl sites for the purposes of these trials. They were selected, because they were thought to be similar to the areas in the Bering Sea, where the trawling impact studies would later be conducted. (See Figure 3) The main selection criteria were depth, slope, length of trawl, and absence of debris, such as boulders. The proposed primary area was rejected due to a gully in the center and the proposed secondary area was rejected due to boulders throughout much of the area. The area ultimately selected for the actual trawl did have a portion that was not covered by either Acoustic Array 01 or 02. However, there were no other alternatives and coverage was better than the theoretical range circles indicated. This area was characterized by hard, irregular bottom, which resulted in frequent damage to the trawl.

All trawls were conducted within the indicated area in a southerly direction. While trawling, the helmsman attempted to steer the vessel along a straight line. When the locations of boulders were discovered the vessel was steered from its straight path on subsequent trawls to avoid these areas. The curved path of the trawl (See Appendix A) is due to these deviations and the natural track of the doors on the sloped bottom. The drag of the trawl also effected the path of the vessel making it difficult to follow a straight line.

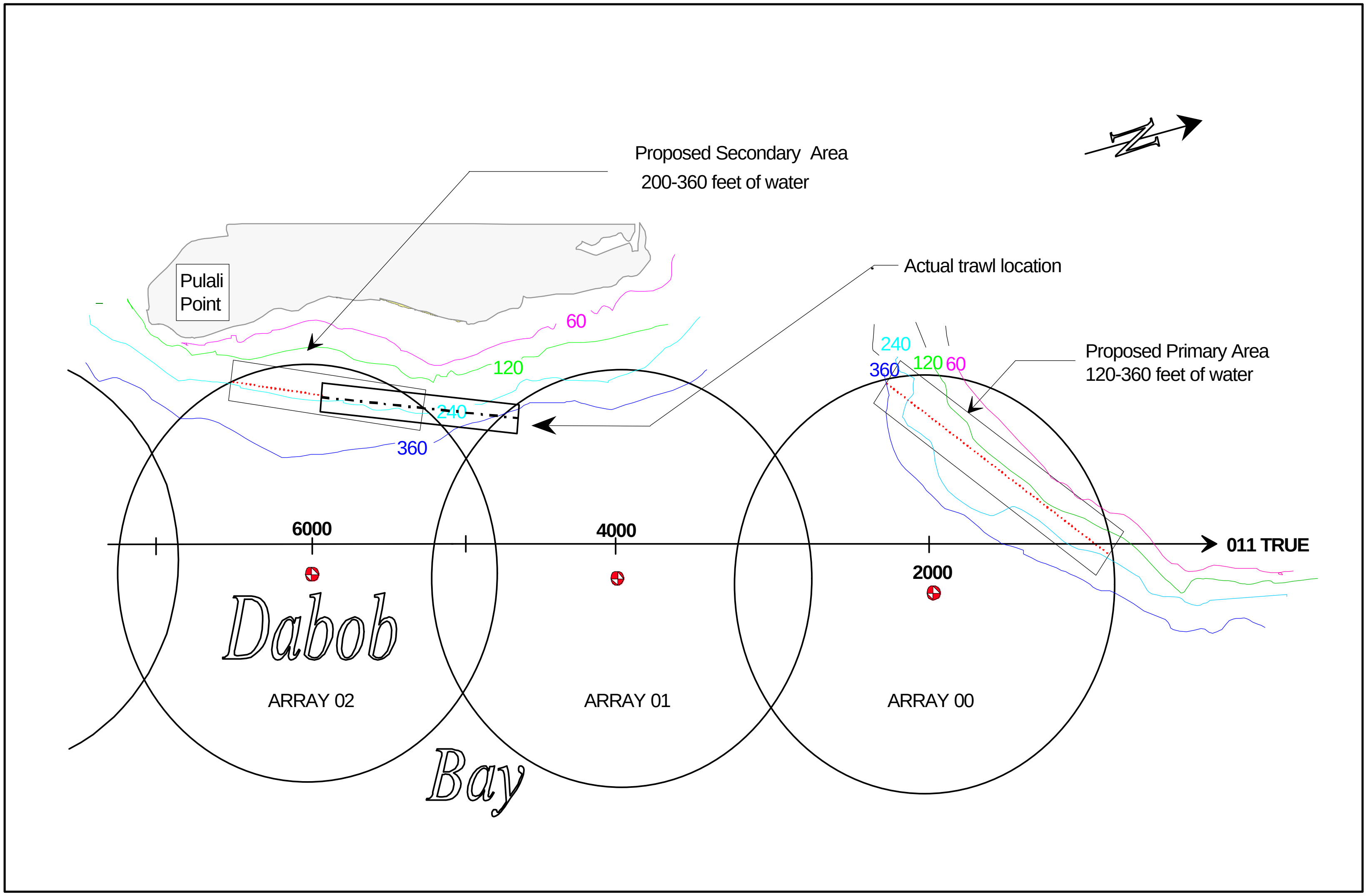


Figure 3 – Test Areas in Dabob Bay

10. DATA COLLECTION

Trawling began on May 19, 1998, with vendor number one, Nautronix. Several untracked trawls were initially made within the primary and secondary areas, described above, in an attempt to find an acceptable test area. Next, underwater equipment was tested individually during a trawl. The first trawl was aborted before data could be recorded. Although the second trawl was recorded and was considered the vendor's first trawl, the U.S. Navy system did not track well during this run.

Initially, the U.S. Navy's beacon was oriented to project down as it was thought that the trawls would be made in different directions. It was reoriented to project horizontally towards their hydrophones at the end of the first day. This improved the U.S. Navy's data and the first accepted Nautronix trawl (number 2) was not processed, but is included in this report.

Trawling continued on May 20 with the first vendor. It was noted that the gyro repeater differed from the gyro and had to be checked and adjusted for each trawl. Seven more acceptable trawls, numbered Trawl 3 through Trawl 9 were made for vendor number one. The ATS II was not affected by the ship's echo sounder equipment.

On May 21, the gyro repeater was replaced and equipment from the second vendor, Simrad, was mobilized. Trawling commenced and was completed on May 22. Eight trawls, numbered Trawl 14 through Trawl 21, were accepted for analysis. On the first trawl of the day, it was discovered that the depth sensor was not functioning. Since none of the other beacons were equipped with depth sensors, manual depths were entered for all subsequent trawls.

The equipment of the third vendor, ORE, was mobilized on May 26. After mobilization, it was found that some interference in the USBL system was caused by the vessel's echo sounders. The vessel had three echo sounders:

Skipper CS116 operating at 50 kHz
Simrad EQ155 operating at either 38 kHz or 50 kHz
Simrad CF100/ED100 operating at 38 kHz

All three produced some false returns in the Trackpoint II Plus system. The Skipper produced the most, while the Simrad EQ155 (operating at 50 kHz on the 40-fathom range) produced the least. Only the Simrad EQ155 (operating at 50 kHz on the 40-fathom range) was used during the trials. Eight trawls, numbered Trawl 28 through Trawl 35, were accepted for analysis.

The sea state for all three vendors was calm with little wind and mild temperatures.

11. DATA ANALYSIS AND PROCESSING

The data used for this analysis were the recorded USBL track positions. The raw data were not processed to recompute USBL beacon positions. Thus, the fix interval for the analysis was that of the fix recording interval not the interrogation rate. Although the ATS II's interrogation rate was one second, the fix recording rate was three seconds. Both the Trackpoint II's interrogation rate and fix recording interval was four seconds.

As mentioned above, two U.S. Navy fixes could occur at the same epoch. When there were two U.S. Navy fixes for a single epoch the mean position was not used, rather the corresponding single USBL fix was compared separately to both of the U.S. Navy fixes.

The primary objective of this test was to "evaluate the accuracy of each USBL system." This was accomplished by comparing USBL positions of a trawl to those positions determined by the U.S. Navy underwater tracking system of the same trawl. The data had to be processed before any statistical comparison could be made. The data processing consisted of the following main steps:

a) determination of outliers
b) removal of outliers
c) translation of USBL beacon position to the U.S. Navy beacon position
d) merging or interpolation of new USBL positions to match the U.S. Navy positions, with respect to time
e) application of gyro correction
f) application of correction for sound velocity error
g) estimation of the accuracy of each USBL system by comparison to synthetically generated distributions

11.1 DETERMINATION OF OUTLIERS

The first step in the processing of data was the identification and removal of outliers. The main cause of outliers was due to angular errors in the USBL measurements, which resulted in large across track errors. It is not thought that snagging the net on the bottom contributed significantly to the outliers. One can eliminate these errors (spikes) through graphical methods, by looking at a post plot of the USBL data. The observer can easily identify a main track, which contains most of the data; however, a few fixes will plot tens of meters from this main track. These points are considered outliers. In the case of vendor one and vendor three, these spikes could be readily seen and eliminated. In the case of vendor two, however, it was difficult to determine the main track.

To determine outliers in the USBL data, piecewise linear sections were fitted through the majority of the data. Any fix greater than eight meters from the line, defined by these linear sections, was rejected. The Test Plan stated that if this distance was greater than 2σ, the fix would be considered an outlier. However, with a quoted angular resolution of 0.15° for Nautronix and 0.1° for ORE or using any of the other published accuracy values, 2σ would be less than 2 meters. This would have made it difficult to determine the mean centerline of the track of reasonable length and would have eliminated too much data. Thus, a nominal value of 8 meters was chosen as the criteria for the elimination of obvious spikes. Smoothing all the data including the outliers was not considered, as the outlier would bias the remaining data. The only outliers removed from the U.S. Navy data were large spikes greater than about 50 meters. Consideration was given to smoothing the U.S. Navy data, however smoothing can introduce biases, thus no other processing of the U.S. Navy data was done.

When viewing the sample plots of vendor number two, it is apparent that the trawl track is jagged. This was caused by the low resolution at which the data were logged. Only two decimal points of a minute of latitude and longitude were used. This translates into a position resolution of only 20 meters. There were also large across track jumps of up to 200 meters. Thus, there was no obvious track that could have been used to eliminate outliers. In fact, a tolerance of 8 meters would eliminate data simply due to the resolution at which it was recorded.

As a result of the above facts and given the published equipment accuracy, vendor number two's data were not processed for outliers and the statistical comparison was not performed. The Simrad ITI system was designed for fishing and must not be confused with Simrad's HPR, which is a survey grade USBL system.

The following table summarizes the outlier analysis of the other two vendors. The sample size was based upon the number of data points found in the supplied field files.

USBL System	**Sample Size**	**Outliers**	**% Outliers**
ATS II	1610	218	13.5
Track Point II Plus Beacon #1	1288	40	3.1

Table 1 - Outliers

The majority of the ATS II's outliers occurred during quick changes in vessel heading. The "spikes" in the raw Nautronix track plots (Appendix A) correspond to these changes in heading and are where most of the outliers occur. Although the gyro was interfaced to the ATS II, north-corrected data were not output to the navigation program, rather ship-relative coordinates of a beacon were output. The navigation program did not accept north-corrected data. When the navigation program received the ship-relative coordinates, it applied the last vessel heading to compute the geographic coordinates of the beacon. Thus, if the relative coordinates of the beacon and the vessel heading are of different epochs, an erroneous fix may occur. The corrections applied in Table 2 correct for these navigation software errors as well as for head misalignment and gyro error.

11.2 GYRO CORRECTION

The gyro compass, while not part of the USBL system, can introduce large errors into the position calculations. An error of only 1° will result in a six meter across track error, when the trawl is towed 350 meters behind the vessel. Thus, any gyro biases had to be removed prior to the comparison of the USBL positions to the U.S. Navy positions.

Typically, when one applies a gyro correction to this type of data, one value is used for all data. However, due to the poor performance of the digital gyro repeater used by the first vendor, a gyro correction was determined for each trawl. The gyro corrections are shown in Table 2.

Trawl	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**
ATS II	*	3.9°	2.9°	0.8°	1.3°	0.9°	2.6°	1.6°

Trawl	**28**	**29**	**30**	**31**	**32**	**33**	**34**	**35**
Track Point II Plus	-1.1°	-1.0°	-1.0°	-1.0°	-1.0°	0.5°	0°	-0.6°

Table 2 - Gyro Corrections

*The U.S. Navy track data for this trawl was logged as “bad” when collected.

11.3 SOUND VELOCITY CORRECTION

A correction for an error in sound velocity was determined on a per trawl basis. Rather than calculate the correction in terms of speed of sound, the correction was determined in terms of a shift, of the USBL point, towards or away from the tow vessel. The magnitude of the correction was set equal to the mean along track difference between the USBL fixes and corresponding U.S. Navy fixes for each trawl. The direction was chosen as the average trawl azimuth (towards or away from the vessel). Table 3 below lists the corrections applied.

Trawl	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**
Average trawl direction		197°	201°	198°	198°	194°	198°	198°
ATS II	*	0.8	-5.6	-2.3	-3.8	-4.4	-.9	-3.5

Trawl	**28**	**29**	**30**	**31**	**32**	**33**	**34**	**35**
Average trawl direction	196°	196°	195°	195°	193°	194°	188°	194°
Track Point II Plus	4.0	14.5	-1.6	-5.1	-2.5	-8.4	-7.5	-5.9

Table 3 – Resultant Sound Velocity Corrections (positive value moves point towards vessel)

*The U.S. Navy track data for this trawl was logged as “bad” when collected.

11.4 TRANSLATION AND INTERPOLATION OF DATA

As mentioned previously, the beacons on the trawl were located in different positions depending upon the vendor and on the trawl number. In order to compare the U.S. Navy positions to the USBL positions, the USBL fixes were translated to the U.S. Navy beacon location. The geometric relationship between all beacons is shown in Figure 2. In order to translate coordinates from one location on the trawl to another, an azimuth is required. The azimuth chosen in these calculations was the course-made-good of the trawl, as determined by the USBL data itself.

In order to compare a USBL fix to a U.S. Navy fix they must be at the same point in time. Since the data was collected asynchronously it was necessary to interpolate one data set to the other. The USBL data was interpolated to points in time corresponding to U.S. Navy fixes. Since both the U.S. Navy data and USBL data may have had gaps a maximum tolerance of 8.1 seconds, or just greater than twice the U.S. Navy ping interval, was used as rejection criteria when finding USBL fixes. This meant that if two USBL fixes did not occur within 8.1 seconds of a U.S. Navy fix, a USBL fix would not be interpolated. One USBL fix must occur before a U.S. Navy fix and one after.

Tables 4 and 5 list the gyro corrections applied and some other information. The "Number of Common Points" item is the number of interpolated USBL points for which a U.S. Navy point exists.

Trawl Number	2(see note*)	3	4	5	6	7	8	9
Tickler Chain		Yes	No	No	No	No	No	No
Outliers	19%	19%	16%	8%	11%	11%	11%	11%
Number of fixes (less outliers)	208	188	121	208	136	174	178	179
Gyro Correction		3.9°	2.9°	0.8°	1.3°	0.9°	2.6°	1.6°
Resultant sound velocity correction		0.8	-5.6	-2.3	-3.8	-4.4	-.9	-3.5
Number of common points		150	106	219	149	118	87	142

Table 4 - Nautronix ATS II

Trawl Number	28	29	30	31	32	33	34	35
Tickler Chain	No	No	Yes	Yes	Yes	Yes	Yes	Yes
Outliers	4%	10%	2%	0%	6%	4%	2%	0%
Number of fixes (less outliers)	179	106	166	169	148	117	226	177
Gyro Correction	-1.1°	-1.0°	-1.0°	-1.0°	-1.0°	.5°	0°	-.6°
Resultant sound velocity correction	4.0	14.5	-1.6	-5.1	-2.5	-8.4	-7.5	-5.9
Number of common points	153	81	161	178	74	111	353	219

Table 5 - ORE Trackpoint II Plus

*The U.S. Navy track data for this trawl was logged as "bad" when collected.

11.5 STATISTICAL COMPARISON OF USBL AND U.S. NAVY FIXES

A statistical test was used to estimate the error of a USBL fix given that the error of a U.S. Navy fix was 3.1 meters. The following briefly describes the procedure that has been attributed to Dr. Lloyd Huff of NOAA in Washington D.C. (Dr. Lloyd Huff, NOAA National Ocean Service, Coast Survey Development Lab, Silver Spring MD).

Given independent determinations of the same point on a Cartesian plane, the independent variates ΔX and ΔY are distributed Gaussian. For the derived polar coordinates, the range is distributed Rayleigh and the bearing is distributed evenly. Essentially, this means that there is no particular azimuth that is more likely to occur than any other azimuth and the distance is most likely to be non-zero rather than zero. The radius from the “true” net position to the USBL position is always positive and is just as likely to be left or right of track as it to be nearer or farther to the tow vessel. This radius is distributed Rayleigh and the bearing is evenly distributed. The U.S. Navy position of the net is assumed to be the “true” position. The root mean square error (RMSE) can be determined between each U.S. Navy net position and corresponding USBL net position. To evaluate the accuracy of a USBL system this RMSE is compared to a series of synthetically generated Rayleigh distributions. When a match is found, the underlying information used to generate the synthetic Rayleigh distribution indicates the error in the USBL system, as detailed below. For further reference see: A. Bruce Carlson *Communication Systems: An Introduction to Signals and Noise in Electrical Communications* pages 138-141 McGraw-Hill Electrical and Electronic Engineering Series.

The estimation of the error of each USBL system was accomplished synthetically by generating a Rayleigh distribution corresponding to the U.S. Navy data with its given error and a series of test Rayleigh distributions each corresponding to a different error. The errors of each test series differed by 0.1 meter. The U.S. Navy data Rayleigh distribution was then combined with each of the test distributions in the following manner:

$$x_{S\ com\ i,j} = ((x_{US\ Navy\ i})^2 + (x_{test\ i,\ j})^2)^{1/2}$$

Where:

$x_{US\ Navy\ i}$ = the ith element of the synthetic distribution corresponding to the U.S. Navy data

$x_{test\ i,\ j}$ = the ith element of the jth test distribution

$x_{S\,com\,i,j}$ = the resulting ith element of the jth combined synthetic distribution

Then the RMS of each combined distribution was computed using:

$$RMS_j = \left[\frac{\sum_{n}^{i=1} \left(x_{S\,com\,i,j} \right)^2}{n} \right]^{1/2}$$

The root mean square error (RMSE) of the observed distances (radii) between each USBL fix and corresponding U.S. Navy fix was computed for each vendor using:

$$RMSE_{USBL} = \left[\frac{\sum_{n}^{i=1} \left(D_{USN\,i \quad USBL\,i} \right)^2}{n} \right]^{1/2}$$

Where:

$D_{USN\ i \quad USBL\ i}$ = distance between the i[th] U.S. Navy fix and corresponding USBL fix.
n = number of common points

The value $RMSE_{USBL}$ was then compared to each RMS_j of the synthetically generated distributions. The synthetic RMS_j, which was closest to the observed $RMSE_{USBL}$, was selected and the underlying error used to generate this synthetic RMS_j is estimated to be error of this USBL system.

A synthetic Rayleigh distribution is generated from two independent normal distributions both with the same standard deviation (e.g. 3.1 meters for the U.S. Navy data) and zero mean. The normal distributions are combined using the following equation to produce the Rayleigh distribution with underlying error equal to the standard deviations used to generate the normal distributions.

$$x_{Rayleigh\,i} = ((x_{first\,normal\,i})^2 + (x_{\sec ond\,normal\,i})^2)^{1/2}$$

The normal distributions were generated using Microsoft Excel. Each vendor's data from all of their trawls was combined to produce the results in the following table and the graphs in Appendices B and C. Only the matching synthetic distributions are provided.

System	Number of data points	Observed RMSE	RMS of combined synthetic distribution with an underlying error of 3.7m
ATS II	971	6.8m	6.8 m

Table 6 – Comparison of Observed RMSE and Synthetic RMS Values

System	Number of data points	Observed RMSE	RMS of combined synthetic distribution with an underlying error of 5.9m
Trackpoint II Plus	1330	9.6m	9.4m

Table 7– Comparison of Observed RMSE and Synthetic RMS Values

11.6 RESULTS OF STATISTICAL COMPARISON

Since the bearing error from the true position to the USBL position is theoretically evenly distributed, only the distance error is considered. As mentioned above the USBL position is just as likely to be left or right of the true position as it to be nearer of farther to the tow vessel or at any other bearing. Consequently the estimated errors below can be considered across or along track errors. The results indicate that the ATS II data set corresponded to a synthetic Rayleigh distribution with an underlying error of 3.7 +/-.2 meters and the Trackpoint II Plus data set corresponded to a synthetic Rayleigh distribution with an underlying error of 5.9 +/-.2 meters. The ATS II's smaller error is likely due to its method of signal processing. The uncertainty of these values was determined by regenerating the normal distribution using the same standard deviation and noting the change in the RMS of the Rayleigh distribution. This could result in a change to these values of between 10 and 20 centimeters.

The bearing distributions (0º being towards the tow vessel) of both the ATS II and Trackpoint II Plus are not evenly distributed (as expected), but are both similar in shape. The application of a sound velocity correction has removed any bias towards or away from the vessel. However the ATS II data shows a bias at about 90° and 270° indicating a cross track bias. The Trackpoint II Plus data displays a bias nearer 40° and 240°.

12. MISCELLANEOUS

12.1 INTERROGATION RATE

The ITI interrogates each beacon individually, with one interrogation every five seconds. The ATS II also interrogates it's beacons individually, but at an operator-selectable interval. The Trackpoint II Plus transmits a common interrogation pulse at an operator-selectable interval. During this trial the interrogation rate of the ATS II was set by that vendor to one second and the Trackpoint II Plus was set by that vendor to four seconds. Although the ATS II's interrogation rate was one second and all the raw data was recorded at that interval, the computed fix data storage rate was every three seconds. The real-time computed fix data was used for the analysis for all vendors; the raw data was not reprocessed.

A higher interrogation rate is more desirable from a data standpoint. Assuming the rejection rate is a constant percentage of the interrogations, having a higher interrogation rate will produce more usable data. This is also advantageous as filters usually function better when more data are available. One disadvantage to a higher interrogation rate is that it will reduce battery life.

A longer interrogation interval also has it's advantages as it allows time for any reverberation or reflection to dissipate. This reduces the chance of interference, which may cause an outlier in the next cycle.

12.2 DISTANCE DIFFERENCES ALONG AND ACROSS TRACK

The distance between the U.S. Navy fix and corresponding USBL fix was computed parallel and perpendicular to the vessel's average track. The mean along track distances are all zero this is due to the sound velocity correction. A positive across track value indicates the USBL fix was further port of the track than the U.S. Navy fix. The results are tabulated below.

Trawl #	# of common Fixes	Mean difference Along Track (M)	Mean difference Across Track (M)	RMSE Along Track (M)	RMSE Across Track (M)
2	*				
3	150	0	0.3	3.3	4.4
4	106	0	-2.0	4.2	4.2
5	219	0	-0.8	4.9	4.6
6	149	0	-1.3	2.9	3.3
7	118	0	-1.0	2.7	4.4
8	87	0	-0.4	5.2	9.6
9	142	0	-1.1	4.1	7.6

Table 8a Difference between Nautronix Fixes & Corresponding Navy Fixes along and across track

*The U.S. Navy data were logged as "bad" for this trawl.

Trawl #	# of common Fixes	Mean difference Along Track (M)	Mean difference Across Track (M)	RMSE Along Track (M)	RMSE Across Track (M)
28	153	0	1.0	10.3	6.9
29	81	0	0.2	16.5	3.4
30	161	0	1.3	5.5	4.1
31	178	0	-2.2	4.6	3.7
32	74	0	0.9	12.8	5.8
33	111	0	-2.1	3.0	3.3
34	353	0	-1.0	3.9	7.5
35	219	0	-1.5	7.5	5.9

Table 8b Difference between ORE Fixes and Corresponding Navy Fixes along and across track

13. CONCLUSIONS AND RECOMMENDATIONS

13.1 CONCLUSIONS

The results of this test show that the Simrad ITI, as tested, is less accurate than the Nautronix ATS II and ORE Trackpoint II Plus. The statistical analysis using synthetic distributions indicates that the accuracy of the ATS II is 3.7 meters and the Trackpoint II Plus is 5.9 meters when compared to the U.S. Navy system whose accuracy was stated as 3.1 meters. It can be seen from the raw data plots in Appendix A, that there are large angular problems in the ITI data. The Simrad ITI appears to be designed for fishing applications and while it may meet those requirements, it is not a survey class USBL system. It should be noted that Simrad does manufacture a survey class USBL system, HPR, but it was not included in this study.

These determined accuracies are not just a measure of the acoustic system itself. Rather, they include all of the random errors propagated from each source through to the beacon position, but without most of the biases due to a gyro or sound velocity error. The random errors begin with the GPS system at the antenna. Then, using the gyro, the errors propagate along the traverse to the acoustic head and on to the beacon using the acoustic data, speed of sound, and gyro. Additionally, it involves the U.S. Navy system and the accuracy of that system. The major sources of error in the U.S. Navy's system include speed of sound, internal clock offset and drift, and geometric dilution of precision due to the long distance to the acoustic arrays. Finally, one must include the error introduced when merging the two data sets to determine common points. Latencies in tagging the data and time differences between the U.S. Navy clock and acoustic logging clocks are also involved.

Table 1 shows that the ATS II had many more outliers than the Trackpoint II Plus. This has been attributed to the fact that the vessel heading was applied within the navigation computer and not within the USBL system. It is recommended that the gyro be interfaced directly to the USBL system and that north-corrected beacon coordinates be output to any navigation program in use. Furthermore, analog gyro data is preferred over digital data as an input to the USBL system as there are delays in the sending units when converting the data from analog to digital. However the quality of the analog signal may be degraded if there are ground loops or other sources of interference such as radios.

The equipment from each of the three vendors is approximately the same size and shape with the following exceptions. The ITI console consists of two units, while the ATS II and Trackpoint II Plus consists of only one. Additionally, the Trackpoint II Plus hydrophone head was smaller and lighter than the other two. All systems came with manuals and documentation that could permit non-technical personnel to operate the equipment, without any special training. To do this successfully; however, one would need to spend a few days with the equipment prior to actually using it. The ITI hydrophone appears to be less vulnerable to damage than the ATS II or Trackpoint II Plus as the latter two both have a more exposed transducer. This is necessary to achieve omni-directional directional operation. The ITI beacons are designed for attachment to trawls and appear more rugged than the general purpose ATS II and Trackpoint II Plus beacons. The ATS II beacons, as tested, had thick rubber sheaths around them, which would offer some protection, during deployment and recovery of the trawl.

A single USBL fix is a uniquely determined quantity from a single range, bearing, and depth. Since there are no redundant observations, quality must be determined from other means, such as signal strength or through filtering. Both the ATS II and Trackpoint II Plus do output quality status values with each raw USBL fix, which can be used by most navigation programs.

In this trial the USBL systems cannot be viewed as a weak link in determining the trawl position. In fact both the ATS II and Trackpoint II Plus performed very well. The gyro was the largest source of error.

Only one hydrophone pole was used during these trials. Generally, a poorly designed pole results in a diminished maximum range and fewer good fixes. The maximum range was not assessed with this pole, as it did not become a factor. All three systems performed adequately at the ranges tested here (about 350 meters). The faring probably aided in reducing vibration although no testing of this was done.

13.2 RECOMMENDATIONS

The trawling to be done in the Bering Sea is a “destructive procedure." Thus, if a trawl is conducted in the wrong location, the effects can not be undone and the overall results may be effected. Furthermore, if an area is to be trawled and there are gaps between the lines, the results could also be effected. When designing parallel track lines to drag a fishing trawl, one should not use the statistically determined accuracies of 3.7m for the ATS II or 5.9m for Trackpoint II Plus. These were obtained under controlled conditions with most of the biases removed, as they were similar to the biases that might be encountered in the Bering Sea. The primary biases that may be encountered during a trawl survey are: a sound velocity error, which effects the along track position, and an angular error which effects the across track position. The estimated error should be increased to allow for these potential biases and an allowance may also be considered for the ability of the helmsman to keep the trawl on its designated line.

Increasing the estimated error essentially increases the confidence interval. The amount to increase the error is subjective. However, if we consider the biases determined in this report, for sound velocity and the gyro, as likely to be found in the Bering Sea we can use them to estimate the expected error which can then be used when designing the Bering Sea trawls. To ensure the biases do not cancel each other, the absolute value of each will be used. From Tables 4 and 5, it can be seen that the average gyro bias is 1.3° or 7.9 meters at a 350m tow length and the average resultant of the sound velocity error is 4.7 meters. For practical purposes these values will be added to the above errors to determine the following: for the ATS II - 8.4m along track and 11.6m across track and for the Trackpoint II Plus - 10.6m along track and 13.8m across track. To further increase the confidence interval one may want to roughly double these values to 20m along track and 30m across track.

When calibrating the USBL system, a dynamic calibration should be performed at the trawl site. The dynamic method produces many more observations over a wider arc and with ranges similar to those that will be encountered during the trawls than a dockside calibration can achieve. Half of a day should be allotted to perform a dynamic calibration. Most navigation software packages allow for a dynamic USBL calibration, but this should be checked if this method is to be used. Two or three velocity casts should be made over the trawl area. If the trawl area is large or if the trawl area is near shore where there are sources of fresh water, then several casts should be made over the whole trawl area. A harmonic mean sound velocity should be determined. The method of weighting should be based upon the velocity over a certain depth interval. The top interval should start at the transducer and the bottom interval end at the deepest part of the trawl at the height of the beacon. After calibration and sound velocity determination the calibration values can be checked by "tracking" a stationary beacon placed on the bottom at the average trawl depth. First, begin by sailing towards the beacon from a distance of about 500m, pass over top of it, and continue to a distance of about 500m on the other side. Plotting each beacon position during this procedure will indicate the quality of the calibration. If 95% or more of the beacon positions are evenly spread in a circle 5m in radius, it can be considered a good calibration. An angular error will cause the plotted beacon position to start on one side (left or right of the ship) and shift to the other as the ship makes its run. A sound velocity error that is high will cause the beacon position to come towards the vessel as it approaches and move away as it passes. A velocity that is too low will cause the plotted beacon positions to move away as the vessel approaches the beacon and come towards the vessel after it passes the beacon.

In order to compute and display real-world coordinates of the trawl, a navigation software package is required for either the ATS II and Trackpoint II Plus systems. Although navigation data can be input directly into the Simrad ITI to display vessel and trawl location, it does not provide much flexibility, with respect to antenna offsets. All three systems accept gyro data directly into their console. Commercially available navigation programs typically come with plotting and post-processing packages that may or may not be required.

To facilitate accurate trawl surveys in the future, additional equipment, such as a survey quality gyro and a CTD probe, is recommended. Since the gyros on different fishing vessels will be of various ages and will be maintained at different levels, it is suggested that the fishing vessel's gyro not be used. Instead, a portable gyro that is compatible with the USBL system and navigation program, be mobilized with the USBL system on the boat. The gyro is, potentially, the largest source of error. Thus, providing one's own gyro will keep consistency throughout the trawl surveys from one year and vessel to the next. However, care must be taken to ensure compatibility with both the USBL equipment and/or the navigation software, if one is to be used. It is also important to conduct a calibration in order to determine any heading misalignment. If the hydrophone head is misaligned with the vessel centerline, an angular error can occur which has the same effect as a gyro error. Consequently, a hydrophone head calibration must be conducted. The static method used by both Nautronix and ORE on these trials is less accurate than a dynamic "box in" method. In order to conduct a dynamic calibration, navigation software that supports this approach is required. The vertical reference unit should be placed as near as possible to the vessel's center of gravity. This reduces the error in pitch and roll observations that can be affected by angular accelerations.

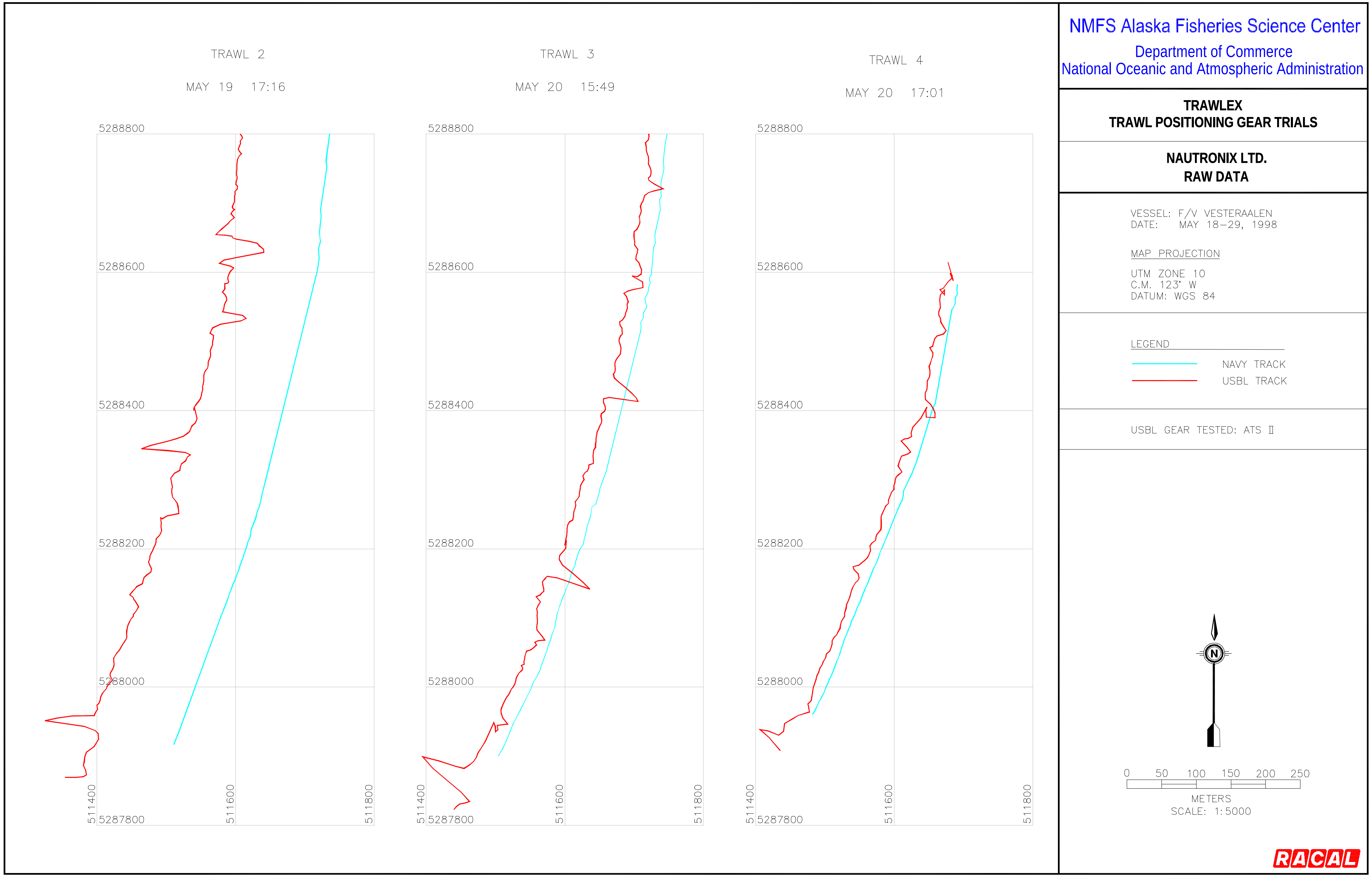
A good hydrophone pole must extend below the keel. It must also be of sufficient diameter and mounted in such a way that it causes minimal vibration. Faring is recommended but should be modified with a wooden form to keep the faring sections from losing shape.

Installation of the pole can usually be done at dockside. Bracing the pole at the bottom can reduce vibration and was performed for this trial. To mount the brace at or below the water line, the ballast can be shifted so the vessel exposes more of the hull on the pole. To prevent "knocking" of the pole against the bottom brace, a rubber sleeve of sufficient diameter wrapped around the pole will eliminate any play between the pole and brace. Guy wires can also be used to keep the pole snug to the brace. However, if the guy wires are partially in the water, they can generate acoustic noise. Nautronix recommends not using guy wires that enter the water when using their equipment.

Finally, a support person, familiar with the navigation software, installation and calibration of the gyro, and USBL equipment is recommended for the first trawl tracking survey. That person could train Alaska Fisheries Science personnel who would then be able to conduct future operations.

APPENDIX A

DATA CHARTS



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5287800
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NMFS Alaska Fisheries Science Center
Department of Commerce
National Oceanic and Atmospheric Administration
TRAWLEX
TRAWL POSITIONING GEAR TRIALS
NAUTRONIX LTD.
RAW DATA
VESSEL: F/V VESTERAALEN
DATE: MAY 18–29, 1998
MAP PROJECTION
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C.M. 123° W
DATUM: WGS 84
LEGEND
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USBL TRACK
USBL GEAR TESTED: ATS II
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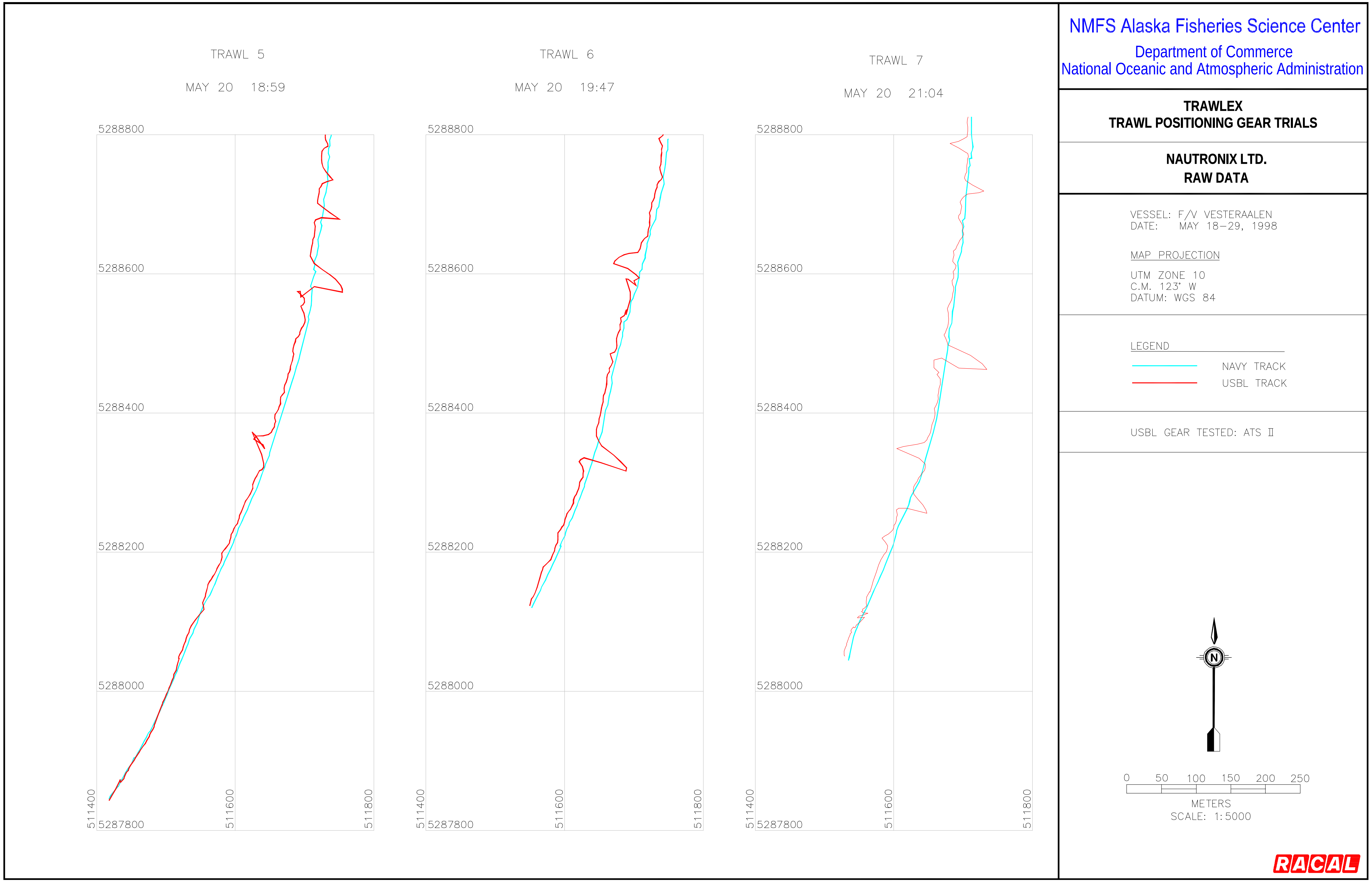
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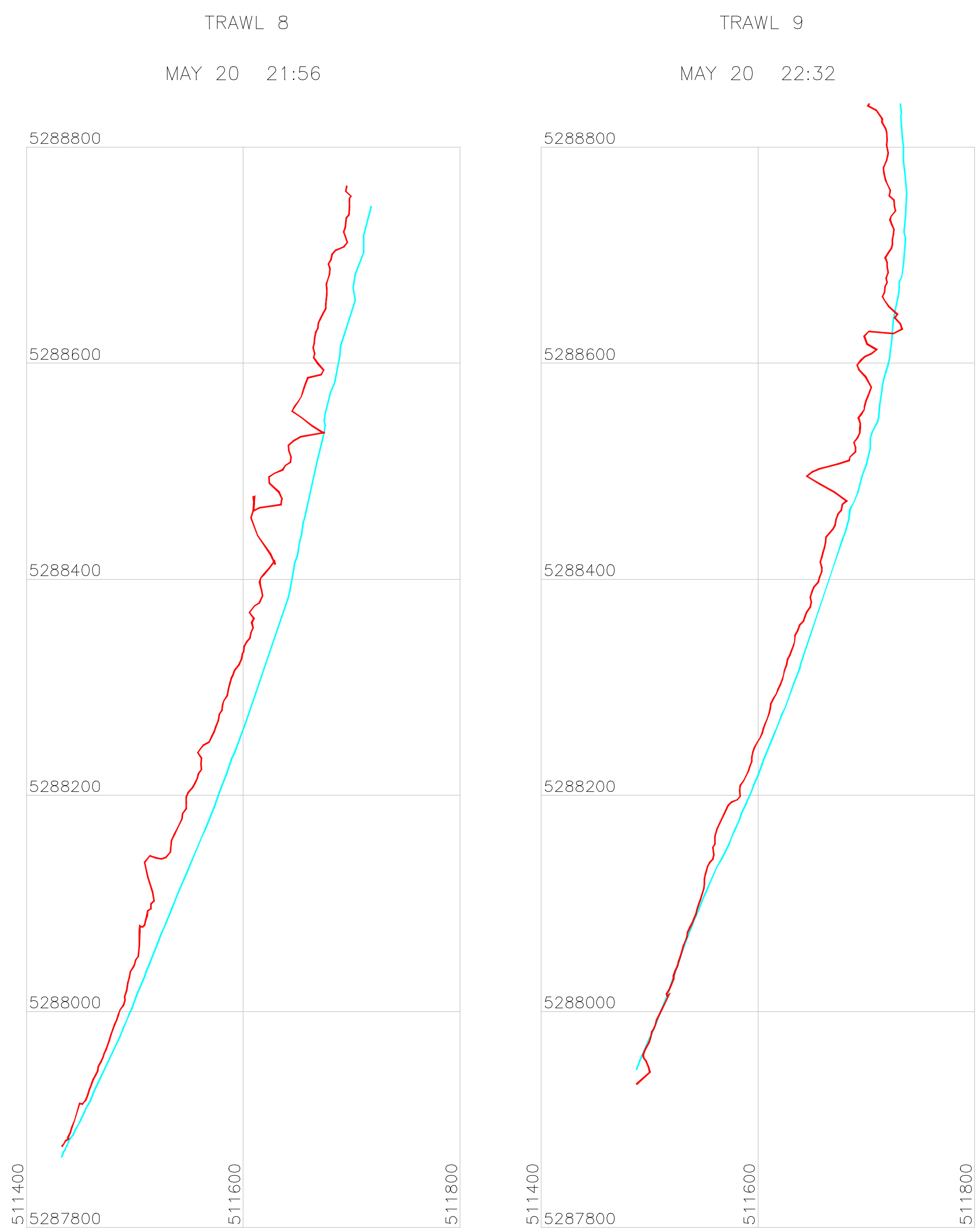

NMFS Alaska Fisheries Science Center

Department of Commerce
National Oceanic and Atmospheric Administration

TRAWLEX
TRAWL POSITIONING GEAR TRIALS

NAUTRONIX LTD.
RAW DATA

VESSEL: F/V VESTERAALEN
DATE: MAY 18-29, 1998

MAP PROJECTION

UTM ZONE 10
C.M. 123° W
DATUM: WGS 84

LEGEND

NAVY TRACK
USBL TRACK

USBL GEAR TESTED: ATS II

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METERS
SCALE: 1:5000

RACAL

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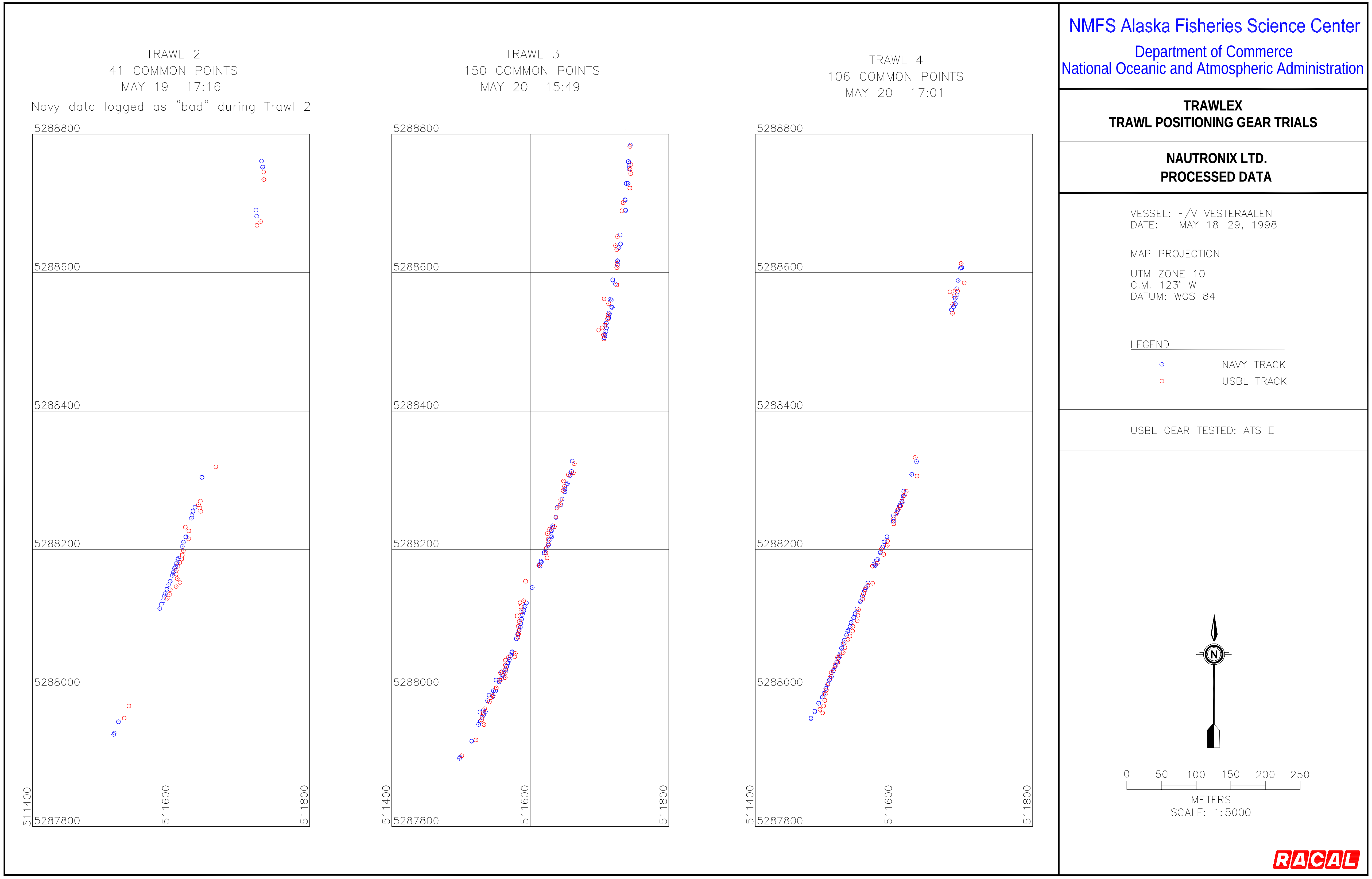
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511600
511800
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LEGEND
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USBL TRACK
USBL GEAR TESTED: ATS II
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SCALE: 1:5000
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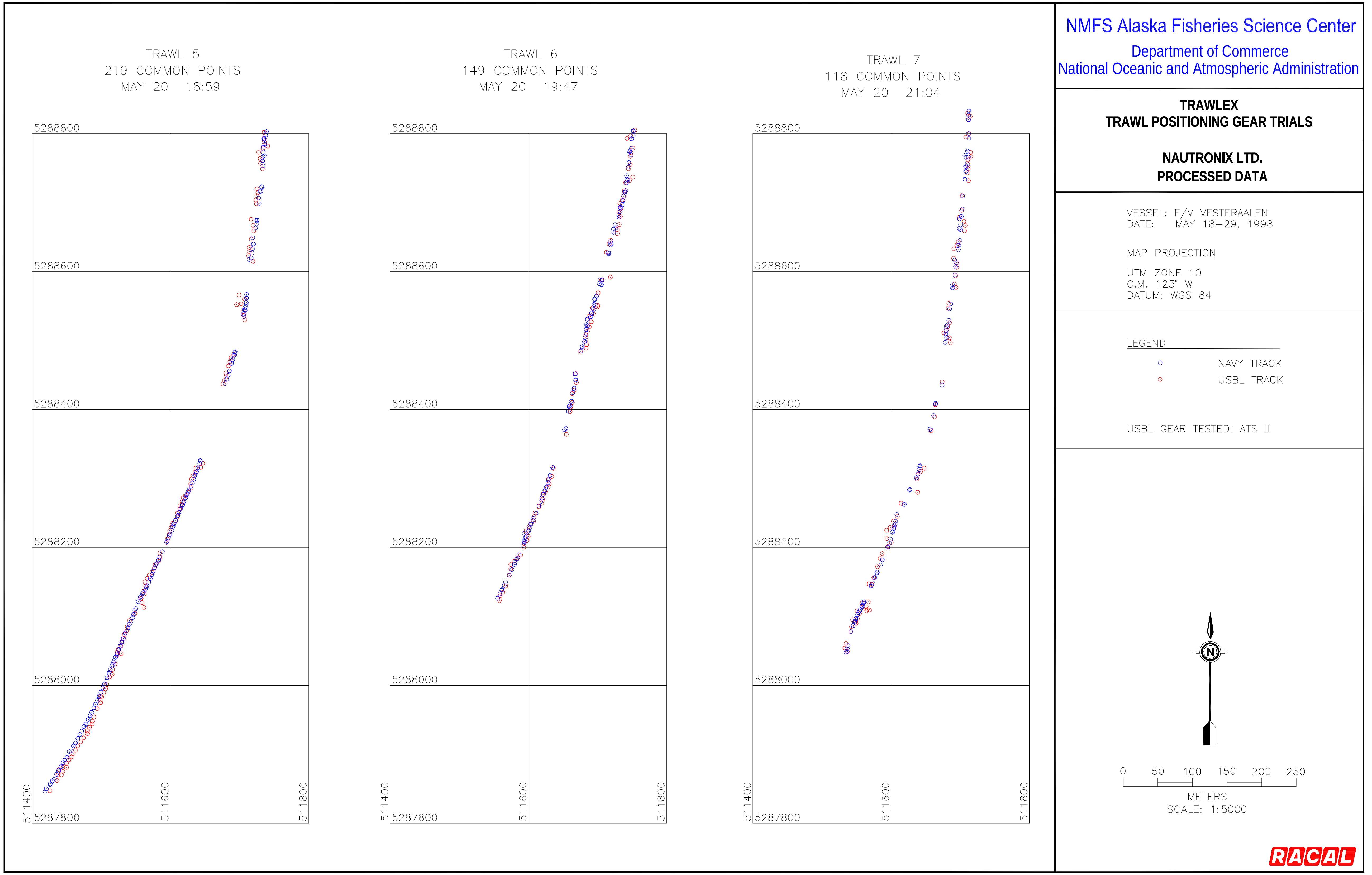
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MAY 20 18:59
TRAWL 6
149 COMMON POINTS
MAY 20 19:47
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118 COMMON POINTS
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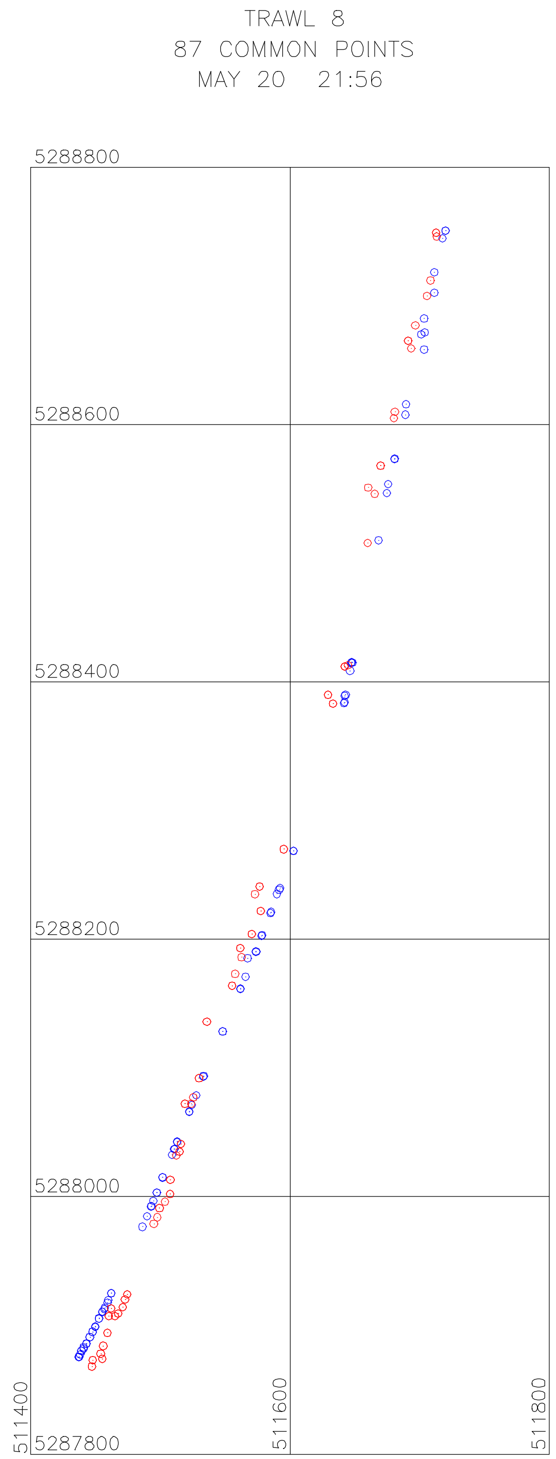

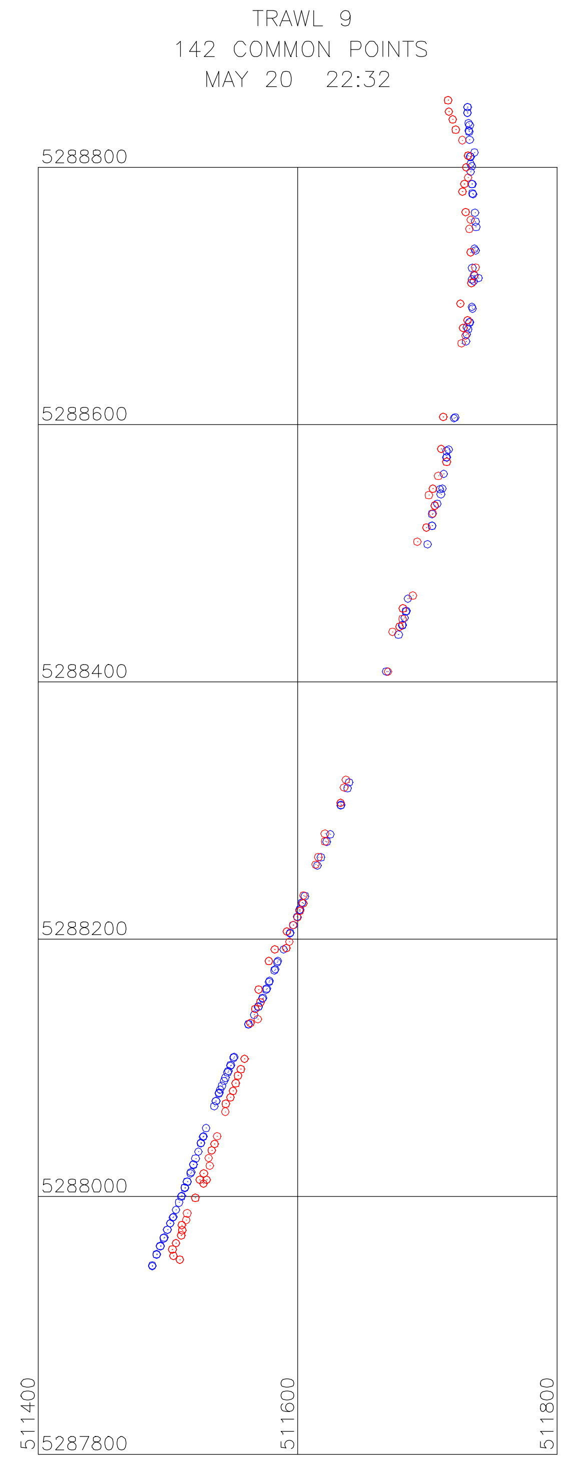

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Department of Commerce
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TRAWLEX
TRAWL POSITIONING GEAR TRIALS

NAUTRONIX LTD.
PROCESSED DATA

VESSEL: F/V VESTERAALEN
DATE: MAY 18-29, 1998

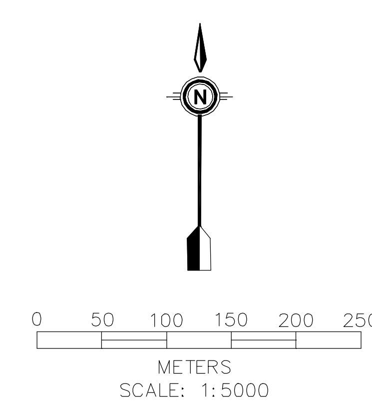
MAP PROJECTION

UTM ZONE 10
C.M. 123° W
DATUM: WGS 84

LEGEND

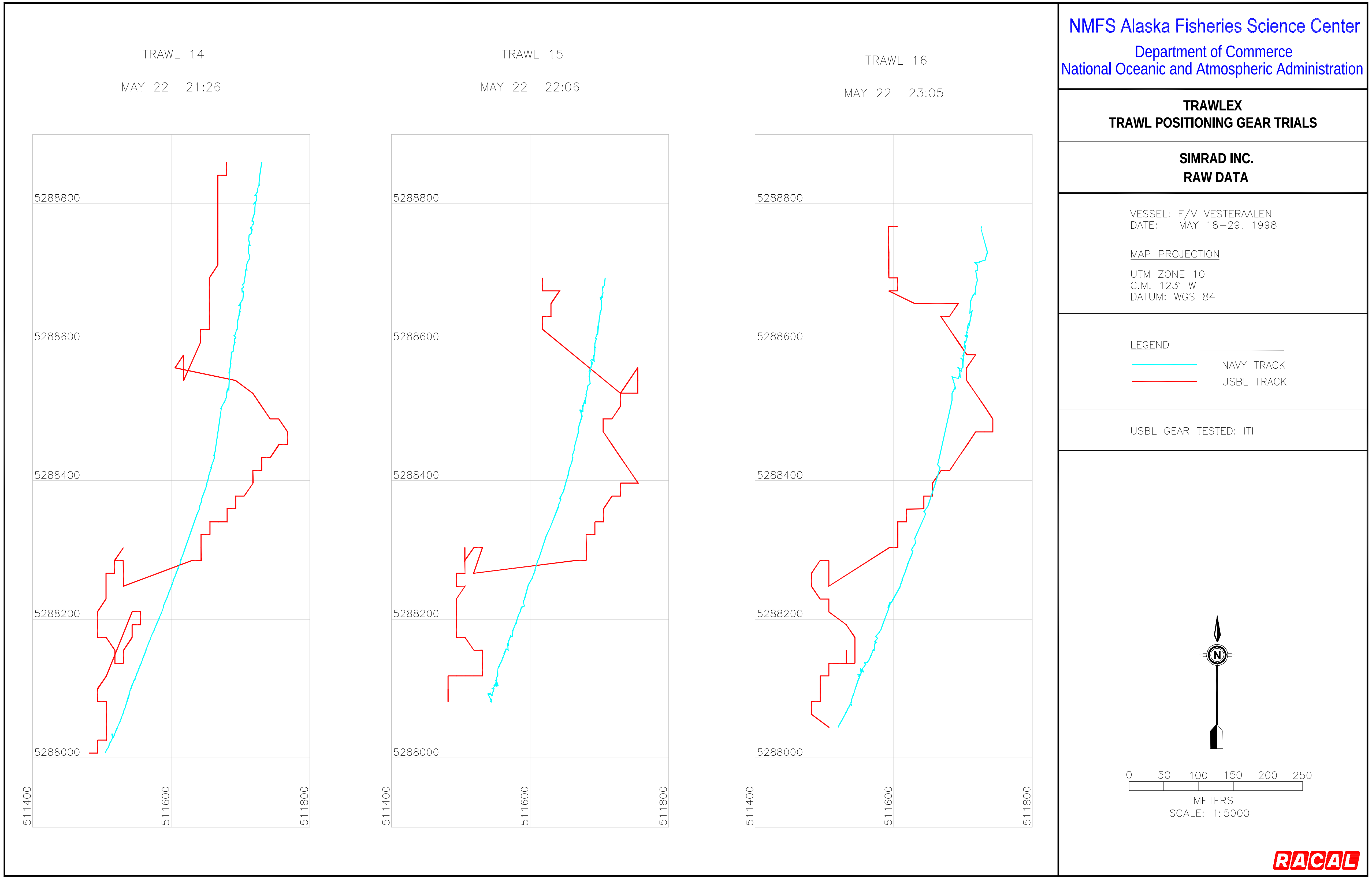
o NAVY TRACK
o USBL TRACK

USBL GEAR TESTED: ATS II

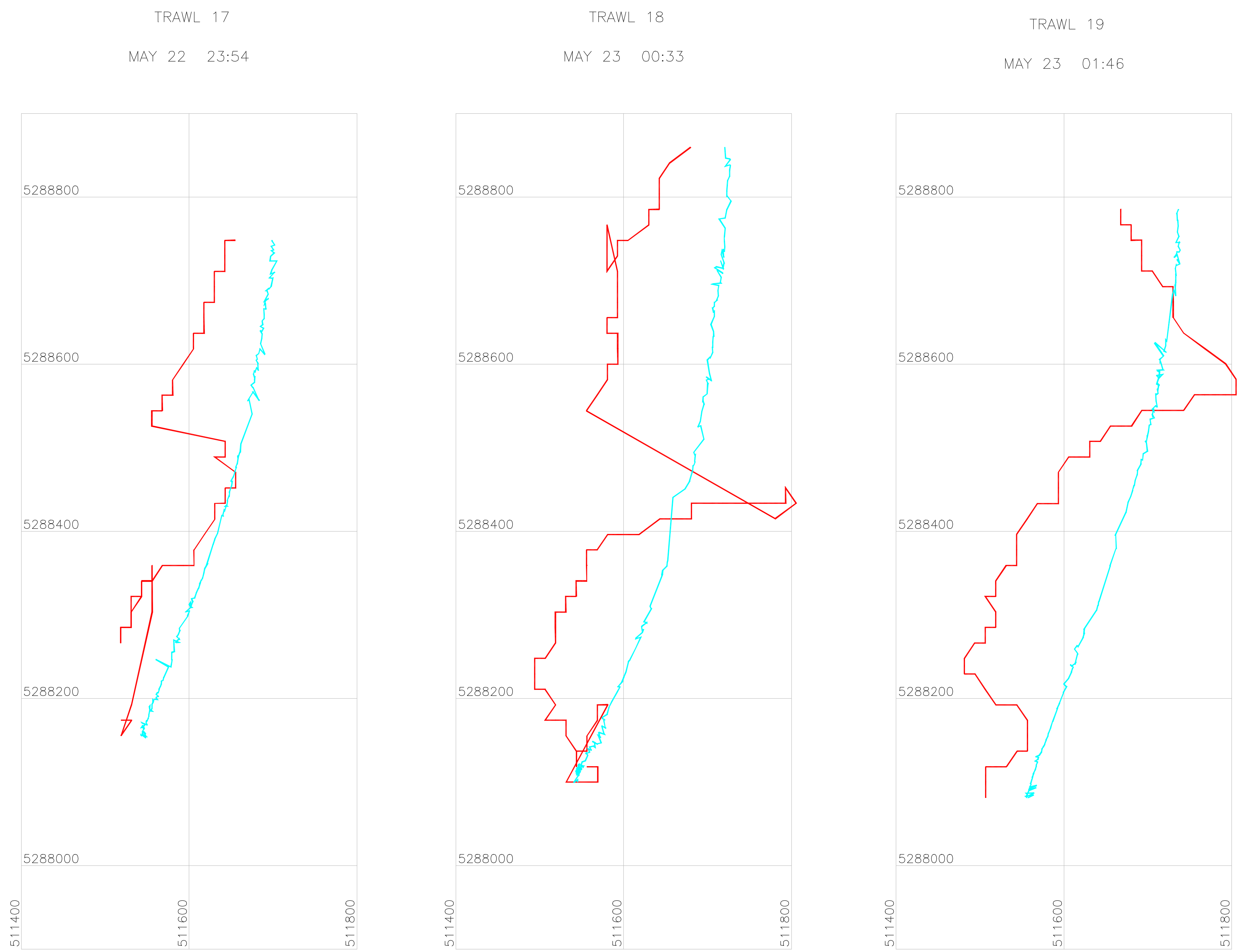


RACAL

PROCESSNAU3.DWG



TRAWL 14
MAY 22 21:26
TRAWL 15
MAY 22 22:06
TRAWL 16
MAY 22 23:05
5288800
5288600
5288400
5288200
5288000
511400
511600
511800
NMFS Alaska Fisheries Science Center
Department of Commerce
National Oceanic and Atmospheric Administration
TRAWLEX
TRAWL POSITIONING GEAR TRIALS
SIMRAD INC.
RAW DATA
VESSEL: F/V VESTERAALEN
DATE: MAY 18–29, 1998
MAP PROJECTION
UTM ZONE 10
C.M. 123° W
DATUM: WGS 84
LEGEND
NAVY TRACK
USBL TRACK
USBL GEAR TESTED: ITI
N
0 50 100 150 200 250
METERS
SCALE: 1:5000
RACAL
RAWSIM1.DWG



NMFS Alaska Fisheries Science Center

Department of Commerce
National Oceanic and Atmospheric Administration

TRAWLEX
TRAWL POSITIONING GEAR TRIALS

SIMRAD INC.
RAW DATA

VESSEL: F/V VESTERAALEN
DATE: MAY 18–29, 1998

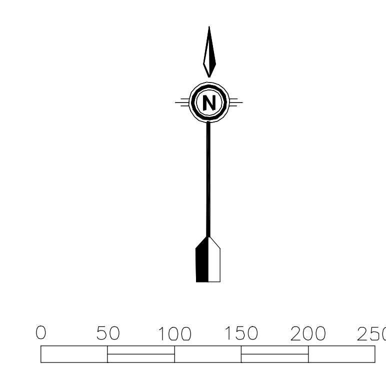
MAP PROJECTION

UTM ZONE 10
C.M. 123° W
DATUM: WGS 84

LEGEND

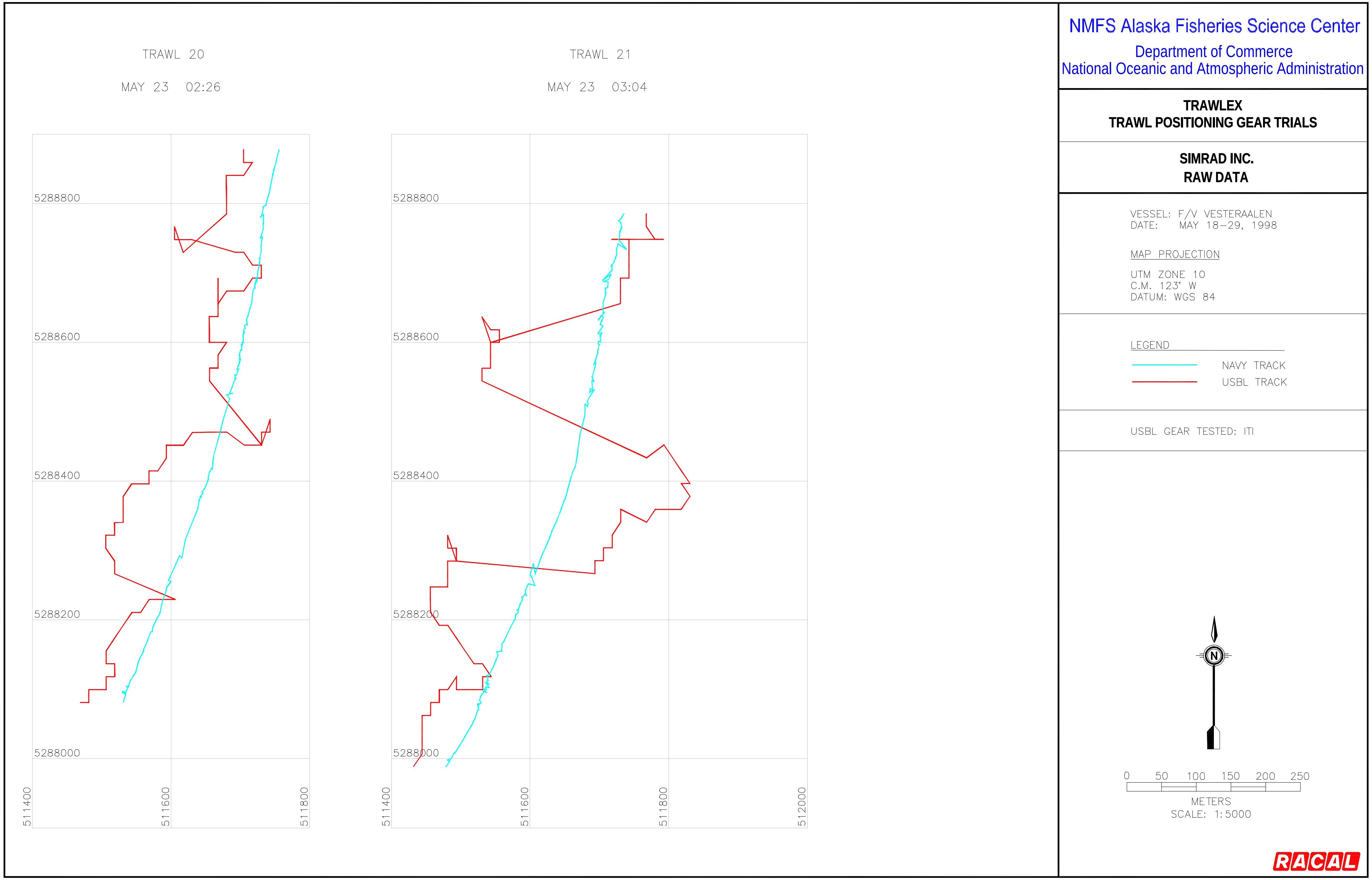
NAVY TRACK
USBL TRACK

USBL GEAR TESTED: ITI

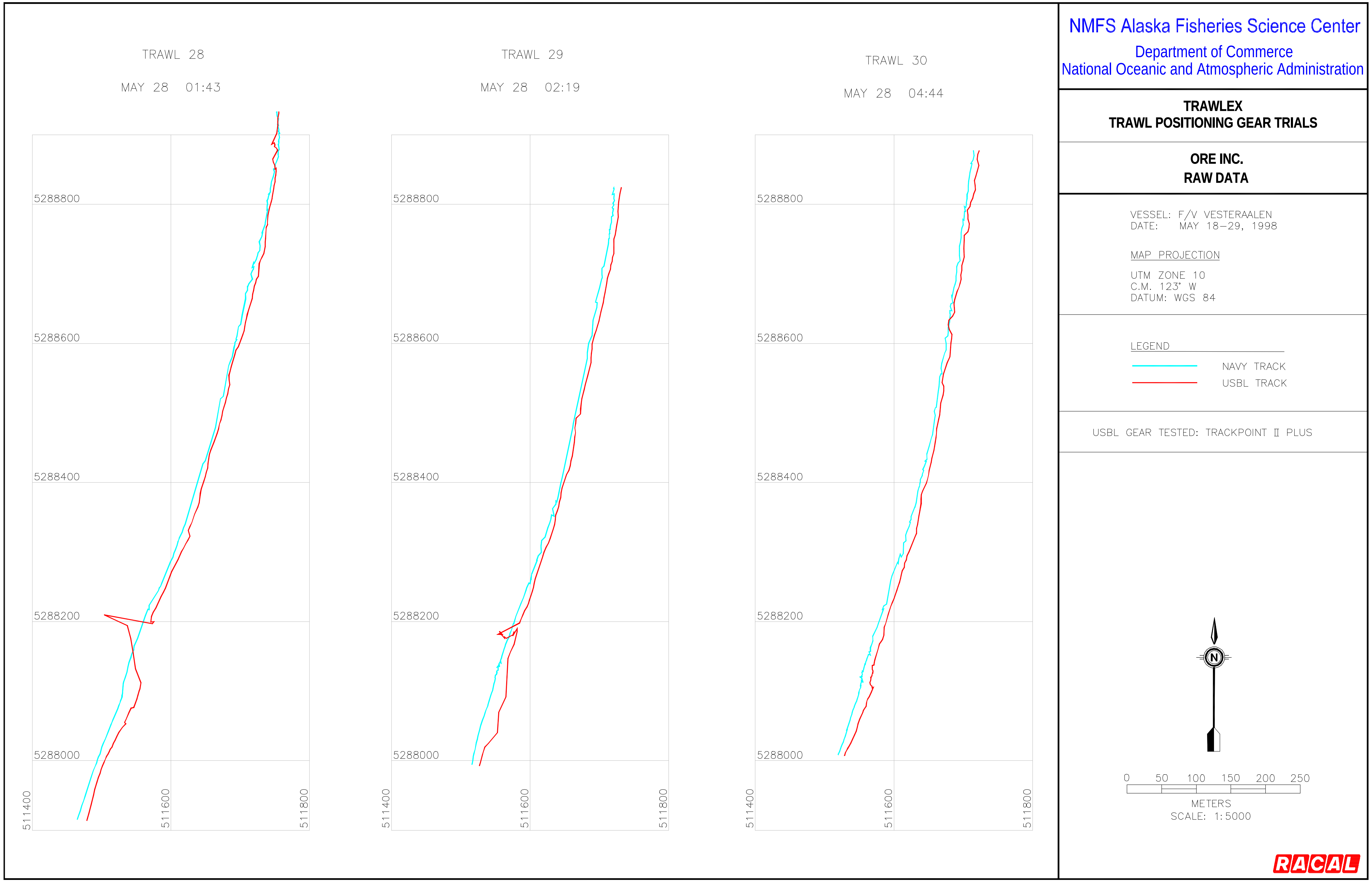


RACAL

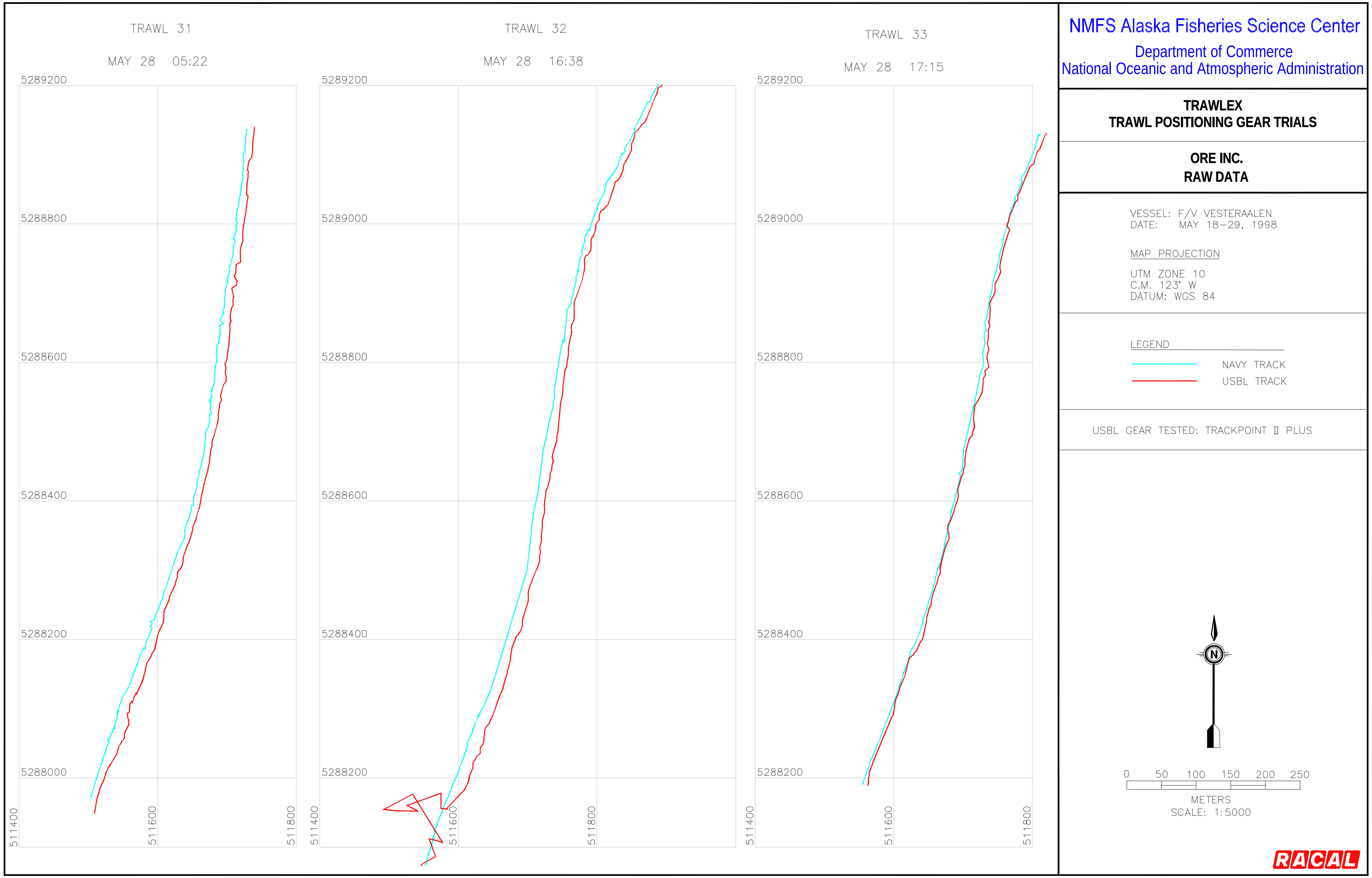
RAWSIM2.DWG

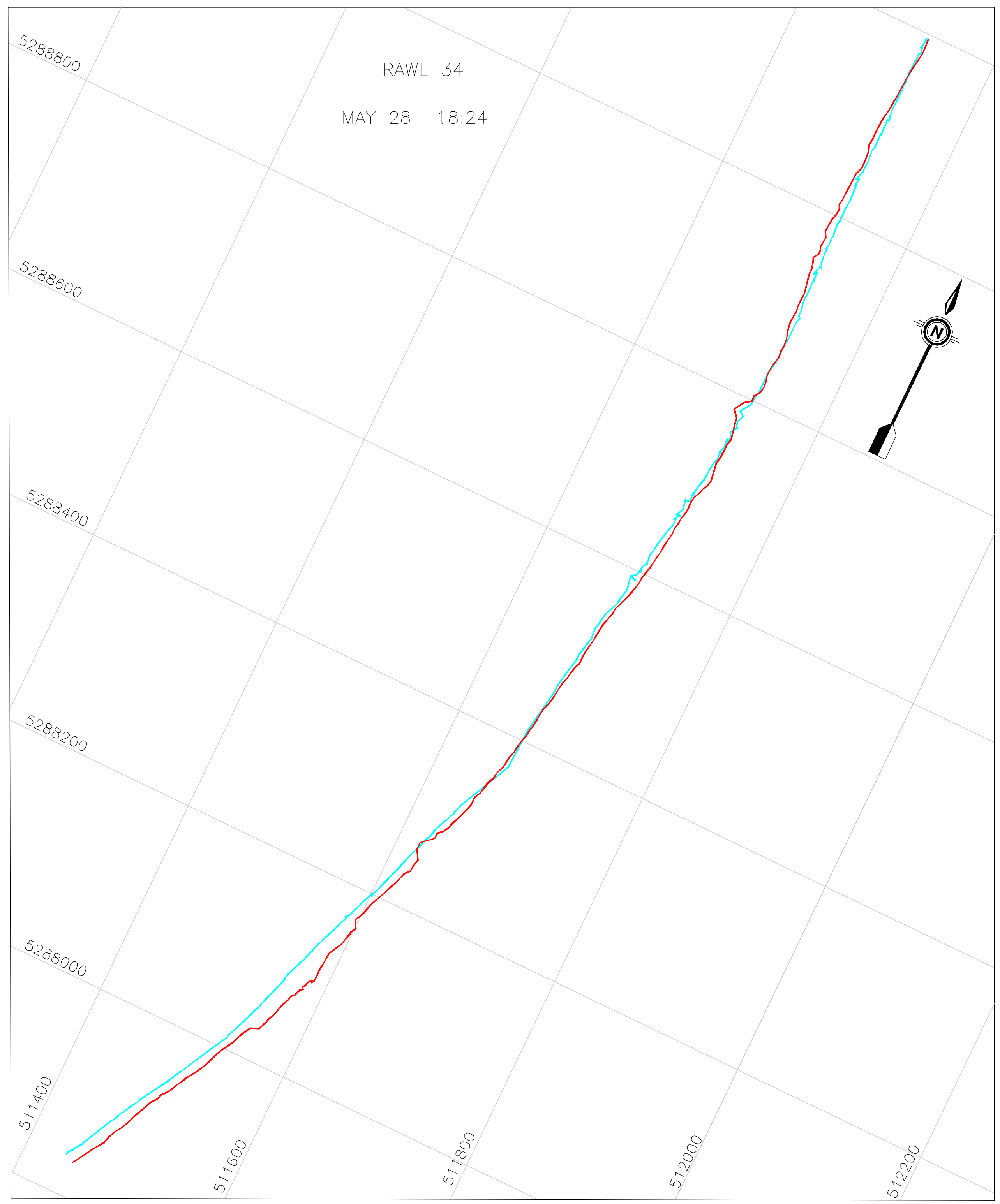


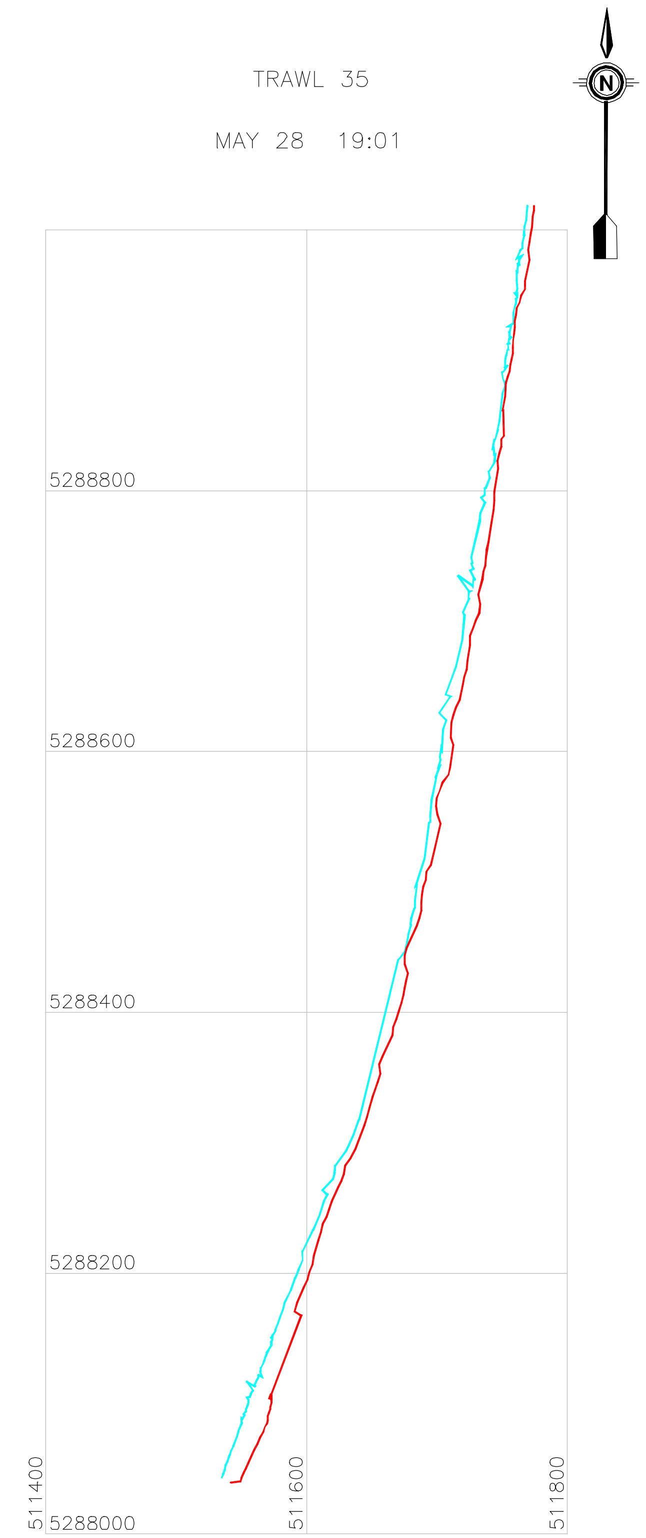
TRAWL 20
MAY 23 02:26
TRAWL 21
MAY 23 03:04
5288800
5288600
5288400
5288200
5288000
511400
511600
511800
512000
NMFS Alaska Fisheries Science Center
Department of Commerce
National Oceanic and Atmospheric Administration
TRAWLEX
TRAWL POSITIONING GEAR TRIALS
SIMRAD INC.
RAW DATA
VESSEL: F/V VESTERAALEN
DATE: MAY 18–29, 1998
MAP PROJECTION
UTM ZONE 10
C.M. 123° W
DATUM: WGS 84
LEGEND
NAVY TRACK
USBL TRACK
USBL GEAR TESTED: ITI
N
0 50 100 150 200 250
METERS
SCALE: 1:5000
RACAL
RAWSIM3.DWG



TRAWL 28
MAY 28 01:43
TRAWL 29
MAY 28 02:19
TRAWL 30
MAY 28 04:44
5288800
5288600
5288400
5288200
5288000
511400
511600
511800
NMFS Alaska Fisheries Science Center
Department of Commerce
National Oceanic and Atmospheric Administration
TRAWLEX
TRAWL POSITIONING GEAR TRIALS
ORE INC.
RAW DATA
VESSEL: F/V VESTERAALEN
DATE: MAY 18–29, 1998
MAP PROJECTION
UTM ZONE 10
C.M. 123° W
DATUM: WGS 84
LEGEND
NAVY TRACK
USBL TRACK
USBL GEAR TESTED: TRACKPOINT II PLUS
N
0 50 100 150 200 250
METERS
SCALE: 1:5000
RACAL
RAWORE1.DWG


TRAWL 31
MAY 28 05:22
TRAWL 32
MAY 28 16:38
TRAWL 33
MAY 28 17:15
5289200
5288800
5288600
5288400
5288200
5288000
5289000
5288800
5288600
5288400
5288200
511400
511600
511800
NMFS Alaska Fisheries Science Center
Department of Commerce
National Oceanic and Atmospheric Administration
TRAWLEX
TRAWL POSITIONING GEAR TRIALS
ORE INC.
RAW DATA
VESSEL: F/V VESTERAALEN
DATE: MAY 18–29, 1998
MAP PROJECTION
UTM ZONE 10
C.M. 123° W
DATUM: WGS 84
LEGEND
NAVY TRACK
USBL TRACK
USBL GEAR TESTED: TRACKPOINT II PLUS
N
0 50 100 150 200 250
METERS
SCALE: 1:5000
RACAL
RAWORE2.DWG





NMFS Alaska Fisheries Science Center
Department of Commerce
National Oceanic and Atmospheric Administration

TRAWLEX
TRAWL POSITIONING GEAR TRIALS

ORE INC.
RAW DATA

VESSEL: F/V VESTERAALEN
DATE: MAY 18–29, 1998

MAP PROJECTION

UTM ZONE 10
C.M. 123° W
DATUM: WGS 84

LEGEND

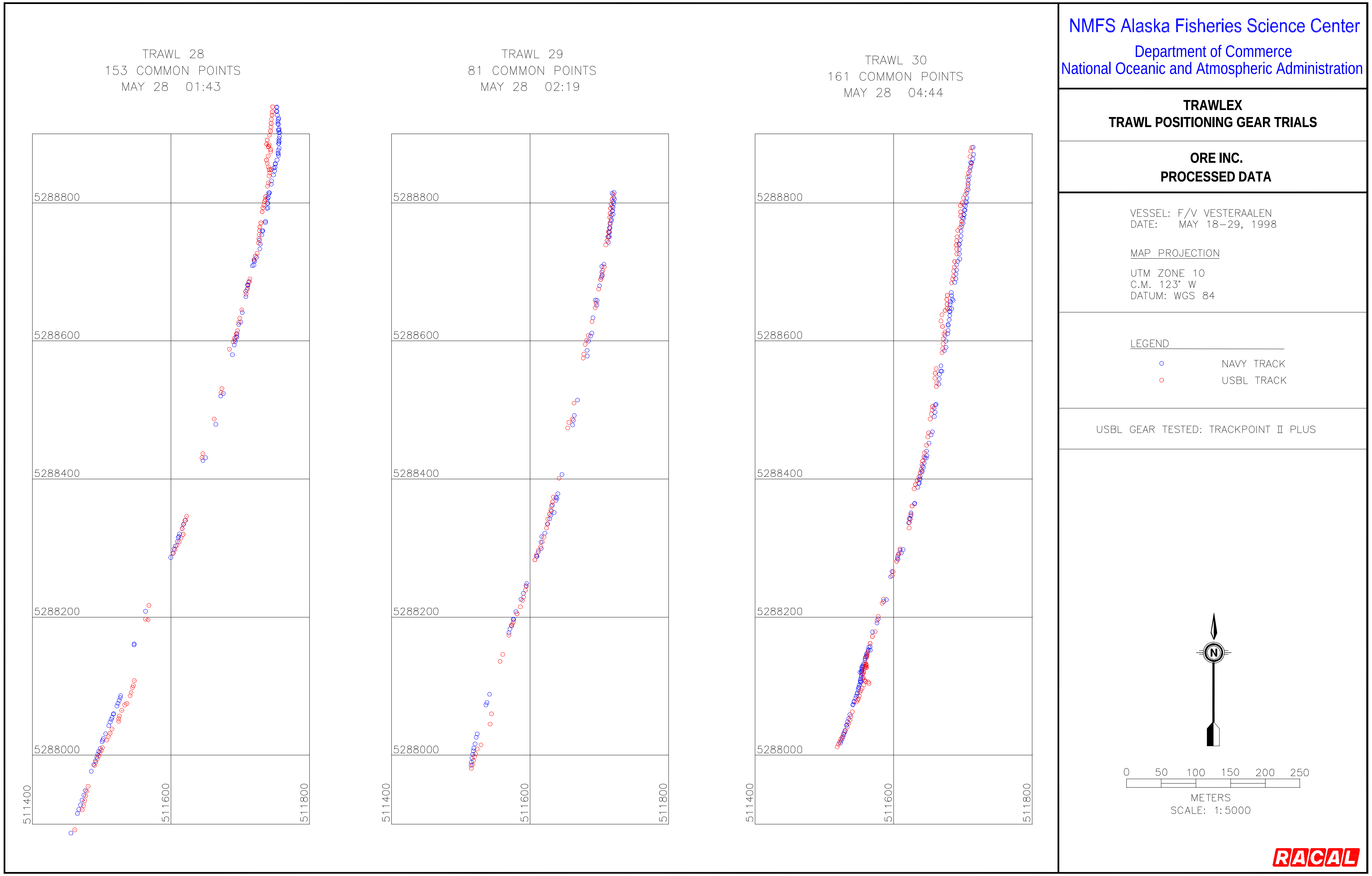
NAVY TRACK
USBL TRACK

USBL GEAR TESTED: TRACKPOINT II PLUS

0 50 100 150 200 250
METERS
SCALE: 1:5000

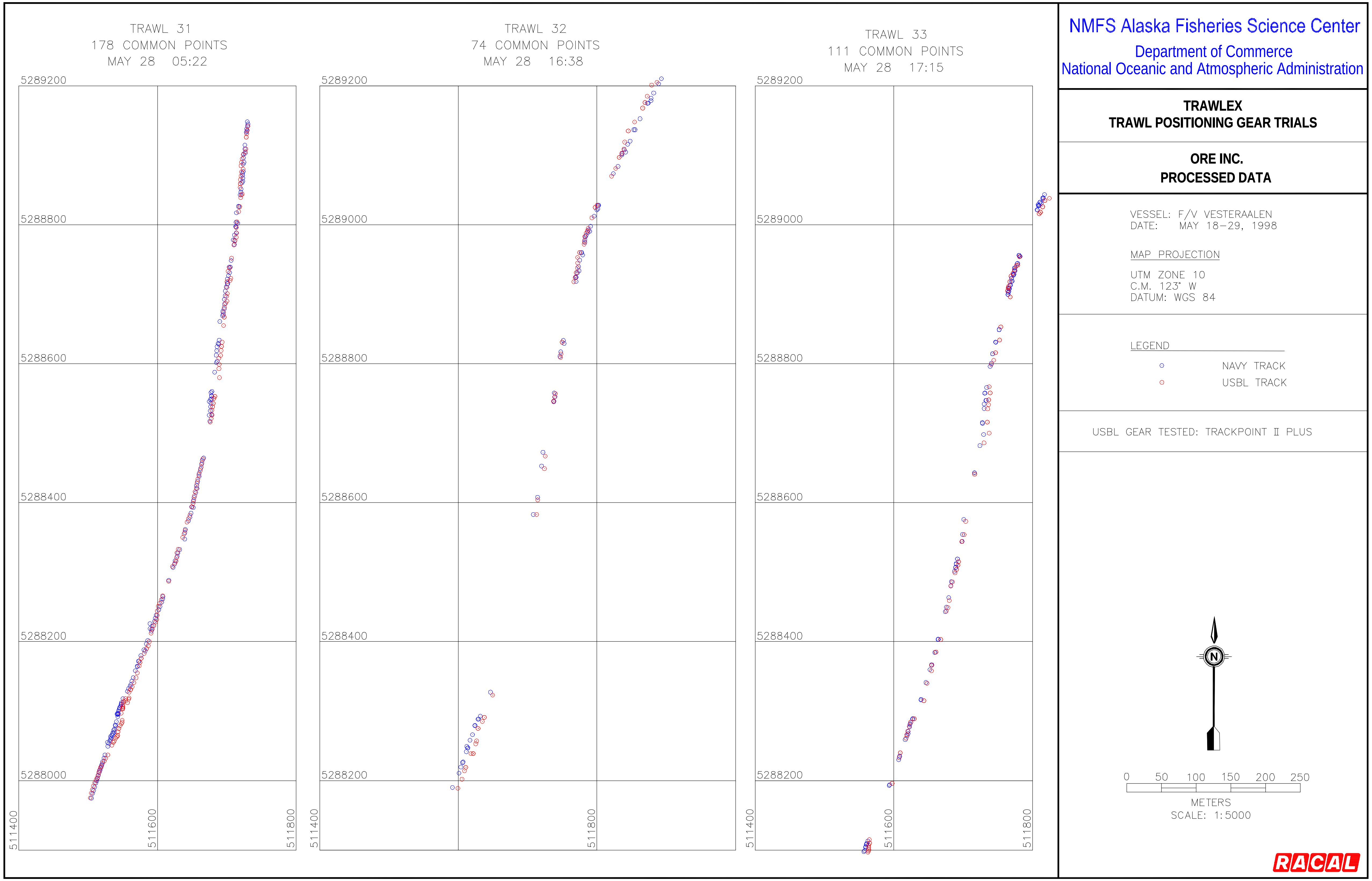
RACAL

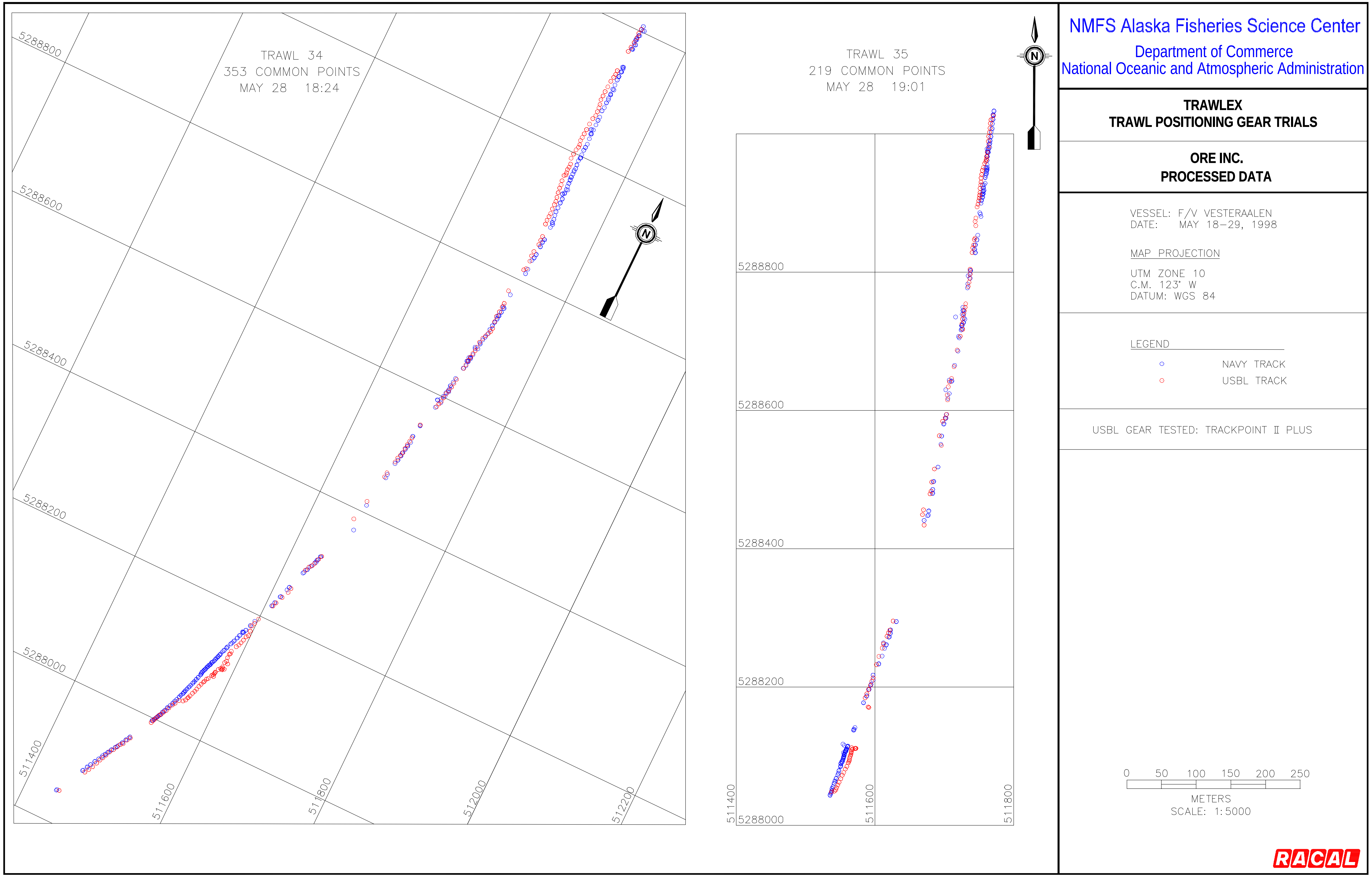
RAWORE3.DWG



TRAWL 28
153 COMMON POINTS
MAY 28 01:43
TRAWL 29
81 COMMON POINTS
MAY 28 02:19
TRAWL 30
161 COMMON POINTS
MAY 28 04:44
5288800
5288600
5288400
5288200
5288000
511400
511600
511800

NMFS Alaska Fisheries Science Center
Department of Commerce
National Oceanic and Atmospheric Administration
TRAWLEX
TRAWL POSITIONING GEAR TRIALS
ORE INC.
PROCESSED DATA
VESSEL: F/V VESTERAALEN
DATE: MAY 18–29, 1998
MAP PROJECTION
UTM ZONE 10
C.M. 123° W
DATUM: WGS 84
LEGEND
NAVY TRACK
USBL TRACK
USBL GEAR TESTED: TRACKPOINT II PLUS
N
0 50 100 150 200 250
METERS
SCALE: 1:5000
RACAL
PROCESSORE1.DWG


TRAWL 31
178 COMMON POINTS
MAY 28 05:22
TRAWL 32
74 COMMON POINTS
MAY 28 16:38
TRAWL 33
111 COMMON POINTS
MAY 28 17:15
5289200
5289000
5288800
5288600
5288400
5288200
5288000
511400
511600
511800
NMFS Alaska Fisheries Science Center
Department of Commerce
National Oceanic and Atmospheric Administration
TRAWLEX
TRAWL POSITIONING GEAR TRIALS
ORE INC.
PROCESSED DATA
VESSEL: F/V VESTERAALEN
DATE: MAY 18–29, 1998
MAP PROJECTION
UTM ZONE 10
C.M. 123° W
DATUM: WGS 84
LEGEND
NAVY TRACK
USBL TRACK
USBL GEAR TESTED: TRACKPOINT II PLUS
N
0 50 100 150 200 250
METERS
SCALE: 1:5000
RACAL
PROCESSORE2.DWG



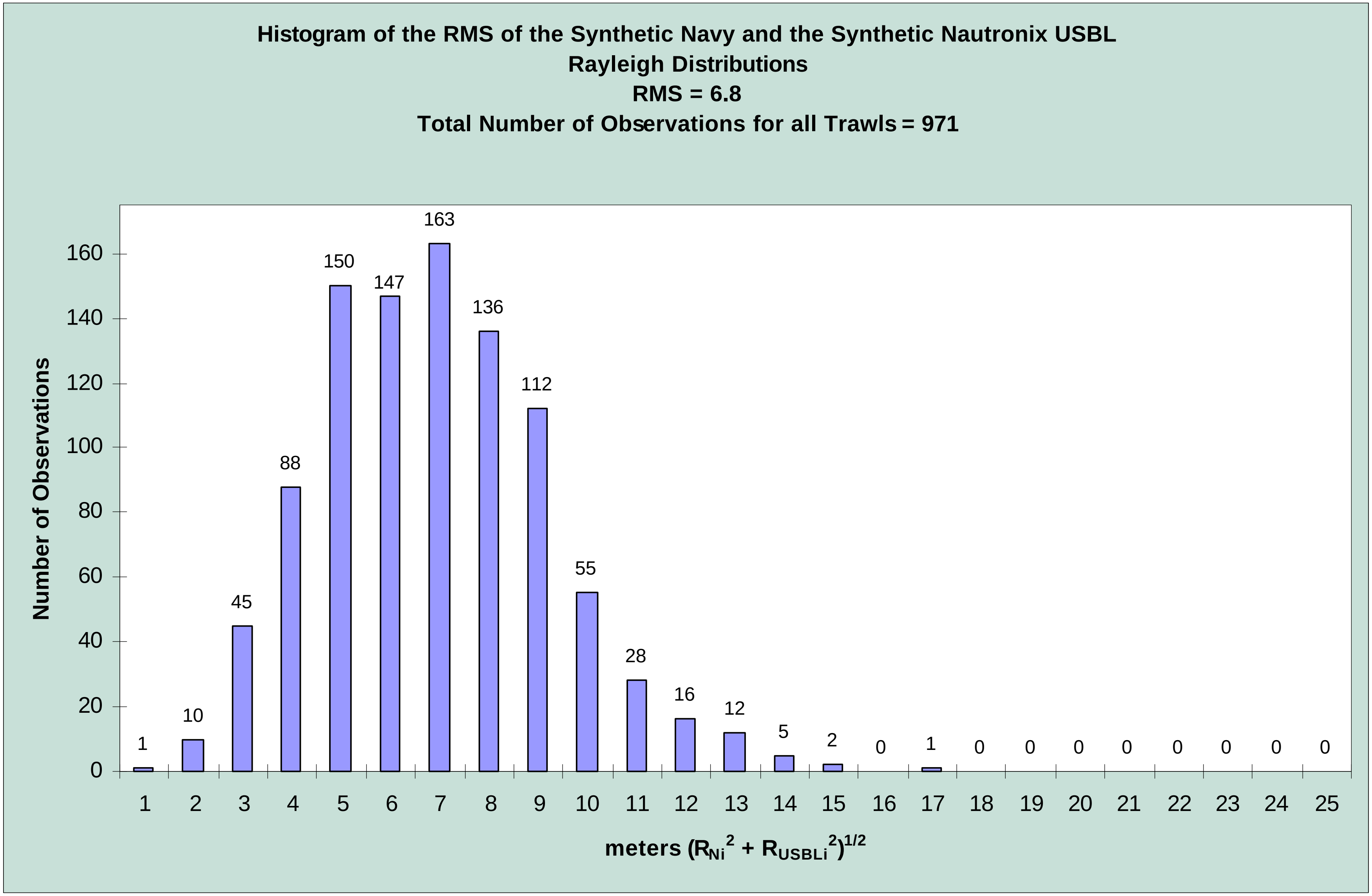
TRAWL 34
353 COMMON POINTS
MAY 28 18:24
5288800
5288600
5288400
5288200
5288000
511400
511600
511800
512000
512200
N
TRAWL 35
219 COMMON POINTS
MAY 28 19:01
5288800
5288600
5288400
5288200
5288000
511400
511600
511800
N
NMFS Alaska Fisheries Science Center
Department of Commerce
National Oceanic and Atmospheric Administration
TRAWLEX
TRAWL POSITIONING GEAR TRIALS
ORE INC.
PROCESSED DATA
VESSEL: F/V VESTERAALEN
DATE: MAY 18–29, 1998
MAP PROJECTION
UTM ZONE 10
C.M. 123° W
DATUM: WGS 84
LEGEND
NAVY TRACK
USBL TRACK
USBL GEAR TESTED: TRACKPOINT II PLUS
0 50 100 150 200 250
METERS
SCALE: 1:5000
RACAL
PROCESSORE3.DWG

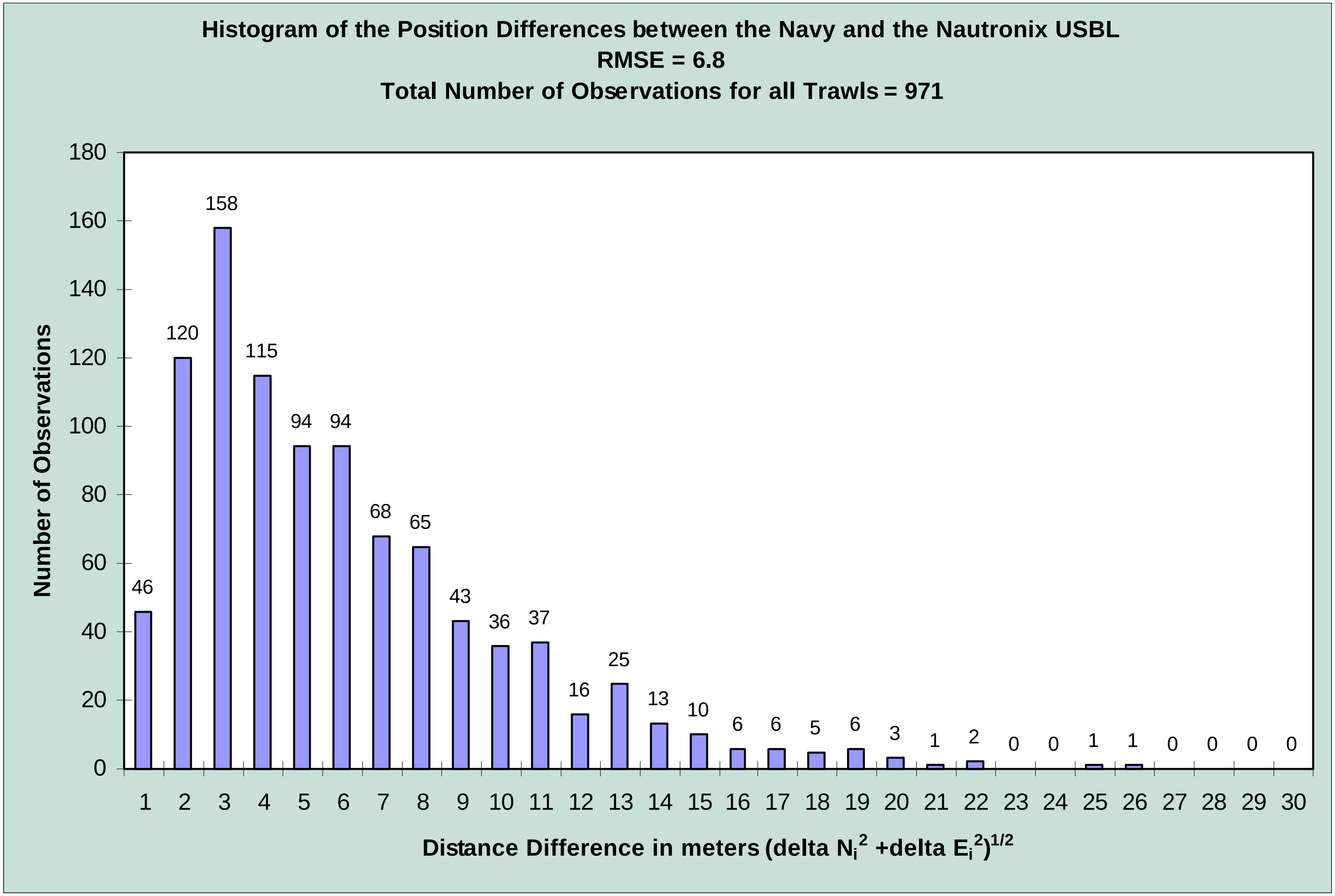
APPENDIX B

SYNTHETIC DISTRIBUTIONS AND OBSERVED RMSE VALUES

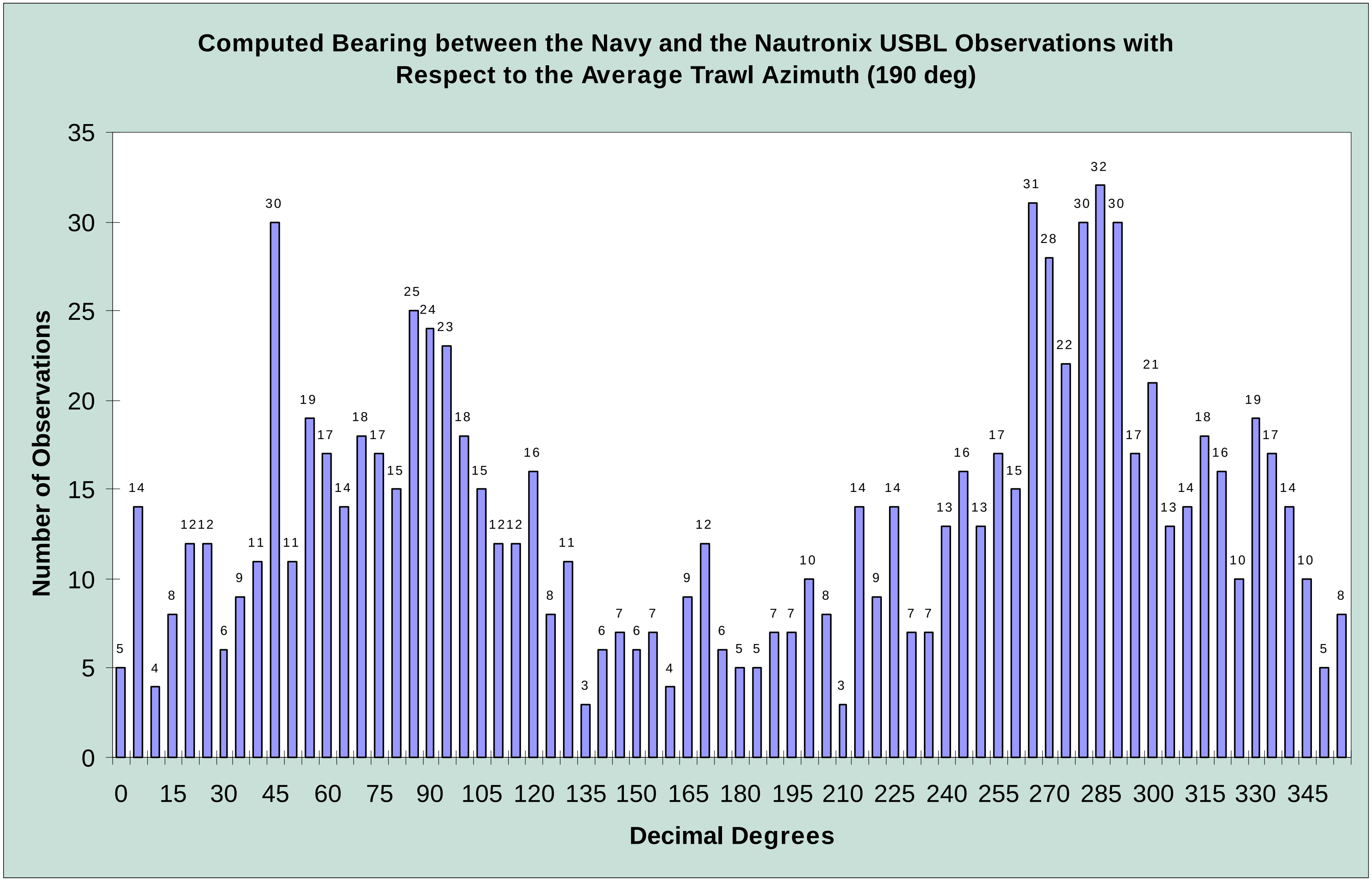
FOR

NAUTRONIX ATS II

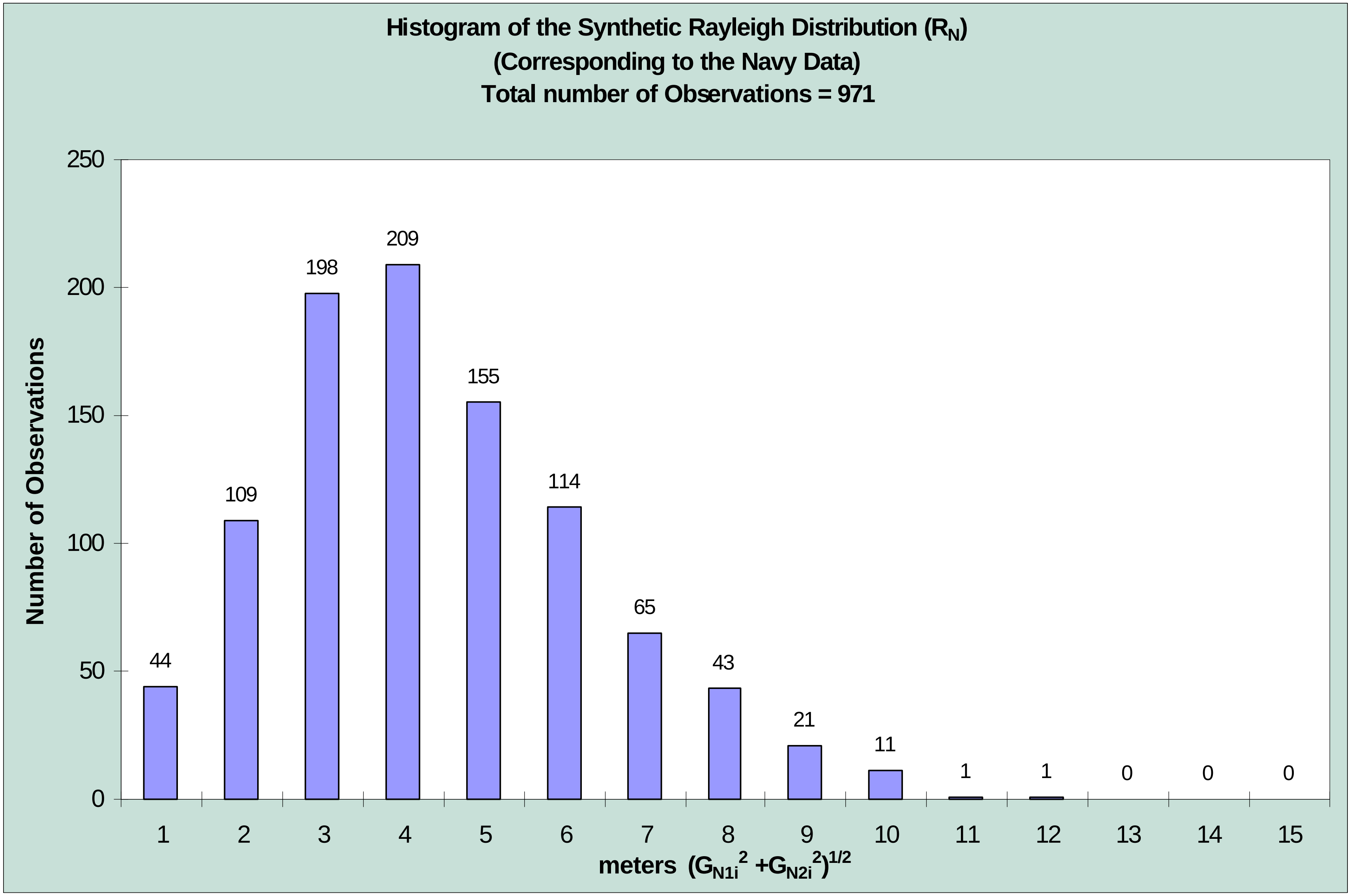

Histogram of the RMS of the Synthetic Navy and the Synthetic Nautronix USBL
Rayleigh Distributions
RMS = 6.8
Total Number of Observations for all Trawls = 971
Number of Observations
0
20
40
60
80
100
120
140
160
1
10
45
88
150
147
163
136
112
55
28
16
12
5
2
0
1
0
0
0
0
0
0
0
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
22
23
24
25
meters $(R_{Ni}^2 + R_{USBLi}^2)^{1/2}$



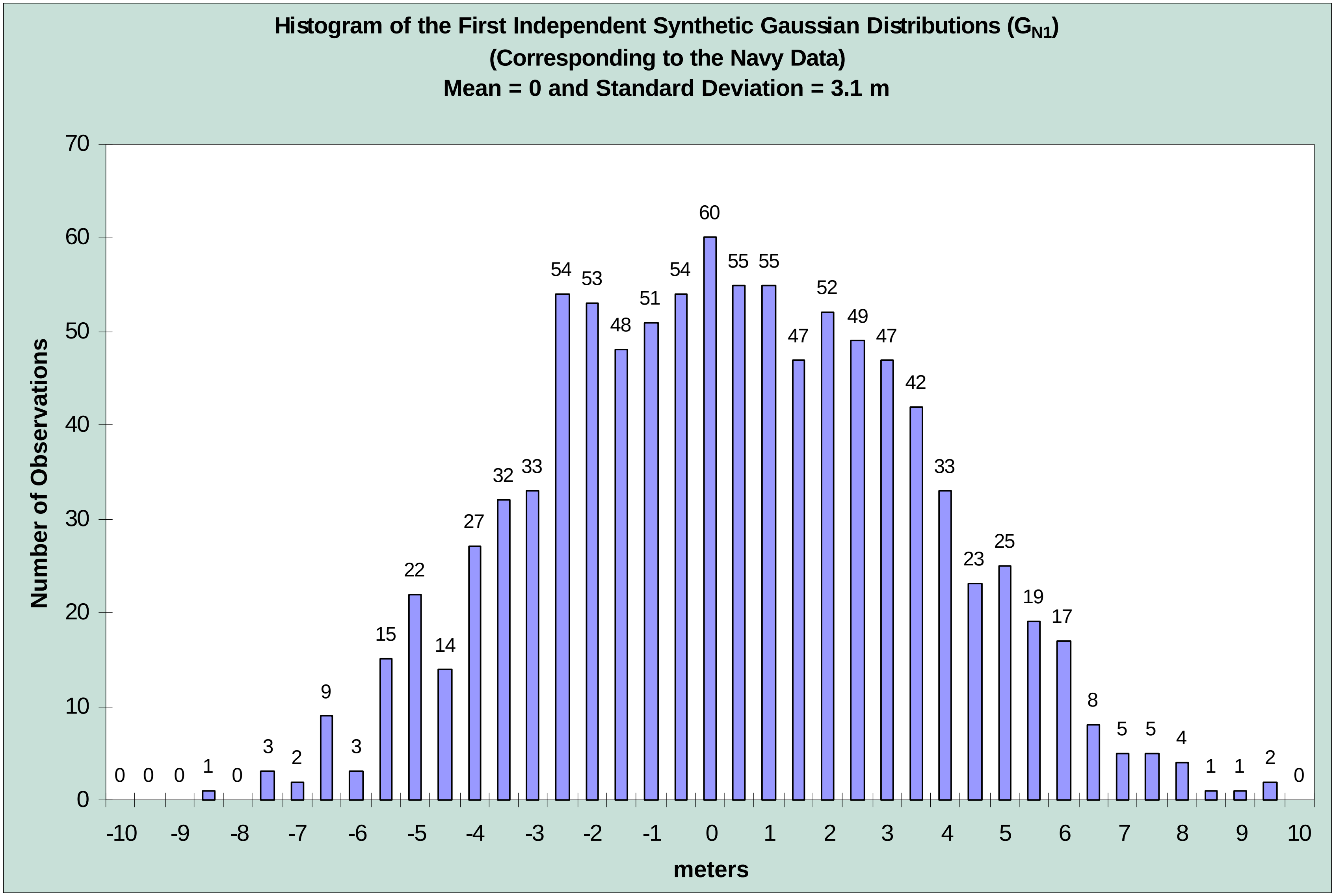
Histogram of the Position Differences between the Navy and the Nautronix USBL
RMSE = 6.8
Total Number of Observations for all Trawls = 971
Number of Observations
0
20
40
60
80
100
120
140
160
180
46
120
158
115
94
94
68
65
43
36
37
16
25
13
10
6
6
5
6
3
1
2
0
0
1
1
0
0
0
0
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30
Distance Difference in meters (delta N_i^2 +delta E_i^2)$^{1/2}$

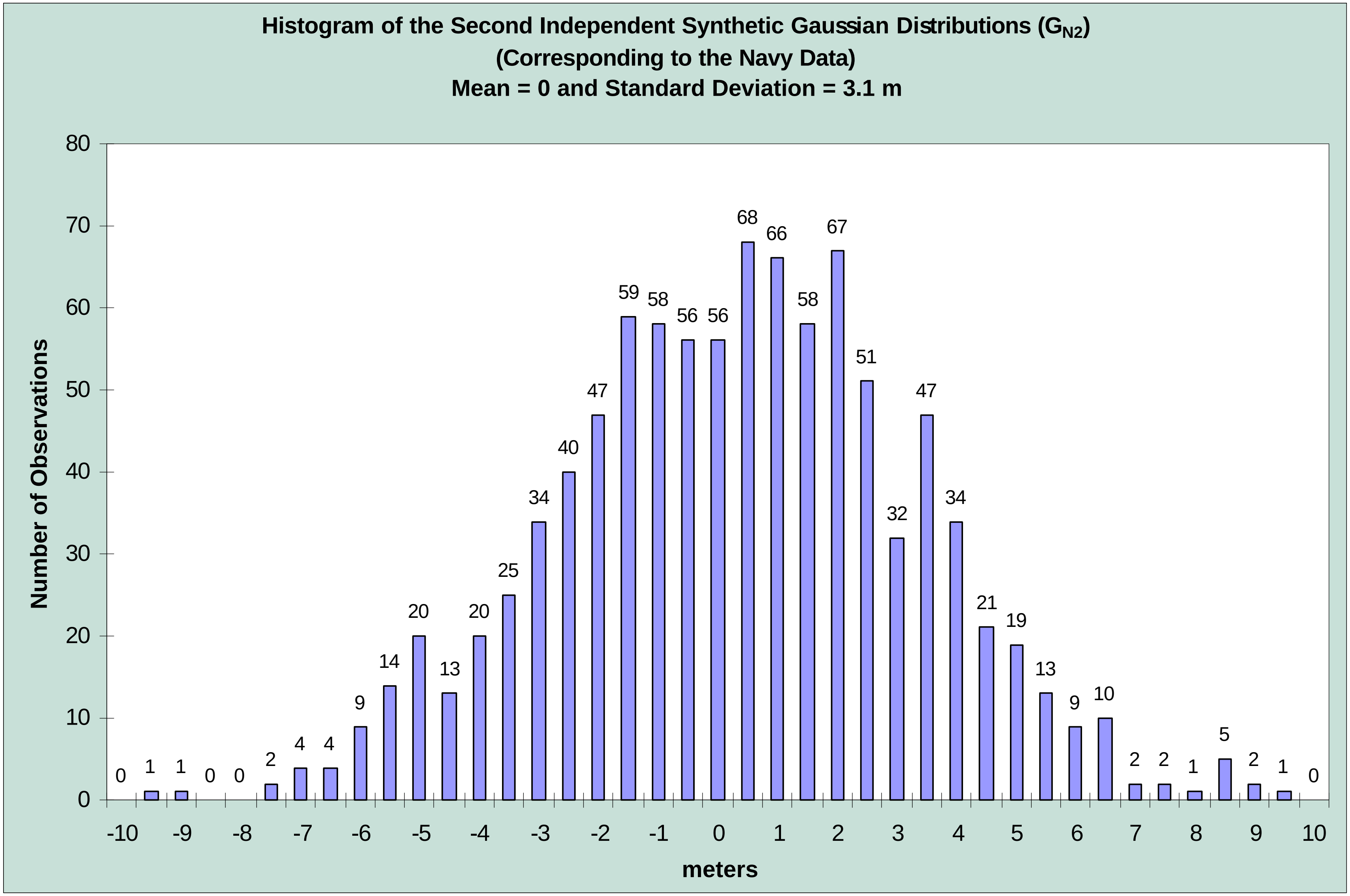


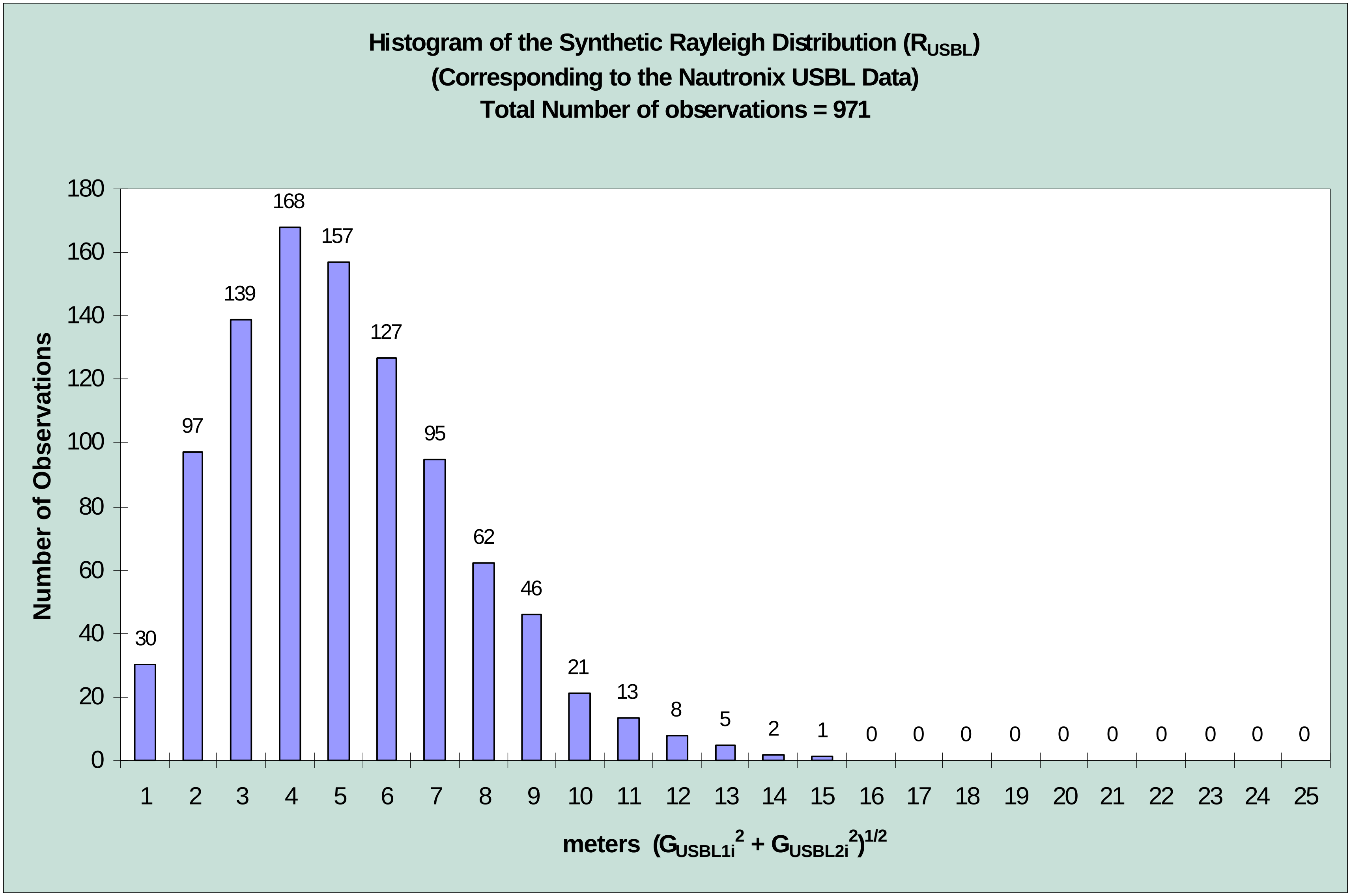
Computed Bearing between the Navy and the Nautronix USBL Observations with Respect to the Average Trawl Azimuth (190 deg)
Number of Observations
Decimal Degrees
0 5 10 15 20 25 30 35
0 15 30 45 60 75 90 105 120 135 150 165 180 195 210 225 240 255 270 285 300 315 330 345
5 14 4 8 12 12 6 9 11 30 11 19 17 14 18 17 15 25 24 23 18 15 12 12 16 8 11 3 6 7 6 7 4 9 12 6 5 5 7 7 10 8 3 14 9 14 7 7 13 16 13 17 15 31 28 22 30 32 30 17 21 13 14 18 16 10 19 17 14 10 5 8



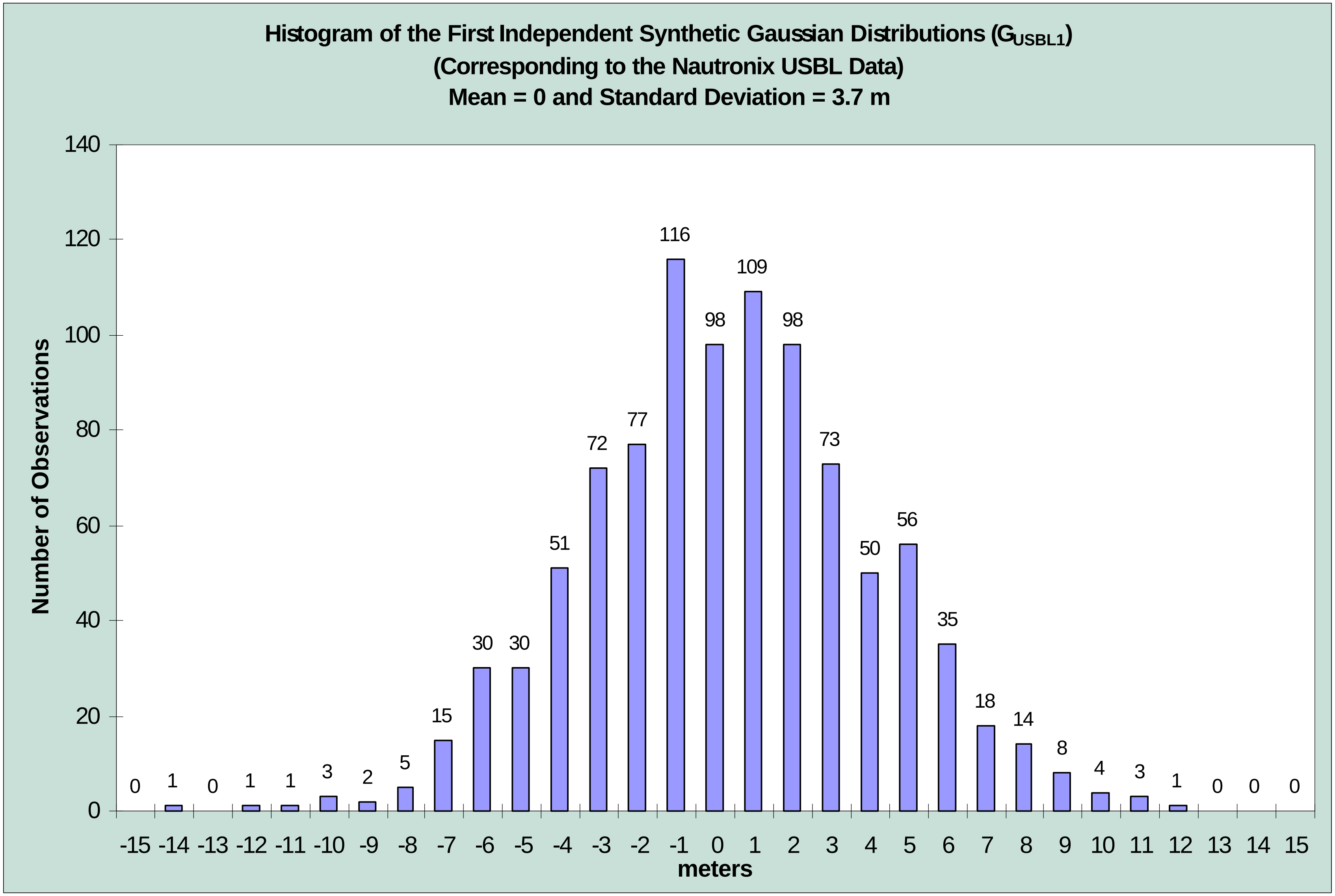
Histogram of the Synthetic Rayleigh Distribution (R_N)
(Corresponding to the Navy Data)
Total number of Observations = 971
Number of Observations
250
200
150
100
50
0
44
109
198
209
155
114
65
43
21
11
1
1
0
0
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
meters $(G_{N1i}^2 + G_{N2i}^2)^{1/2}$

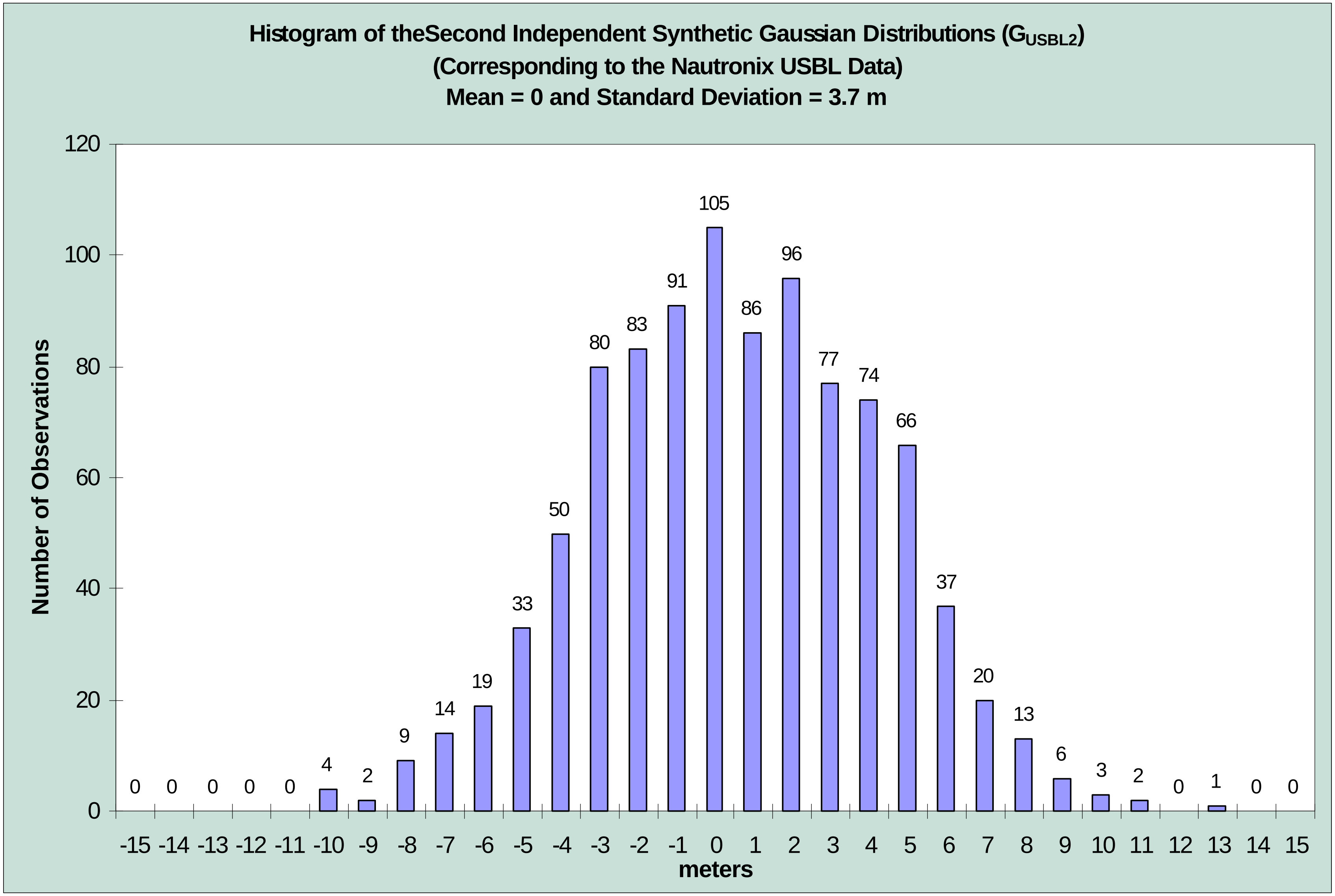

Histogram of the First Independent Synthetic Gaussian Distributions (G_{N1})
(Corresponding to the Navy Data)
Mean = 0 and Standard Deviation = 3.1 m
Number of Observations
meters
0 0 0 1 0 3 2 9 3 15 22 14 27 32 33 54 53 48 51 54 60 55 55 47 52 49 47 42 33 23 25 19 17 8 5 5 4 1 1 2 0
0 10 20 30 40 50 60 70
-10 -9 -8 -7 -6 -5 -4 -3 -2 -1 0 1 2 3 4 5 6 7 8 9 10


Histogram of the Second Independent Synthetic Gaussian Distributions (G_{N2})
(Corresponding to the Navy Data)
Mean = 0 and Standard Deviation = 3.1 m
Number of Observations
80
70
60
50
40
30
20
10
0
0 1 1 0 0 2 4 4 9 14 20 13 20 25 34 40 47 59 58 56 56 68 66 58 67 51 32 47 34 21 19 13 9 10 2 2 1 5 2 1 0
-10 -9 -8 -7 -6 -5 -4 -3 -2 -1 0 1 2 3 4 5 6 7 8 9 10
meters



Histogram of the Synthetic Rayleigh Distribution (R_{USBL})
(Corresponding to the Nautronix USBL Data)
Total Number of observations = 971
Number of Observations
180
160
140
120
100
80
60
40
20
0
30
97
139
168
157
127
95
62
46
21
13
8
5
2
1
0
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25
meters $(G_{USBL1i}^2 + G_{USBL2i}^2)^{1/2}$


Histogram of the First Independent Synthetic Gaussian Distributions (G_{USBL1})
(Corresponding to the Nautronix USBL Data)
Mean = 0 and Standard Deviation = 3.7 m
Number of Observations
meters
0
20
40
60
80
100
120
140
-15 -14 -13 -12 -11 -10 -9 -8 -7 -6 -5 -4 -3 -2 -1 0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15
0 1 0 1 1 3 2 5 15 30 30 51 72 77 116 98 109 98 73 50 56 35 18 14 8 4 3 1 0 0 0

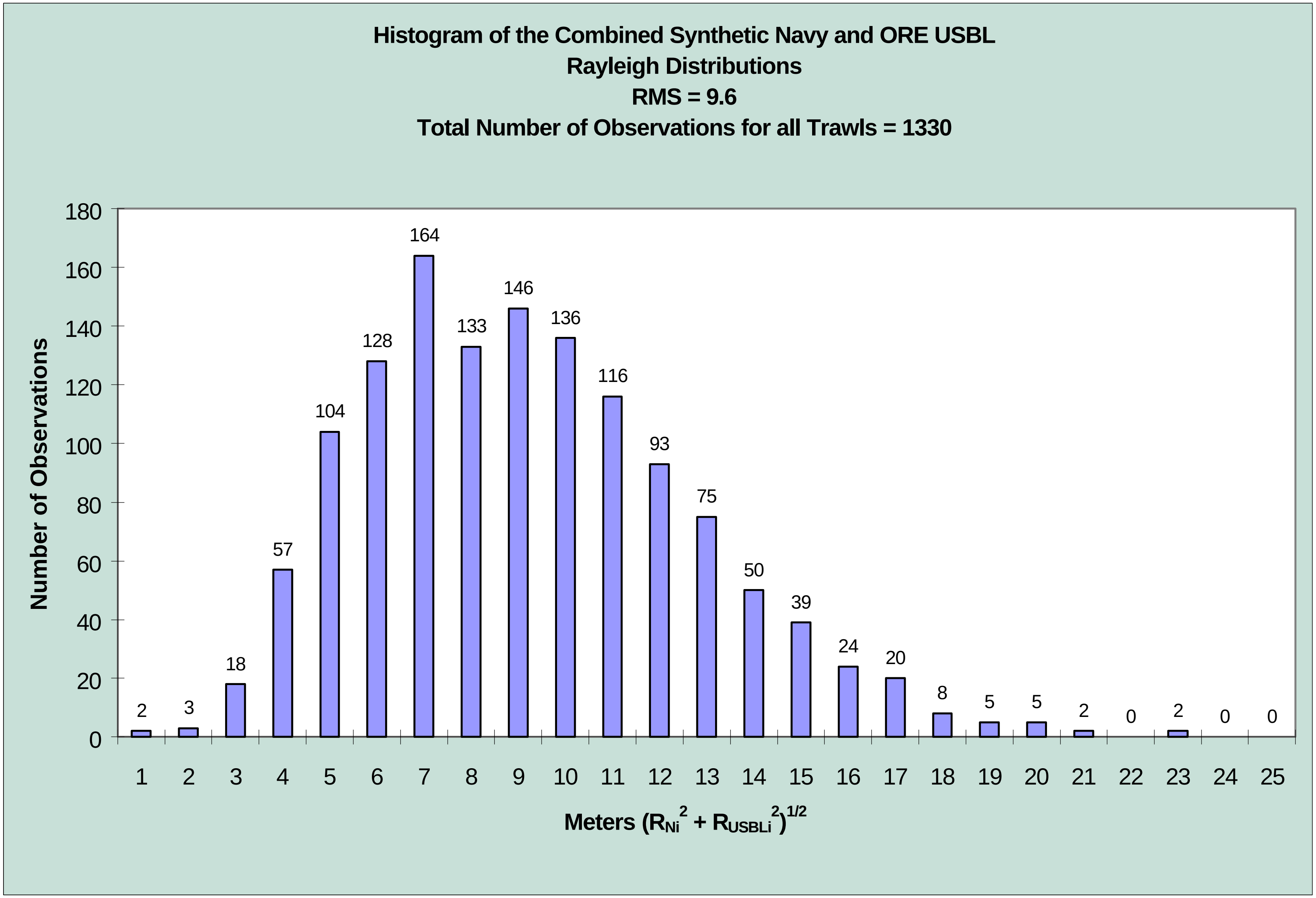

Histogram of theSecond Independent Synthetic Gaussian Distributions (G_{USBL2})
(Corresponding to the Nautronix USBL Data)
Mean = 0 and Standard Deviation = 3.7 m
Number of Observations
0
20
40
60
80
100
120
meters
-15 -14 -13 -12 -11 -10 -9 -8 -7 -6 -5 -4 -3 -2 -1 0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15
0 0 0 0 0 4 2 9 14 19 33 50 80 83 91 105 86 96 77 74 66 37 20 13 6 3 2 0 1 0 0

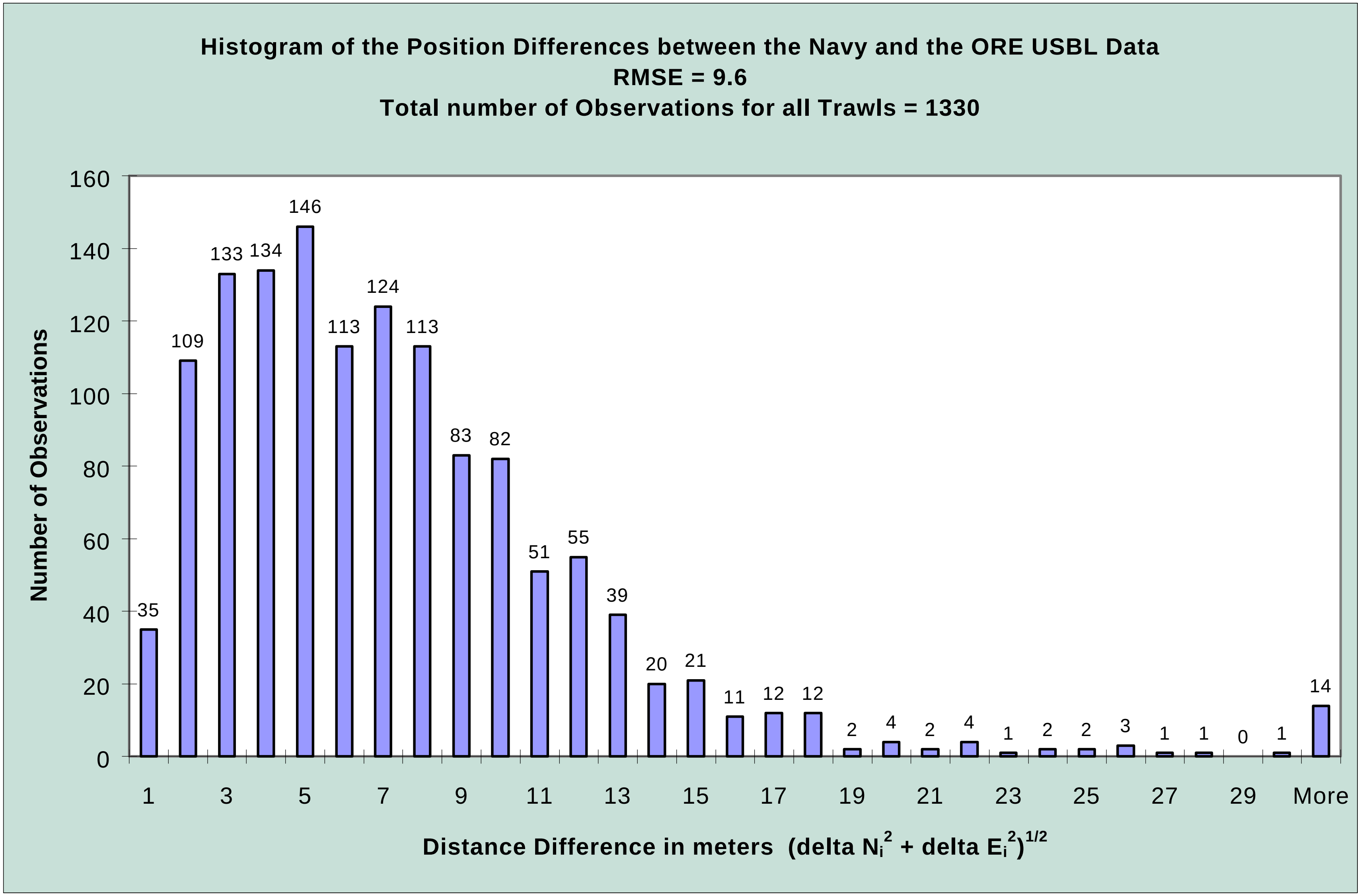
APPENDIX C

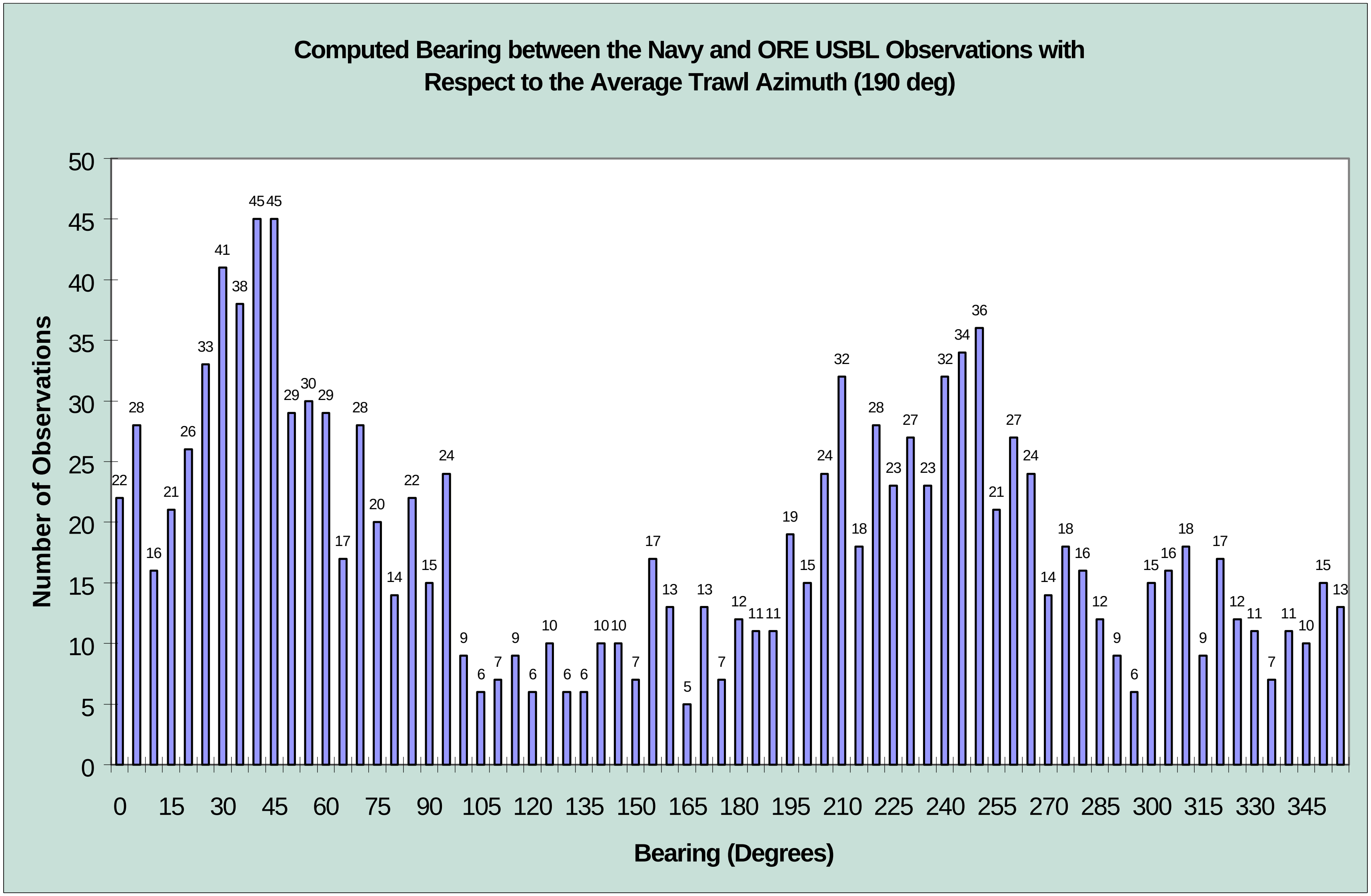
SYNTHETIC DISTRIBUTIONS AND OBSERVED RMSE VALUES

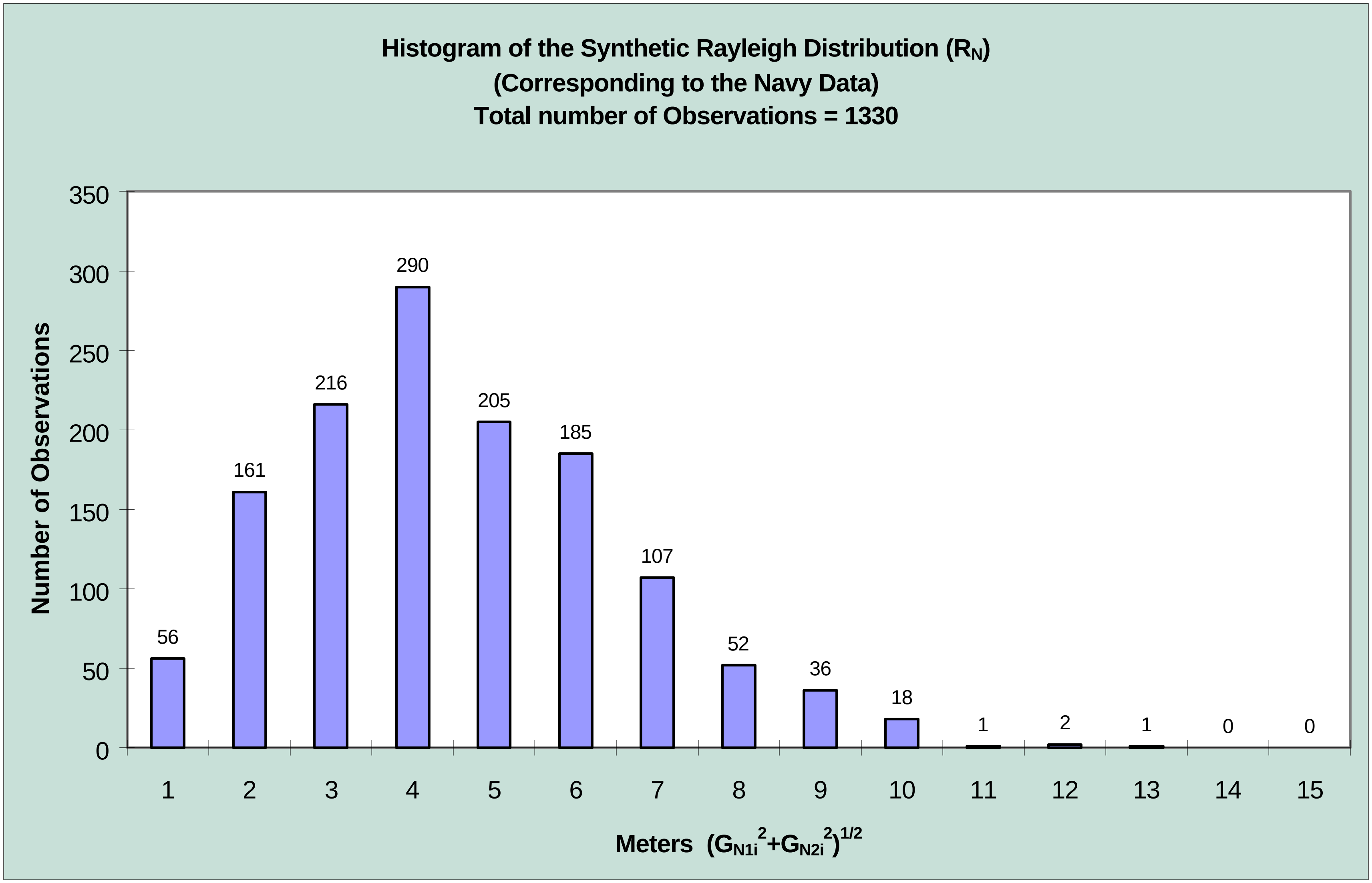
FOR

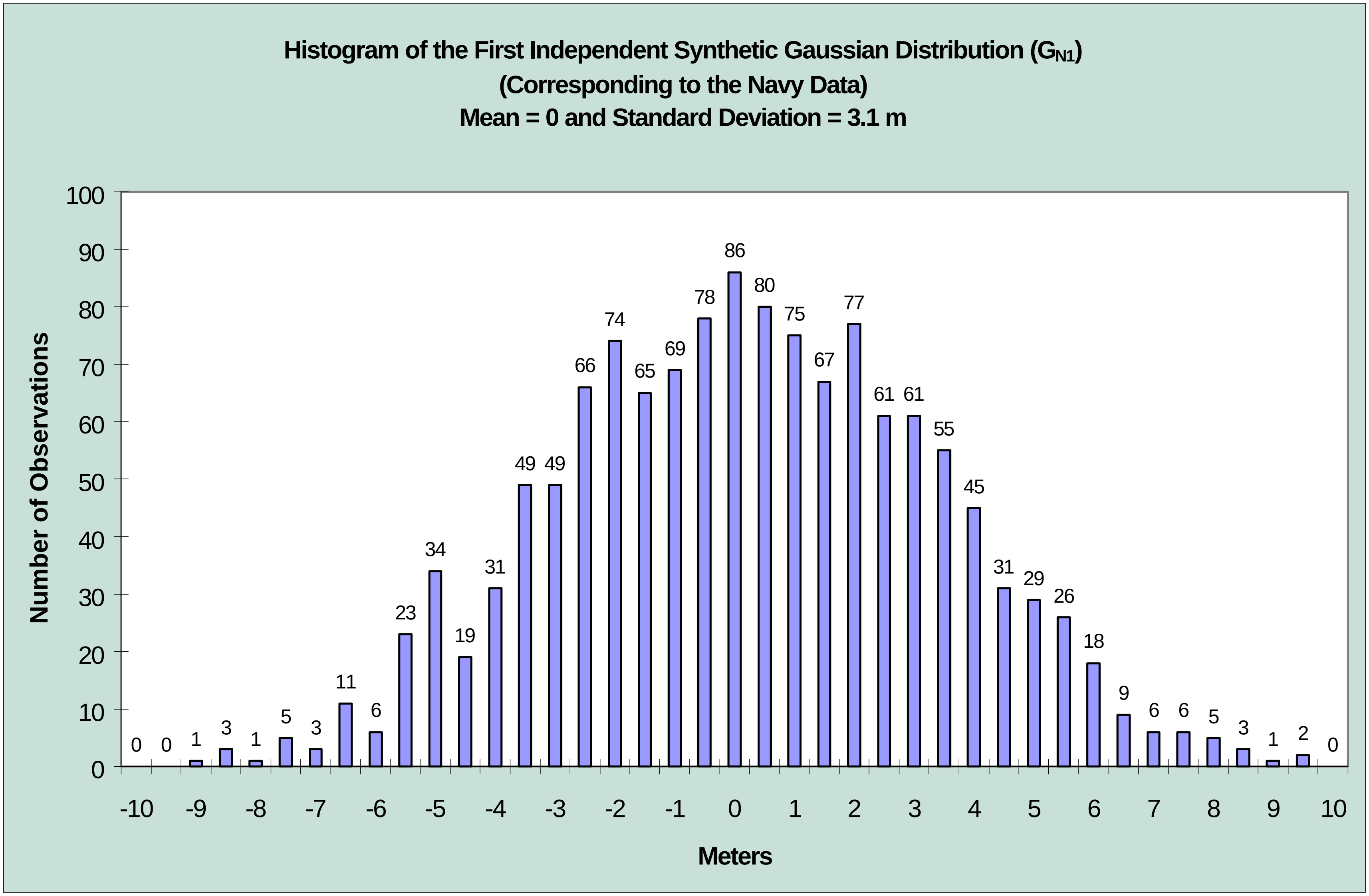
ORE TRACKPOINT II PLUS

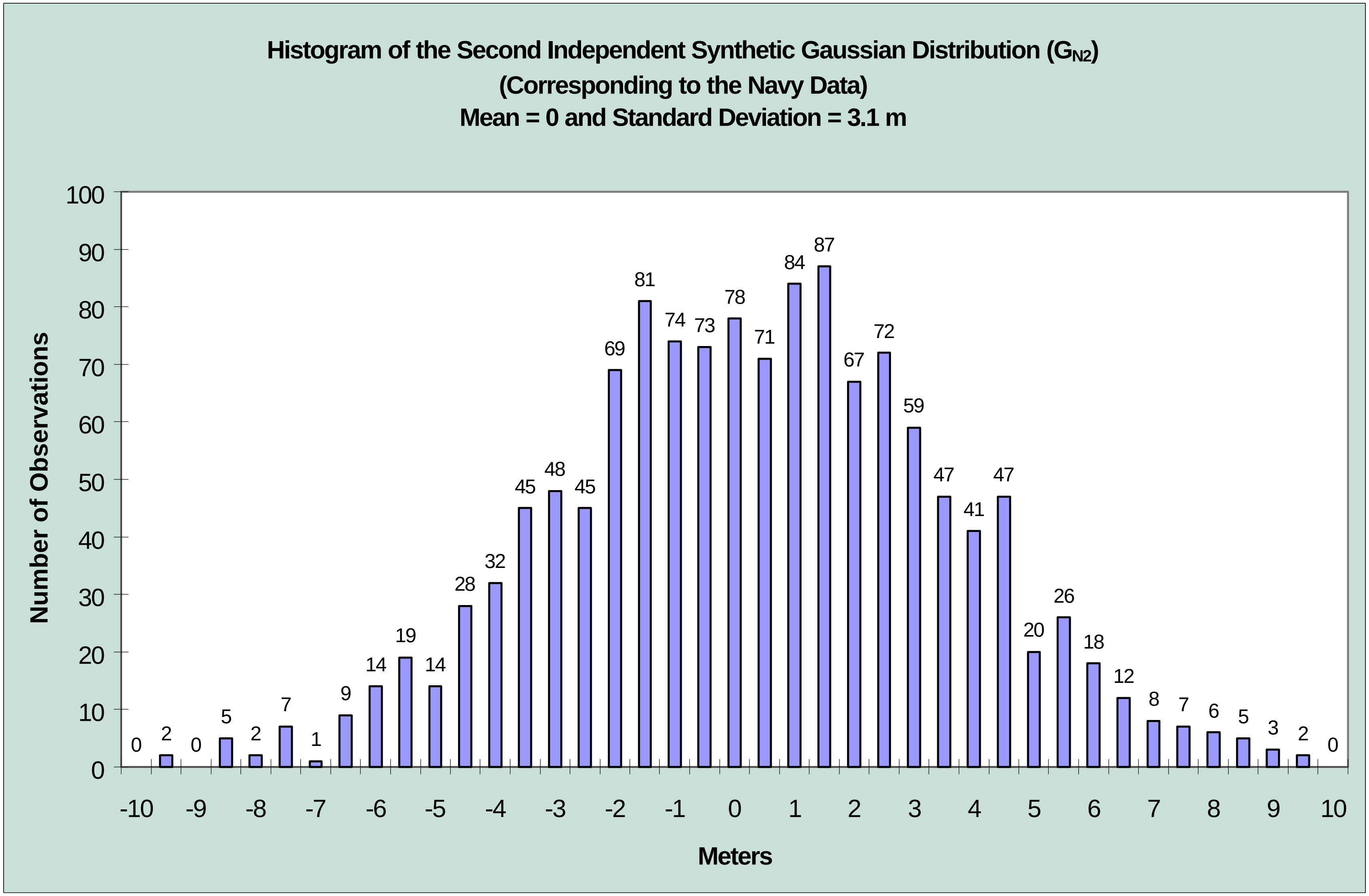

Histogram of the Combined Synthetic Navy and ORE USBL
Rayleigh Distributions
RMS = 9.6
Total Number of Observations for all Trawls = 1330
Number of Observations
0
20
40
60
80
100
120
140
160
180
2
3
18
57
104
128
164
133
146
136
116
93
75
50
39
24
20
8
5
5
2
0
2
0
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
22
23
24
25
Meters $(R_{Ni}^2 + R_{USBLi}^2)^{1/2}$

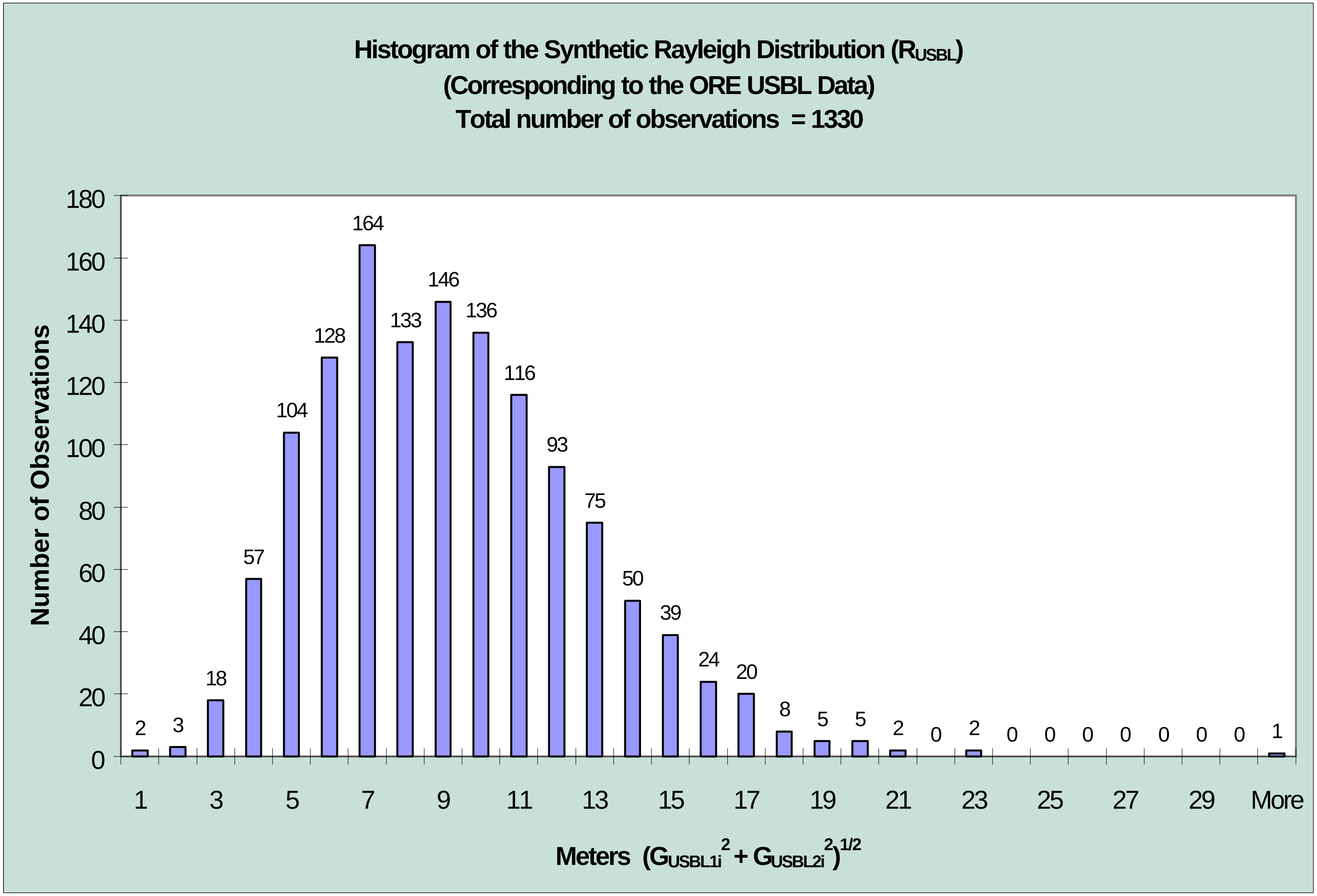

Histogram of the Position Differences between the Navy and the ORE USBL Data
RMSE = 9.6
Total number of Observations for all Trawls = 1330
Number of Observations
160
140
120
100
80
60
40
20
0
35
109
133
134
146
113
124
113
83
82
51
55
39
20
21
11
12
12
2
4
2
4
1
2
2
3
1
1
0
1
14
1
3
5
7
9
11
13
15
17
19
21
23
25
27
29
More
Distance Difference in meters (delta N_i^2 + delta E_i^2)$^{1/2}$

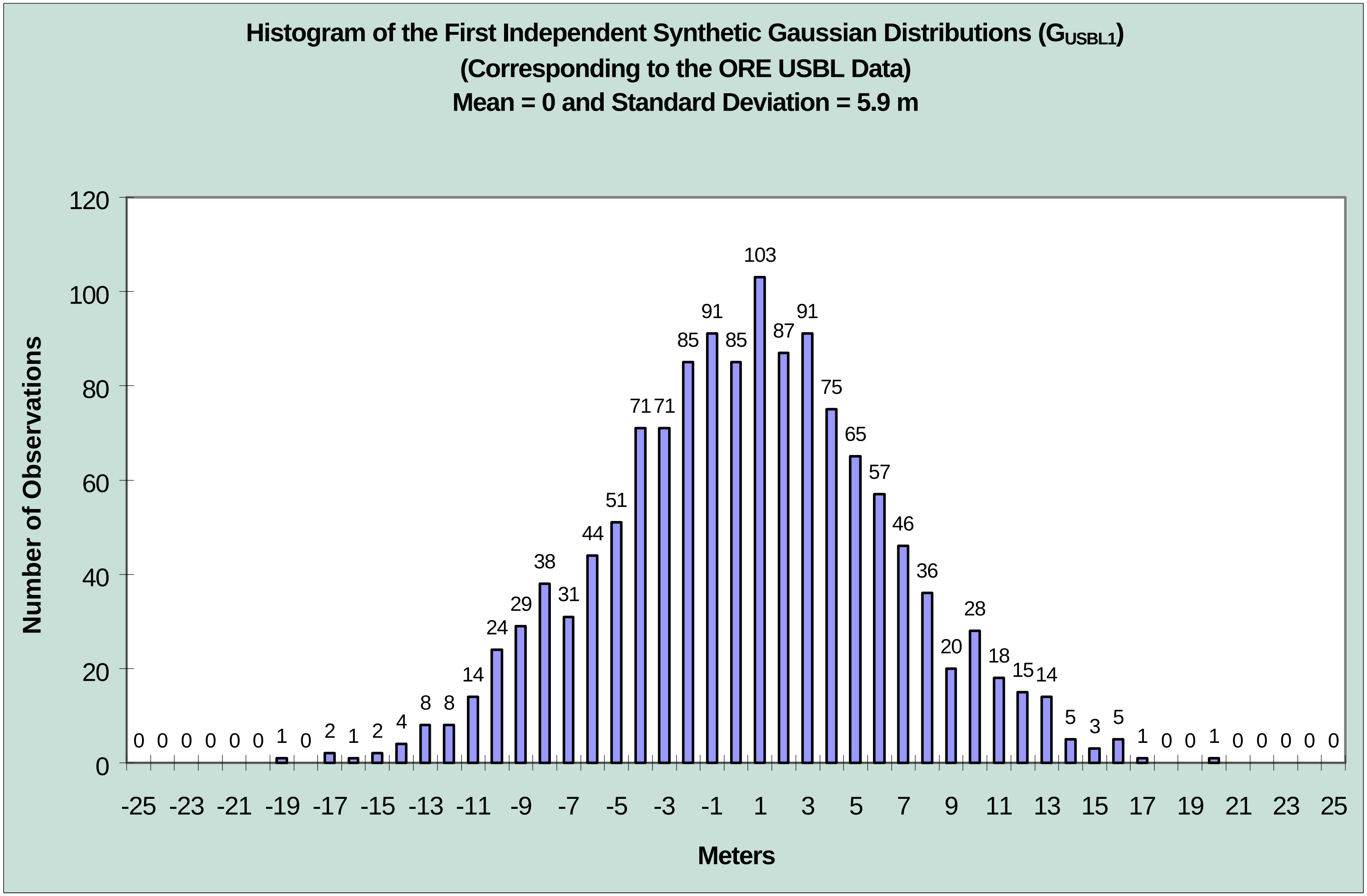

Computed Bearing between the Navy and ORE USBL Observations with Respect to the Average Trawl Azimuth (190 deg)
Number of Observations
Bearing (Degrees)
0 5 10 15 20 25 30 35 40 45 50
0 15 30 45 60 75 90 105 120 135 150 165 180 195 210 225 240 255 270 285 300 315 330 345
22 28 16 21 26 33 41 38 45 45 29 30 29 17 28 20 14 22 15 24 9 6 7 9 6 10 6 6 10 10 7 17 13 5 13 7 12 11 11 19 15 24 32 18 28 23 27 23 32 34 36 21 27 24 14 18 16 12 9 6 15 16 18 9 17 12 11 7 11 10 15 13

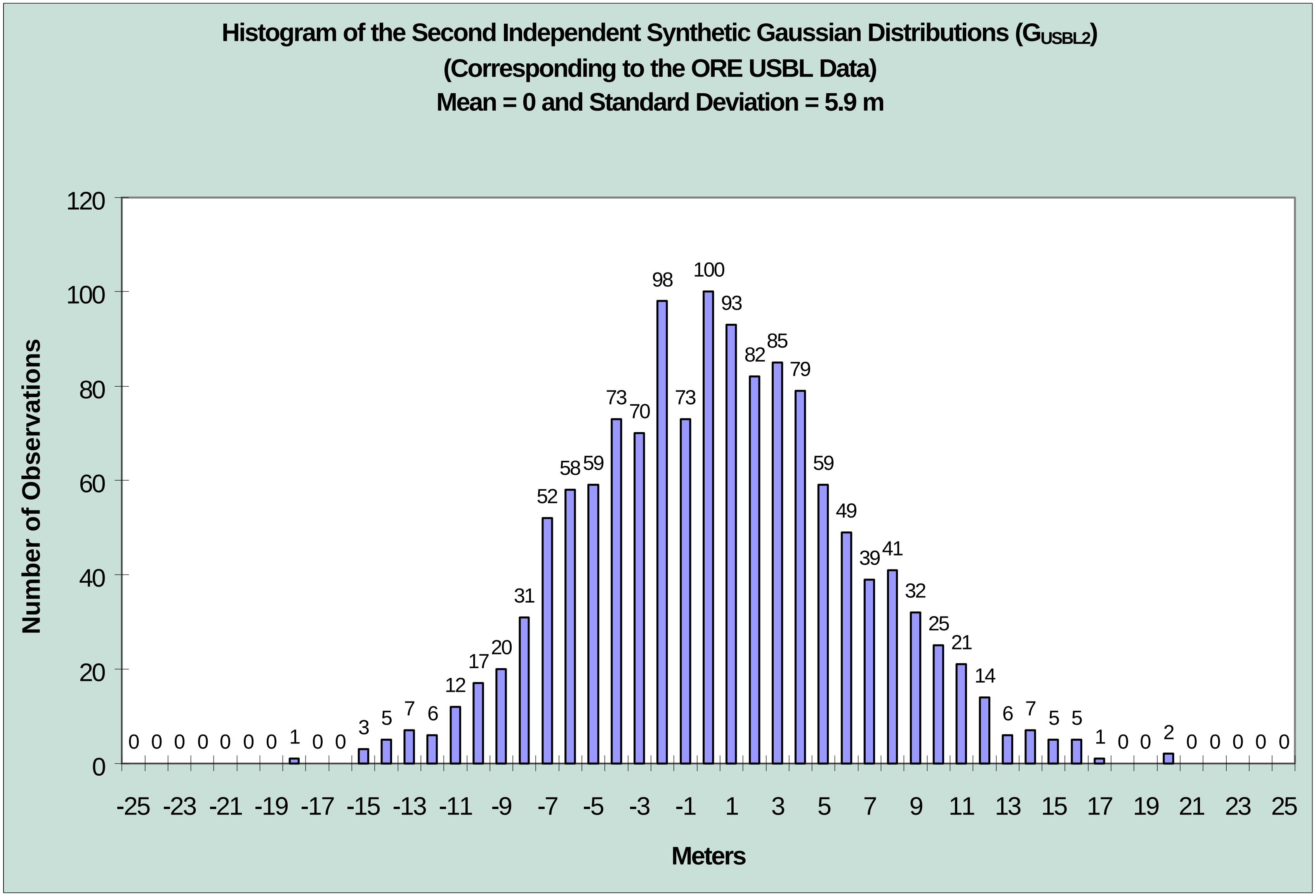

Histogram of the Synthetic Rayleigh Distribution (R_N)
(Corresponding to the Navy Data)
Total number of Observations = 1330
Number of Observations
350
300
250
200
150
100
50
0
56
161
216
290
205
185
107
52
36
18
1
2
1
0
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
Meters $(G_{N1i}^2+G_{N2i}^2)^{1/2}$


Histogram of the First Independent Synthetic Gaussian Distribution (G_{N1})
(Corresponding to the Navy Data)
Mean = 0 and Standard Deviation = 3.1 m
Number of Observations
Meters
0 10 20 30 40 50 60 70 80 90 100
-10 -9 -8 -7 -6 -5 -4 -3 -2 -1 0 1 2 3 4 5 6 7 8 9 10
0 0 1 3 1 5 3 11 6 23 34 19 31 49 49 66 74 65 69 78 86 80 75 67 77 61 61 55 45 31 29 26 18 9 6 6 5 3 1 2 0


Histogram of the Second Independent Synthetic Gaussian Distribution (G_{N2})
(Corresponding to the Navy Data)
Mean = 0 and Standard Deviation = 3.1 m
Number of Observations
Meters
0
10
20
30
40
50
60
70
80
90
100
-10
-9
-8
-7
-6
-5
-4
-3
-2
-1
0
1
2
3
4
5
6
7
8
9
10
0 2 0 5 2 7 1 9 14 19 14 28 32 45 48 45 69 81 74 73 78 71 84 87 67 72 59 47 41 47 20 26 18 12 8 7 6 5 3 2 0


Histogram of the Synthetic Rayleigh Distribution (R_{USBL})
(Corresponding to the ORE USBL Data)
Total number of observations = 1330
Number of Observations
180
160
140
120
100
80
60
40
20
0
2
3
18
57
104
128
164
133
146
136
116
93
75
50
39
24
20
8
5
5
2
0
2
0
0
0
0
0
0
0
1
1
3
5
7
9
11
13
15
17
19
21
23
25
27
29
More
Meters $(G_{USBL1i}^2 + G_{USBL2i}^2)^{1/2}$

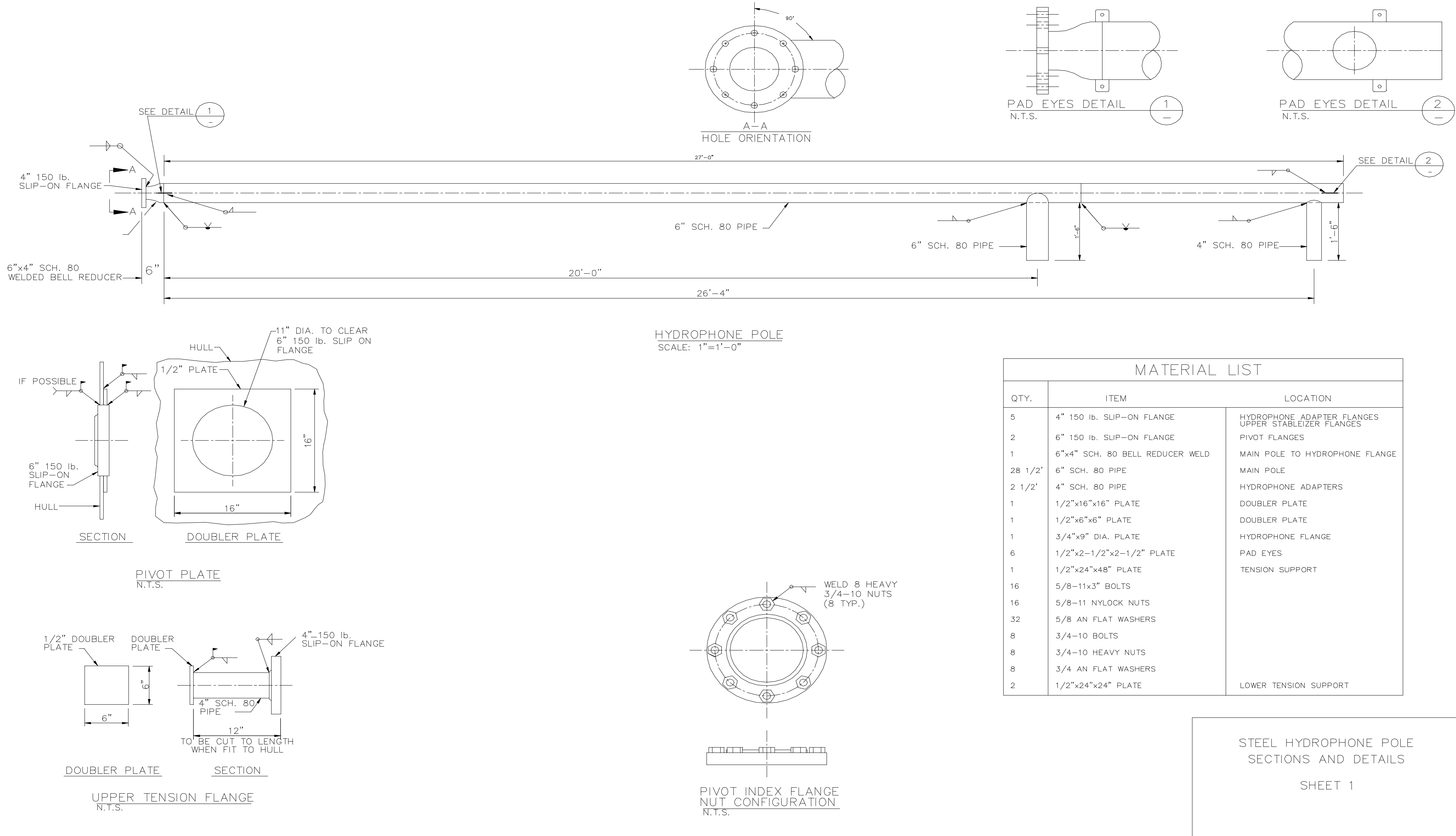

Histogram of the First Independent Synthetic Gaussian Distributions (G_{USBL1})
(Corresponding to the ORE USBL Data)
Mean = 0 and Standard Deviation = 5.9 m
Number of Observations
Meters
0 0 0 0 0 0 1 0 2 1 2 4 8 8 14 24 29 38 31 44 51 71 71 85 91 85 103 87 91 75 65 57 46 36 20 28 18 15 14 5 3 5 1 0 0 1 0 0 0 0 0
0 20 40 60 80 100 120
-25 -23 -21 -19 -17 -15 -13 -11 -9 -7 -5 -3 -1 1 3 5 7 9 11 13 15 17 19 21 23 25



Histogram of the Second Independent Synthetic Gaussian Distributions (G_USBL2)
(Corresponding to the ORE USBL Data)
Mean = 0 and Standard Deviation = 5.9 m
Number of Observations
Meters
0 20 40 60 80 100 120
-25 -23 -21 -19 -17 -15 -13 -11 -9 -7 -5 -3 -1 1 3 5 7 9 11 13 15 17 19 21 23 25
0 0 0 0 0 0 0 1 0 0 3 5 7 6 12 17 20 31 52 58 59 73 70 98 73 100 93 82 85 79 59 49 39 41 32 25 21 14 6 7 5 5 1 0 0 2 0 0 0 0 0

APPENDIX D

HYDROPHONE POLE DESIGN DRAWINGS

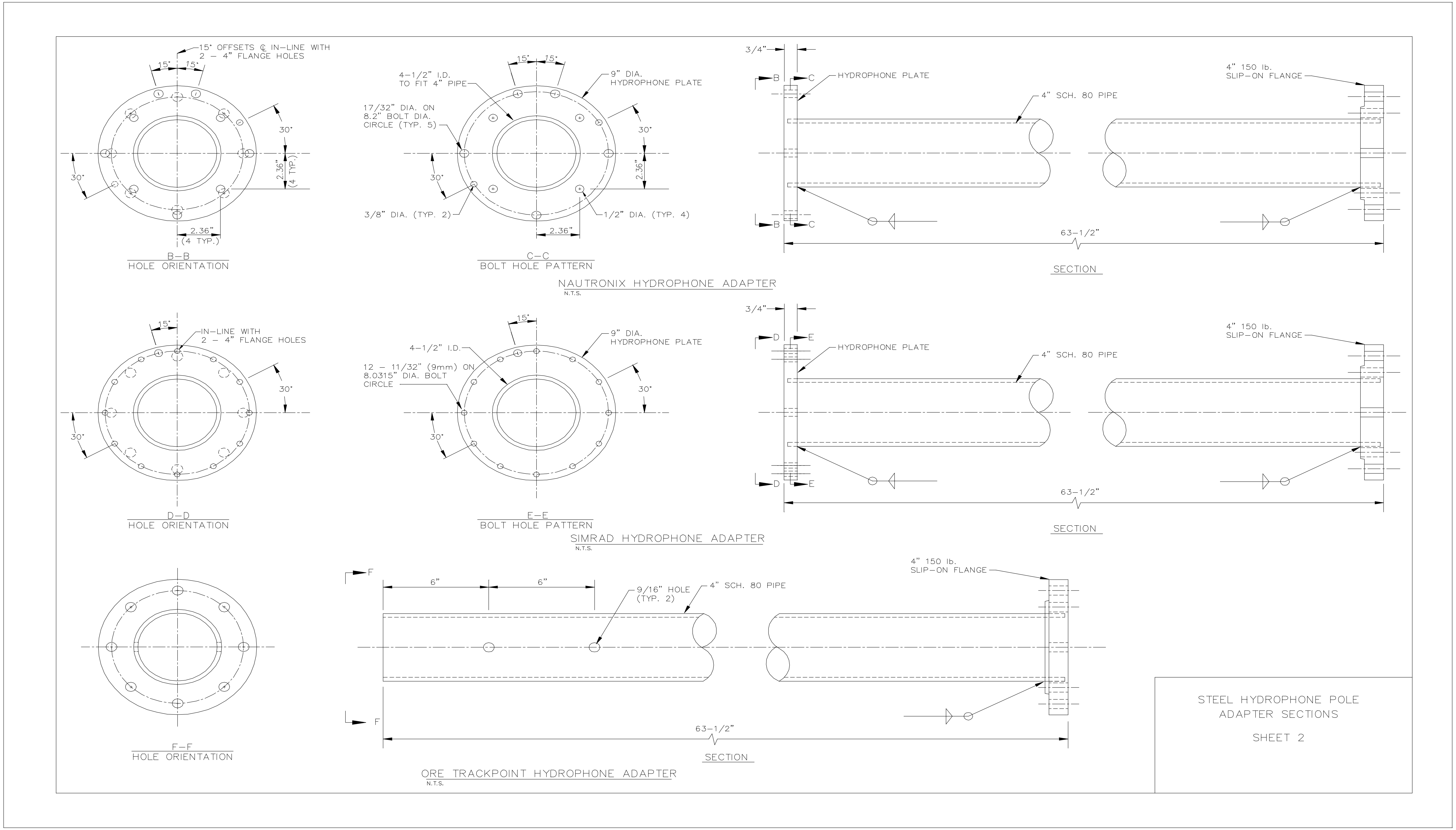


MATERIAL LIST

QTY.	ITEM	LOCATION
5	4" 150 lb. SLIP–ON FLANGE	HYDROPHONE ADAPTER FLANGES UPPER STABLEIZER FLANGES
2	6" 150 lb. SLIP–ON FLANGE	PIVOT FLANGES
1	6"x4" SCH. 80 BELL REDUCER WELD	MAIN POLE TO HYDROPHONE FLANGE
28 1/2'	6" SCH. 80 PIPE	MAIN POLE
2 1/2'	4" SCH. 80 PIPE	HYDROPHONE ADAPTERS
1	1/2"x16"x16" PLATE	DOUBLER PLATE
1	1/2"x6"x6" PLATE	DOUBLER PLATE
1	3/4"x9" DIA. PLATE	HYDROPHONE FLANGE
6	1/2"x2–1/2"x2–1/2" PLATE	PAD EYES
1	1/2"x24"x48" PLATE	TENSION SUPPORT
16	5/8–11x3" BOLTS	
16	5/8–11 NYLOCK NUTS	
32	5/8 AN FLAT WASHERS	
8	3/4–10 BOLTS	
8	3/4–10 HEAVY NUTS	
8	3/4 AN FLAT WASHERS	
2	1/2"x24"x24" PLATE	LOWER TENSION SUPPORT

STEEL HYDROPHONE POLE
SECTIONS AND DETAILS

SHEET 1


15° OFFSETS ℄ IN-LINE WITH 2 – 4" FLANGE HOLES
15°
15°
30°
30°
2.36" (4 TYP.)
2.36" (4 TYP.)
B–B
HOLE ORIENTATION
4-1/2" I.D. TO FIT 4" PIPE
17/32" DIA. ON 8.2" BOLT DIA. CIRCLE (TYP. 5)
9" DIA. HYDROPHONE PLATE
3/8" DIA. (TYP. 2)
1/2" DIA. (TYP. 4)
2.36"
C–C
BOLT HOLE PATTERN
3/4"
HYDROPHONE PLATE
4" SCH. 80 PIPE
4" 150 lb. SLIP-ON FLANGE
63-1/2"
SECTION
NAUTRONIX HYDROPHONE ADAPTER
N.T.S.
IN-LINE WITH 2 – 4" FLANGE HOLES
D–D
HOLE ORIENTATION
4-1/2" I.D.
12 – 11/32" (9mm) ON 8.0315" DIA. BOLT CIRCLE
9" DIA. HYDROPHONE PLATE
E–E
BOLT HOLE PATTERN
SIMRAD HYDROPHONE ADAPTER
N.T.S.
F–F
HOLE ORIENTATION
6"
6"
9/16" HOLE (TYP. 2)
4" SCH. 80 PIPE
4" 150 lb. SLIP-ON FLANGE
63-1/2"
SECTION
ORE TRACKPOINT HYDROPHONE ADAPTER
N.T.S.
STEEL HYDROPHONE POLE ADAPTER SECTIONS
SHEET 2

APPENDIX E

PARTICIPANT'S COMMENTS