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Target Positioning Accuracy Analysis Using Geo-referenced Sidescan Sonar Data, RMS TDP Builds 2 and 3

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Technical Memorandum

DRDC Atlantic TM 2003-210

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Abstract

The Remote Minehunting System Technology Demonstrator Project (RMS TDP) was a three–year program with the goal of providing recommendations to the Canadian Navy on semi–submersible–based minehunting technology. A key component of the project was a series of sea trials during which ongoing improvements to design and operation were tested. During the second and third of these trials, Builds 2 and 3, a quantity of sidescan sonar data over deployed and pre–existing target arrays was collected. The subsequent analysis of this data provides a method for assessing the RMS performance in meeting the critical initial specifications on target positioning accuracy of < 10 m rms.

The results of this analysis using geo–referenced sonar data show positioning accuracy that meets the specifications, with Build 2 having a positioning accuracy of 5 m rms, and Build 3, marginally larger at 7–8 m rms. An important difference between the results for the Builds is that for Build 2, the sidescan sonar data were geo–referenced using a simple straight-cable model to determine towfish position, where the Build 3 analysis used towfish position determined by an onboard Inertial Navigation System (INS). The only slightly poorer positioning accuracy for Build 3 is due to observed wander of the towfish INS, however attaining this level of positioning accuracy with any such system is noteworthy.

Résumé

Le projet de démonstration de technologie du système télécommandé de chasse aux mines (PDT STCM) était un contrat de trois ans réalisé dans le but de fournir à la Marine canadienne des recommandations sur la technologie de chasse aux mines basée sur l'utilisation de plates–formes semi–submersibles. Un élément clé du projet consistait en une série d'essais en mer portant sur des améliorations en cours de la conception et de l'exploitation. Durant le deuxième et le troisième de ces essais, on a recueilli une quantité de données de sonar à balayage latéral sur des réseaux de cibles déployées et sur d'autres déjà en place. L'analyse subséquente de ces données permet d'évaluer dans quelle mesure le STCM satisfait aux spécifications critiques initiales selon lesquelles la marge d'erreur de localisation des cibles doit être inférieure à 10 m (valeur efficace).

Les résultats de cette analyse effectuée avec des données sonar géoréférencées montrent une précision de localisation qui satisfait aux spécifications : pour la phase 2, la marge d'erreur de localisation est de 5 m (valeur efficace); pour la phase 3, elle est légèrement plus élevée, soit 7–8 m (valeur efficace). Dans la phase 2, les données de sonar à balayage latéral ont été géoréférencées l'aide d'un modèle de câble droit simple pour déterminer la position du sonar remorqué, alors que dans la phase 3 on a effectué l'analyse en utilisant la position du sonar remorqué déterminée par un système de navigation par inertie (INS) embarqué, ce qui constitue une importante différence entre les deux phases. La précision de localisation de la phase 3 était à peine inférieure, ce qui est attribuable à la dérive observée de l'INS embarqué sur le sonar remorqué, mais il est remarquable qu'on ait pu obtenir une telle précision de localisation avec un système de ce type.

Executive summary

Introduction
An important part of the three–year Remote Minehunting System Technology Demonstration Project was a series of three field trials, "Builds", staged in Esquimalt, BC. During Builds 2 and 3, sidescan sonar survey operations produced a quantity of sonar data over specially deployed and pre–existing minelike targets. Most of the sonar data has been post–processed into geo–referenced images of the seabed, including coverage of the areas where the targets were located.

Results
By analyzing the distribution of the geo–referenced locations of the targets in the seabed imagery, estimates can be made of the RMS target positioning performance. Initial target positioning specifications for the system were set at 10 m rms. The analysis of the geo–referenced data shows this specification has been met, with accuracy of 5 m rms during Build 2 and 7–8 m rms during Build 3.

Significance
At less than 10 m rms, the positioning accuracy achieved by the system is impressive, and necessary for efficiency in minehunting operations. This result was obtained through post-processing of the sonar data and while not representing a real–time operational situation, does allow analysis of system function that can lead to improvements. For example, the difference in positioning accuracy between Builds 2 and 3 is small, but can be traced to behaviour of the Inertial Navigation System onboard the sonar towfish.

Crawford, A., V. Myers, and D. Hopkin, 2003. Target Positioning Accuracy Analysis Using Geo–referenced Sidescan Sonar Data, RMS TDP Builds 2 and 3. TM2003–210. DRDC Atlantic.

Sommaire

Introduction

Une partie importante du projet de démonstration de technologie du système télécommand de chasse aux mines d'une durée de trois ans consistait en une série de trois essais sur le terrain, les "phases", réalisés à Esquimalt (C.B.). Durant les phases 2 et 3, les levés de sonar à balayage latéral ont permis de recueillir une quantité de données sonar sur des cibles de type mine déployées spécialement et sur d'autres cibles de ce type déjà en place. La plupart des données sonar ont été ultérieurement converties en images géoréférencées du fond marin, y compris des zones où les cibles étaient localisées.

Résultats

En analysant la distribution des positions géoréférencées des cibles dans l'imagerie du fond marin, on peut faire des estimations de l'efficacité de localisation des cibles par le STCM. La marge d'erreur initiale pour la localisation des cibles par le système a été fixée 10 m (valeur efficace). L'analyse des données géoréférencées montre que cette exigence est satisfaite, la marge d'erreur obtenue durant la phase 2 étant de 5 m (valeur efficace) et celle obtenue durant la phase 3 étant de 7–8 m (valeur efficace).

Importance

La marge d'erreur de localisation obtenue avec le système, inférieure à 10 m (valeur efficace), est impressionnante, et elle est nécessaire pour assurer l'efficacité des opérations de chasse aux mines. Ce résultat a été obtenu par un traitement ultérieur des données sonar et, même s'il ne représente pas une situation opérationnelle en temps réel, il permet d'effectuer une analyse de fonction du système pouvant mener à des améliorations. Par exemple, la différence de précision de localisation entre les phases 2 et 3 est faible, mais elle peut être attribuée au comportement du système de navigation par inertie embarqué sur le sonar remorqué.

Crawford, A., V. Myers and D. Hopkin, 2003. Analyse de la précision de localisation de cibles à l'aide de données géoréférencées de sonar à balayage latéral, phases 2 et 3 du PDT STCM. TM2003–210. RDDC Atlantique.

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1 Introduction

The Remote Minehunting System Technology Demonstrator Project (RMS TDP) began in June 2000 as a three-year program to provide recommendations to the Canadian Navy on semi–submersible–based minehunting technology. By the close of the project, the RMS had completed 3 comprehensive sea trials averaging 10 days plus 5 days of prior work–up each. These were a key component of the project, during which incremental improvements to the design and operations were rigorously tested.

During the second and third of the sea trials, Builds 2 and 3, a large quantity of sidescan sonar data were collected over arrays of seabed targets. The subsequent analysis of this data provides a method for assessing the RMS performance in meeting critical initial Project specifications for target positioning accuracy. The Technical System Concept document [1] states the horizontal two-dimensional position of a bottom object must be determined with an accuracy of 10 meters root-mean-squared (rms). Note that this is independent of the issues surrounding Computer Aided Detection and Classification (CAD/CAC) of the targets.

Positioning accuracy was assessed by computing statistics of the locations of the multiple instances of single targets in processed (geo–referenced) sidescan sonar data images. Factors contributing to variation in the apparent position of a target can be reduced to three general categories: a) inaccuracy in the determination of the sonar towfish position (such as by tow cable modeling or the towfish Inertial Navigation System). b) inaccuracy in the position of the vehicle (such as Global Positioning System error). c) towfish attitude or heading error leads to incorrect location of the insonified area of the seabed relative to the sonar. Within any of these categories, inaccuracy may be due to measurement error, or may be introduced by improper data processing techniques. In the following report, the positioning accuracy results are presented for each Build, along with discussion relating the results to these possible sources.

2 Summary of Survey Data, Build 2

Build 2 occurred in April of 2002, in Esquimalt, B.C. Over 9 working days, the vehicle performed almost 50 hours of operation underway, including a Search and Rescue response, with over 30 hours of sidescan sonar data logged.

The survey data collected during Build 2, and subsequently processed for positioning accuracy analysis, are summarized in Table 1. "Date" refers to the calendar day in April, 2002. The surveys are identified as "HiRes" (high sonar resolution setting, nominally 10 cm alongtrack resolution) or "LoRes" (nominally 20 cm alongtrack resolution), followed by the sonar maximum slant range setting. "deep tow" refers to a survey conducted at a deep water site away from the target arrays for purposes of testing all systems in a deep tow configuration. Not all of the sidescan sonar data collected on a particular day have been post–processed - "Surveys Geocoded" refers to the number of seabed mosaics completed from available data collected on a particular day. In the resulting mosaics, the deployed or existing mine-shaped targets (described in the following section) that can be identified are located in the georeferenced coordinate system of the mosaic and recorded. In total, 597 locations of images of the targets have been identified in 18 geocoded survey mosaics.

Table 1: *Summary of sonar surveys conducted during Build 2.*

DATE	SURVEYS	SURVEYS GEOCODED	TARGETS LOCATED
8	1 (LoRes 100 m)	1	32
9	1 partial	0	-
11	2 (1 HiRes 75 m; no sonar data from 2nd)	1	8
12	4 (2 LoRes 150 m; 1 LoRes 100 m; 1 HiRes 75 m)	4	182
15	3 (HiRes 75 m)	3	169
16	1 complete, several partial (HiRes 75 m)	4	151
17	1 deep tow; 2 partial (HiRes 75 m)	2	16
18	3 (2 HiRes 75 m, 1 LoRes 150 m)	3	39
19	1 partial	0	-
		18	597

2.1 Target Arrays

Figure 1 shows the positions of the target arrays and the location of the deep tow site, relative to Esquimalt and Victoria Harbours. The main survey area was located just outside Esquimalt Harbour where there were two previously deployed target arrays, the so–called '86 and '88 Arrays, and targets deployed just prior to the Build 2 trial (referred to here as the DRDC targets). A second area farther to the south–west in deeper water was the site of a deep tow test. Target positioning analysis was performed using the geocoded locations of the 5 DRDC targets that were positively identified, and the '88 and '86 Array targets. The following subsections detail some

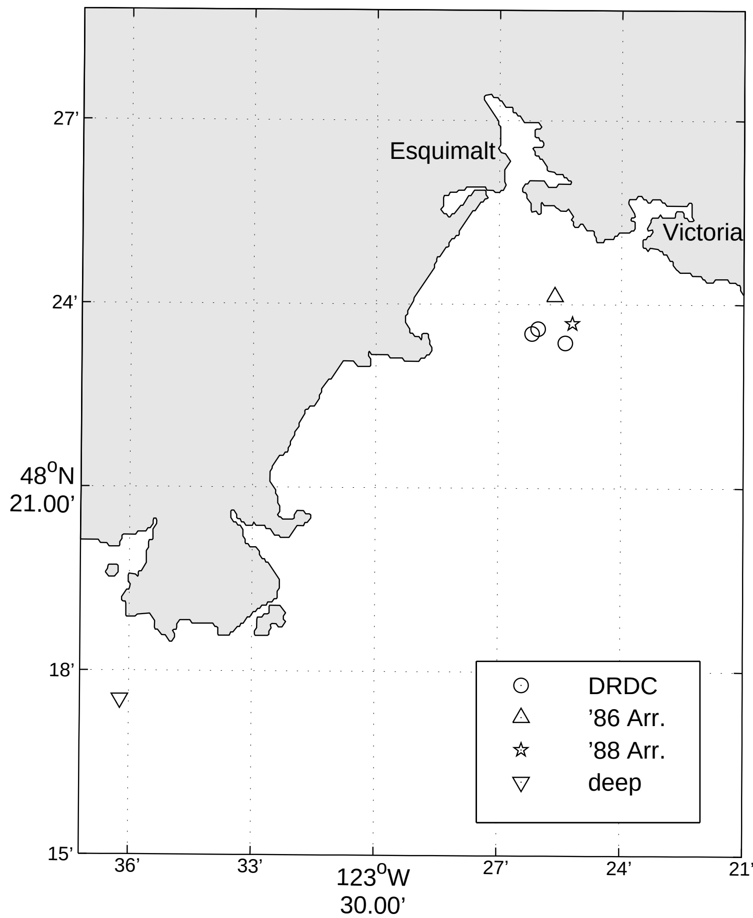

Figure 1: *Map showing the area of the surveys just outside Esquimalt and Victoria harbours, B.C., with target arrays and deep tow site locations indicated.*

information about the targets in the three groups. All target positions are given in units of meters, as UTM coordinates (Easting and Northing, zone 10, WGS84 ellipsoid), with plot axes generally made relative to some central position so that the values are smaller and more easily interpreted.

2.1.1 '86 Array

These have been designated "B1" through "B16". The group of targets identified by being clearly visible, repeatably, in the images may contain some which are actually clutter objects, such as rocks or sunken logs. At this time, prior position information has not been found for the targets in this array. Figure 2 shows the clustering of individual target positions in geocoded sonar mosaics and the mean position for each (star symbol). Positions have been determined from two days of survey data, April 15 (x symbols) and April 16 (+ symbols). The positions for a target have

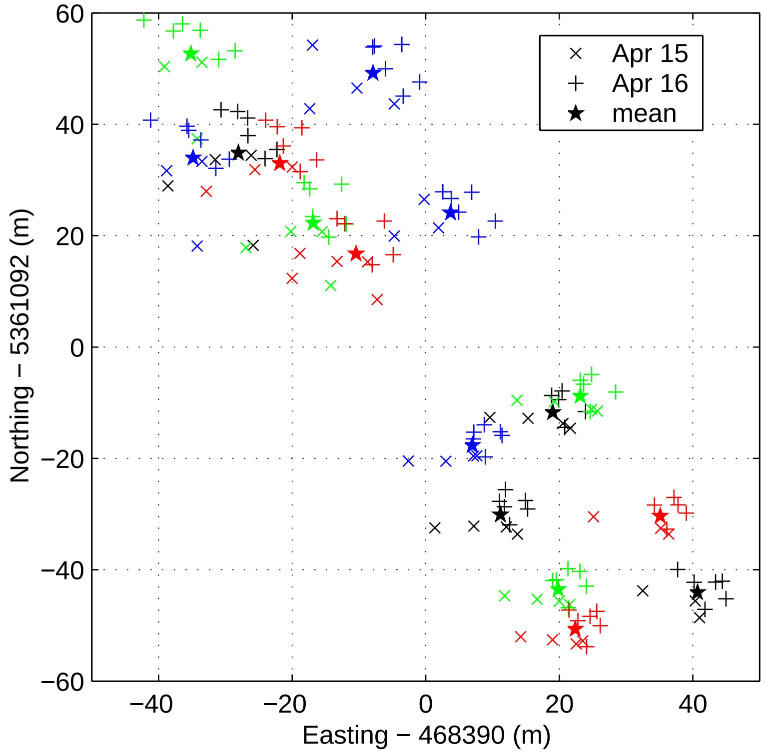

Figure 2: *'86 Array target positions and mean position for each target. Axes units are Eastings and Northings (meters), minus an arbitrary offset.*

been plotted in the same colour to help in separating overlapping clusters, though each colour has been used several times in the plot.

2.1.2 '88 Array

This array is mainly comprised of a group of cylinders which were at one time placed vertically (the "V" targets) and horizontally ("H"). Most of the V targets now lie H. A few other objects were placed in the array ("steel", "poslog", "stove" and a resolution target, "RT"). Historical positioning information for some of these targets is available, determined by researchers at Defence Research Establishment Pacific (DREP) and collaborators. A set of 3 objects in the northernmost part of the array which look like square frames, 4.5 m by 4.5 m, were also repeatably identifiable (called "box"es). Figure 3 shows the clustering of target positions, the mean positions for each target (blue stars) and the historical DREP positions (red stars). Different symbols have been used for the different target types in the array to separate the clusters.

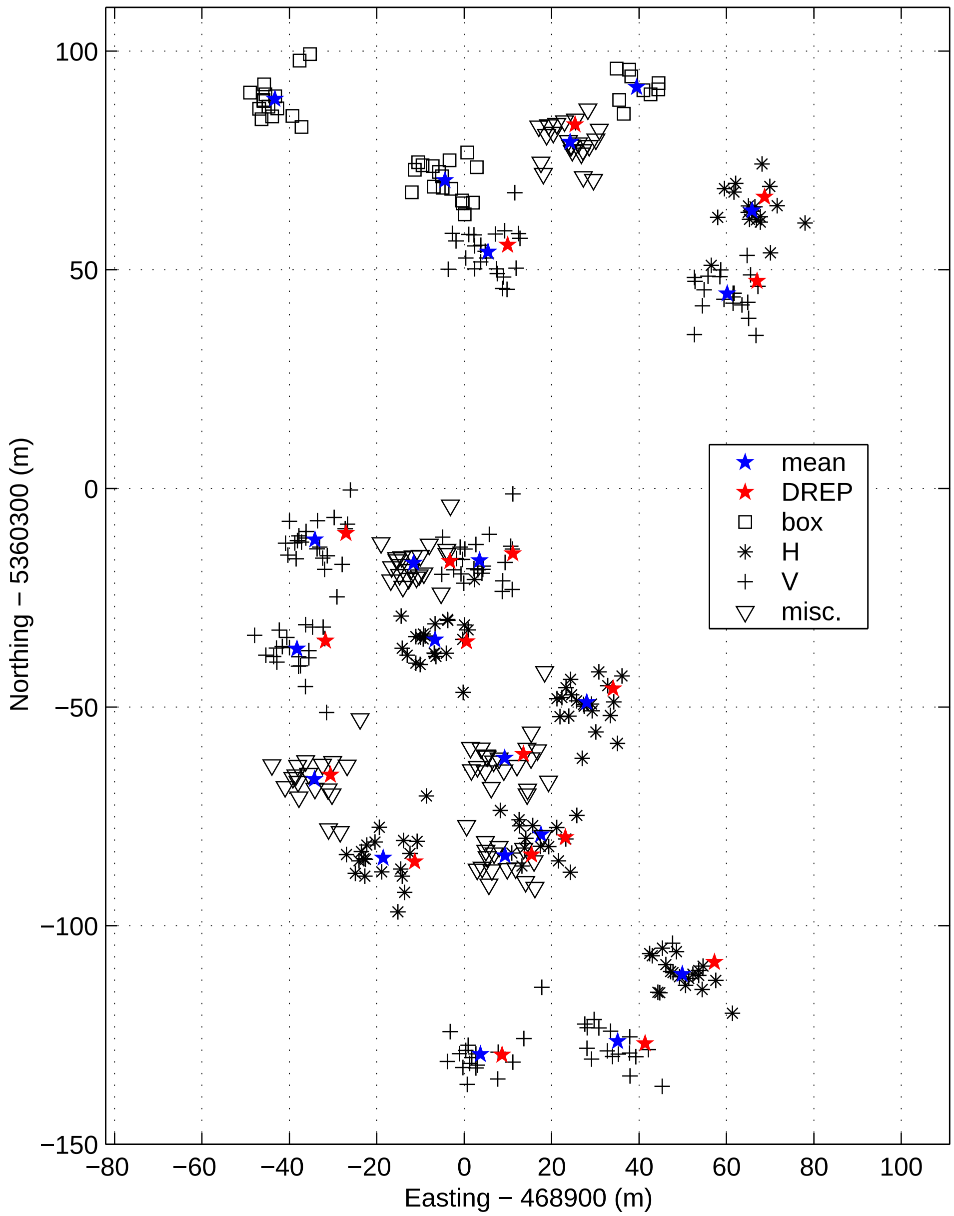

Figure 3: *'88 Array target positions, the mean position for each target and the historical positions as surveyed by DREP.*

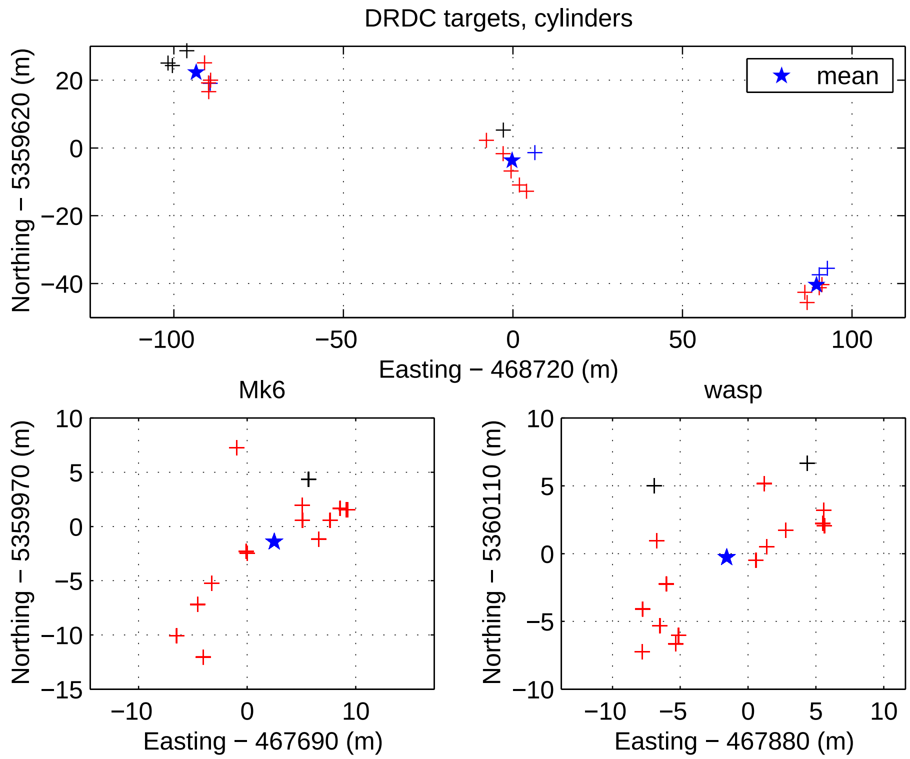

Figure 4: *Build 2 DRDC target positions and the mean position for each.*

2.1.3 DRDC Targets

The DRDC targets were not well positioned on deployment and subsequently only 4 of 12 were positively identified in the sonar data, with a fifth identified by proximity to two of the others. There are several candidate target images for 2 or 3 of the remaining 8 targets, but no definitive identification. The targets that have been identified are three cylinders linked in the most northerly of three lines of three (a Mk56 2.75 m long by 0.5 m diameter, a Mk36 1.75 m long by 0.4 m diameter and a Mk62 1.65 m long by 0.3 m diameter) and two moored targets farther to the north-west, a Mk6 (tethered sphere 0.5 m in diameter, 10 m above the seabed) and the WASP mooring (complex shape including several small floats tethered 10 m above the seabed). The two other strings of cylinders and Manta–like shapes and a second Mk6 have not been positively identified in the data. The second Mk6 was in fact not found for recovery and may have been moved by tidal currents after deployment. Though the buoyant elements of the moored targets are sometimes visible in the sonar data, these targets have been located at the positions of the anchor bases, as the floating parts will have significant variation in position due to elevation above the seabed and drift in the tidal current. Figure 4 shows the clustering of target positions and the mean positions for each of the DRDC targets.

2.2 Data Conditioning

During Build 2, most of the navigation information necessary for geocoding was not inserted into the sonar data files while they were being recorded. As one purpose of the trial was evaluation of a number of separate navigation systems, it was not known at the outset which of these would prove most accurate or reliable. Various navigation and operating condition data from the vehicle and towfish sensors were recorded independently in 3 types of log files while underway: "fast" files at a sample rate of 10 Hz, "slow" at 1 Hz, and "v_slow" at < 1 Hz, all in ASCII .csv format. The relevant information from these log files was later merged with the sonar data in post–processing. A program was written (in C by Vincent Myers) that modifies the sonar data files by matching up the individual sonar ping time stamps with the log file time entries to align the navigation data with the sonar data and then insert the corresponding values into the sonar ping headers. The navigation data inserted from the log files were: vehicle longitude, latitude, heading, speed, and fix time (hour, minute and second). The vehicle log entries used for these fields were: "vcc_dgps_longitude_fb", "vcc_dgps_latitude_fb", "vcc_dgps_course_true_fb", "vcc_dgps_speed_fb_mps", and fix times were parsed from "Time in English".

The sonar towfish inertial navigation system was not functioning reliably during Build 2, so towfish position was determined later using a simple layback calculation from the vehicle position and heading, by then integrated into the data files, the towfish depth and the amount of cable out [3]. Towfish depth had been stored in the sonar data files as they were collected and the cable length was read from the ASCII log files ("vcc_cable_scope_fb_m"). The towfish position calculation was written as an IDL script which was run at the time the sonar data were geocoded. All geocoding was done using DRDC Atlantic in–house software SIPS3 (Sonar Image Processing Software).

As the trial progressed there were processing issues changing daily which will be summarized by day in the following subsections. The survey tracks and the target arrays covered during the 7 days of operations are shown in Figure 5.

2.2.1 April 8th

The first day's sonar data files were written with some fields in the ping headers reverse–endian. These were overwritten with appropriate values while fixing the vehicle navigation fields. Though the file extensions designated the files as "5kd" format, they were actually "sdf" format (both are proprietary Klein formats).

2.2.2 April 9th

The reverse–endian problem in the ping headers was remedied where the files were being written sometime during this day. A survey was started at a site south–west of the target arrays, but was aborted when the towfish crashed and had to be recovered — none of the sonar data collected during this day has been geocoded.

2.2.3 April 11th

Of the two surveys on April 11th, there are some short gaps in the vehicle logs and apparent navigation problems during the first survey, and the sonar data was either not recorded or not recovered for the second survey. During the first survey, a combination of very high towfish altitude ($>$ 50 m in places) and low sonar signal level (transmit power or gain setting?) made for very poor sonar data quality. The southeast DRDC targets can not be identified in this data, even though the area where they were located was covered. The apparent navigation system problems occurred over the '88 Array, so that only half of the array targets were covered in the remaining usable data.

2.2.4 April 12th

The low signal level problem that occurred on April 11th was resolved before surveying started on April 12th. Up to this point in the trial, the Klein onboard altimeter output had been inserted into the sonar data files while underway. On April 12th, these values were replaced by the Doppler Velocity Log (DVL) altitude which was found to be about 20% too small. Subsequently during Build 3, it was determined that most (not all) of the DVL altitude error was due to an incorrectly applied correction factor for beam angle of $\cos(30°)$ that was already being applied by the DVL onboard processor. During Build 2, prior to identification of this problem, the DVL altitude values were simply multiplied in post-processing by 1.185, determined by viewing the raw sonar data with Klein's SonarPro software, and comparing with the range to the first bottom return.

2.2.5 April 15th

Targets from all three arrays were covered on this day. There were some minor data format issues. The format of the vehicle log files was changed to include 9 more columns and the sonar data files were now in "5kd" format. The towfish altitude (from the Klein altimeter) was noisy but usable with smoothing.

2.2.6 April 16th

Several partial and complete patterns were surveyed over and near the targets. The sonar data file format switched back to "sdf" files. From this point forward, there were no "surprises" in processing the sonar data.

2.2.7 April 17th and 18th

Sonar data from a deep tow survey on the 17th have not been geocoded. Surveys on both days covered the '88 Array and the DRDC targets.

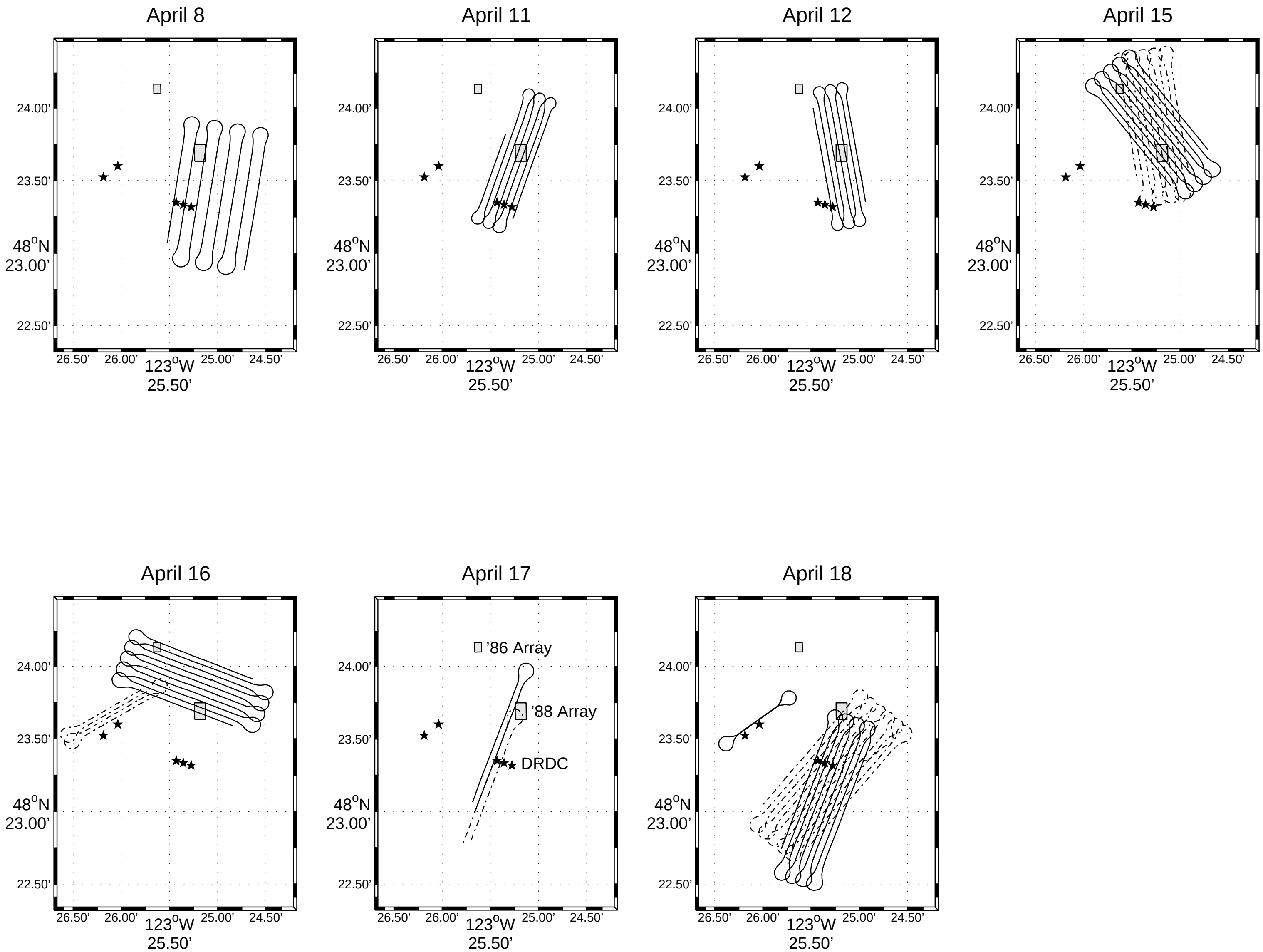

Figure 5: *Survey tracks from seven days of operations during Build 2, with target locations indicated (labelled on the April 17 plot).*

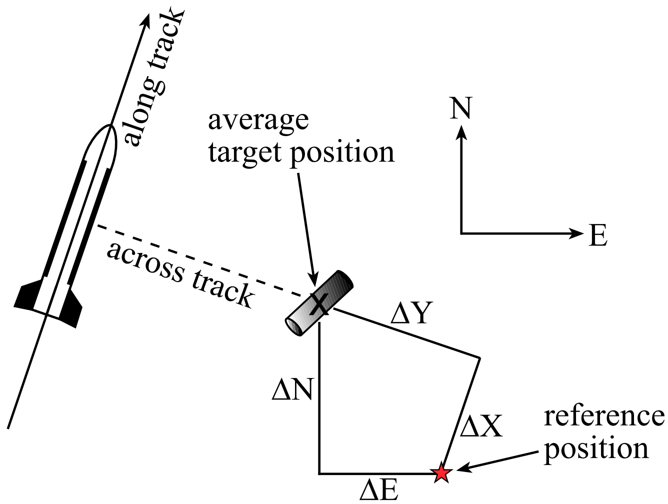

Figure 6: *Positioning errors for an average target location relative to a reference position, the DREP target position.*

3 Results of Target Positioning Analysis, Build 2

Positioning accuracy analysis has been undertaken using target locations in the geocoded survey images from 7 days of surveying. The aims of this analysis were to identify positioning errors introduced by the sonar data post–processing technique or perhaps by the vehicle navigation systems, and to assess the overall positioning accuracy for the trial.

Targets were located in the geocoded sonar imagery using the image display and annotation features of SIPS3. Lists of locations for each target were compiled from the survey data and statistics calculated using Matlab. Position deviations in the Easting and Northing directions, ΔE and ΔN, were determined for a target by comparing the average of the individual positions to the DREP target positions, as shown in Figure 6. More detailed analysis results, including along and across track positioning errors, ΔX and ΔY, are given in Annex 1.

Note that for any one target, gross persistent positioning offsets can not be identified by comparing the individual positions in a data set to the overall mean position in that same data set. It is assumed that the target has been passed at a variety of ranges and headings so that systematic errors in positioning will be averaged out in the overall mean position. Examination of the along and across track errors should reveal systematic errors such as a consistent inaccuracy in layback, for example.

Accepting this restriction on the interpretation of the results, at less than 5 m in any direction (see the tabulated results in Annex 1, Table 6), the root-mean-squared deviations fall within the project target positioning specifications of 10 m rms [1]. The across and along track deviations give no indication of any large

Table 2: *DREP '88 Array target positions, and deviations of Build 2 positions from the DREP positions.*

TARGET	EASTING	NORTHING	$\langle\Delta E\rangle$	$\langle\Delta N\rangle$	ΔE_{rms}	ΔE_{rms}
H1	468968.7	5360366.7	-2.9	-3.1	5.8	6.2
H2	468934.1	5360254.2	-6.0	-3.1	7.6	5.1
H3	468900.6	5360265.0	-7.3	0.4	8.8	5.1
H4	468888.7	5360214.6	-7.2	0.9	8.9	5.6
H5	468923.1	5360220.2	-5.6	0.6	7.9	6.1
H6	468957.3	5360191.7	-7.4	-2.8	8.9	4.6
V1	468967.0	5360347.4	-6.8	-2.9	8.3	5.4
V2	468909.9	5360355.7	-4.5	-1.6	6.6	5.3
V3	468911.2	5360285.1	-7.6	-1.6	9.2	5.1
V4	468872.9	5360289.8	-7.1	-1.5	8.5	4.4
V5	468868.2	5360265.1	-6.5	-1.9	8.1	5.7
V6	468908.7	5360170.4	-5.0	0.2	7.6	4.8
V7	468941.4	5360173.0	-6.3	0.5	8.6	6.9
RT	468925.4	5360383.2	-1.2	-4.0	4.3	5.8
Mean			-5.8	-1.4	7.8	5.4

systematic post-processing error (overall mean values of approximately a meter), which is encouraging given the simplistic straight–cable–with–vehicle–heading model used to determine towfish position. More detailed information on the positioning analysis for each target can be found in Annex 1 (Table 6 and Figures 14–18).

A few of the findings are worthy of comment and will be discussed in the following subsections.

3.1 '88 Array Target Positions

Table 2 lists the '88 Array target positions (UTM coordinates) previously determined by researchers at DREP. These have been quoted as having an accuracy of 1–3 m rms [2], though the origin of this estimate is uncertain. These positions are convenient as a reference, but have not been considered to be definitive. In Table 2, "$\langle\Delta E\rangle$" and "$\langle\Delta N\rangle$" are the means of the Easting and Northing deviations of the Build 2 positions from the DREP positions, and "ΔE_{rms}" and "ΔN_{rms}", the root–mean–square of the deviations for each target. The DREP target positions are consistently to the West of the Build 2 positions, which can also be seen in the scatter plots, Figures 14 and 15, Annex 1. Subsequently, results similar to this have been determined comparing '88 Array target positions in the Build 3 sonar data with the DREP target positions (see Section 5.1).

3.2 GPS Issues

During the first survey on April 12th, the target positions were consistently to the North–East of the mean positions by about 15 m. These can be identified as the farthest outlying points in the scatter plots of the '88 Array target positions shown in Figures 14 and 15 (Annex 1, symbols circled in red). The heading for this survey was almost South–North/North–South, so that the positioning deviations are almost equal in the across and along track directions. This indicates a possible GPS positioning problem. A further indication is that the number of GPS satellites received during this time period was at the minimum for the trial (6 or 7). Note that throughout the trial, the GPS vehicle positions were not being differentially corrected.

At this time, it has not been determined whether GPS latency affects the position information in the vehicle logs. At the average survey speed of 4 m/s, a one second latency would introduce a 4 m negative along track positioning error. There is no evidence of this in the results of the positioning analysis.

3.3 Straight-Cable Towfish Following Model

Towfish position was calculated in post–processing using a simple straight–cable model for layback. The towfish was assumed to follow directly behind the vehicle on a line determined by the current vehicle heading at a distance calculated from the current towfish depth (minus the depth of the towpoint on the vehicle) and the amount of cable out [3].

Excluding turns, where sidescan sonar data is generally considered to be unusable, it is expected that the very simple straight–cable model is most inaccurate where the towfish is approaching a turn and the vehicle has already entered it. Since the vehicle heading actually leads the towfish heading, this has the effect of yawing the swath prior to the towfish negotiating the turn and misplacing the towfish to the outside of any turn since the towfish is assumed to be directly behind the vehicle at the present vehicle heading. Target images were not identified in the sonar data around turns, though several surveys covered the target arrays nearing turns. Figure 16, Annex 1, shows several cases of targets in the '86 Array which are located very near a turn (symbols circled in green, targets B1, B2, B3 and B5). In this case, the along track component of the position deviation is much larger than the across track component, though this would vary depending on factors such as the amount of cable out and how the vehicle negotiates the turn (the amount of cable curvature). Overall, the results show the along track error is larger than the across track error (1.2 m overall mean along track and 0.6 m overall mean across track), though both are small. The majority of targets were located along the straight sections of the vehicle track where the towfish apparently does follow closely to what is predicted by the simple model.

4 Summary of Survey Data, Build 3

Build 3 was also staged from Esquimalt, B.C., in October–November of 2002. Similar to Build 2, the RMS was in operation for about 60 hours of mission time, collecting almost 35 hours of sidescan sonar data.

The sidescan sonar surveys conducted during Build 3 are summarized below in Table 3. "Date" is the day late in October or early in November. The towfish Inertial Navigation System was not functioning properly on Oct 24 and 25, hence the sonar data from that day were not geocoded, and the surveys on Oct 29 (deep tows) and Nov 1 did not cover the target arrays. On two days (Oct. 28 and Nov. 1), there were surveys that were completed in two parts. A total of 337 targets have been identified in 9 geocoded surveys. Figure 7 shows the survey vehicle tracks for Oct 24, 25, 28, 30, 31 and Nov 4.

Table 3: *Summary of sonar surveys conducted during Build 3.*

DATE	SURVEYS	SURVEYS GEOCODED	TARGETS LOCATED
24	1 partial (LoRes 150 m)	0	-
25	1 (HiRes 75 m)	0	-
28	1, 1/2 + 1/2 = 1 (HiRes 75 m)	2	58
29	deep tows	0	-
30	2 (HiRes 75 m)	2	32
31	3 (HiRes 75 m)	3	147
1	1/2 + 1/2 = 1, 1 (HiRes 75 m, neither over tgts)	0	-
4	3 (HiRes 75 m, 2 over tgts)	2	100
5	Demonstrations	0	-
6	Demonstrations	0	-
		9	337

4.1 Target Arrays

As during Build 2, most surveys centred around an area that covered the '88 Array. Other targets were also deployed prior to the trial, which will again be referred to as the DRDC targets, but note that some of these are different targets than were deployed during Build 2 and all targets were redeployed in new locations. It is assumed that there was no change in the positions of the '88 Array targets (see Figure 3). The '86 Array was not surveyed.

The DRDC targets were deployed in one long string of 10, containing 8 cylinders of varying sizes (2 Mk25, 1 Mk36, 1 Mk52, 2 Mk56 and 2 Mk62) and 2 Manta shapes. The relative locations and scatter of the geocoded positions of the targets in the DRDC array are shown in Figure 8. The DRDC Array was centred 300 m north–east of the centre of the '88 Array.

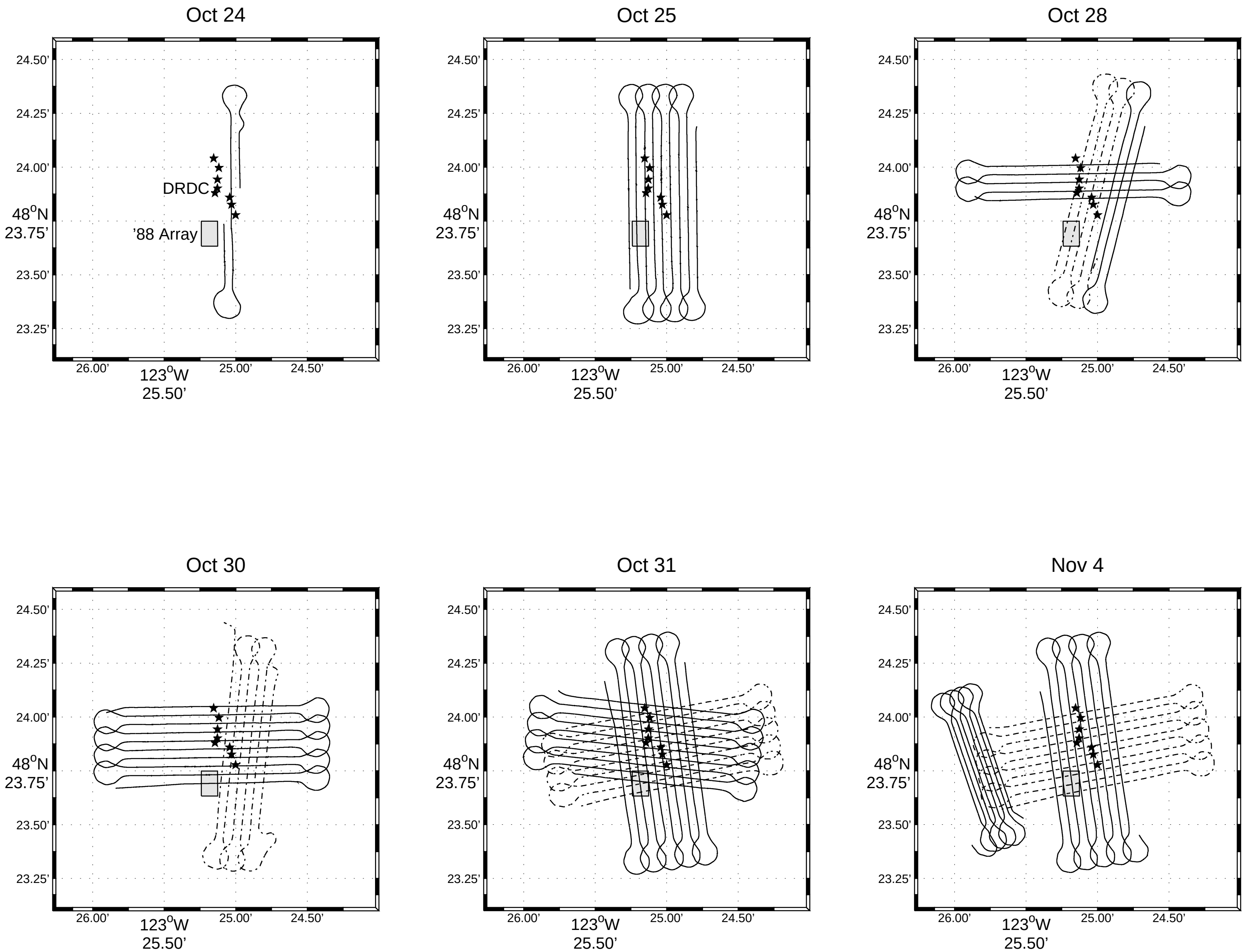

Figure 7: *Survey tracks from six days of operations during Build 3, with target array locations labelled on the Oct 24 plot.*

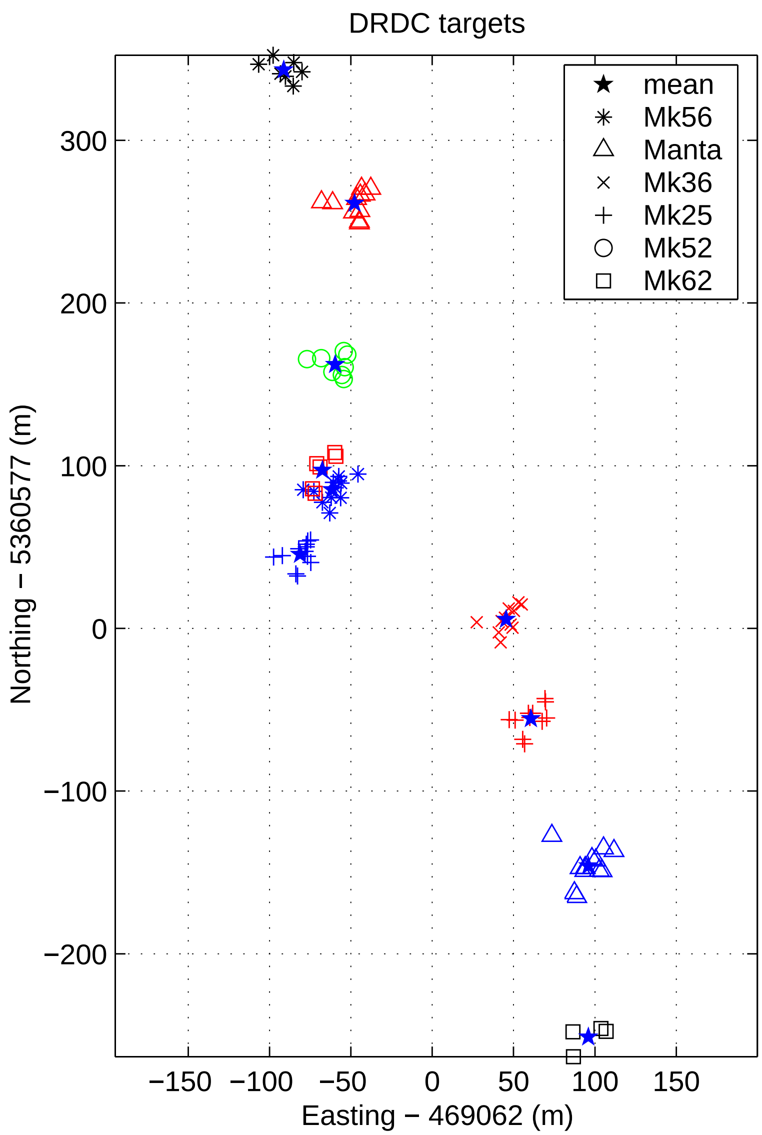

Figure 8: *Build 3 DRDC target positions and the mean position for each.*

4.2 Data Conditioning

The Build 3 trail was a better test of the towfish navigation system (INS) than Build 2. Towfish position and heading, as determined by the sensor suite comprising the INS, were available for geocoding sidescan data directly (rather than calculating towfish position from the simple straight–cable model). Though generally stable, there were some issues with wander of the INS towfish positions, which will be discussed later. Early in the trial, INS positions and headings were extracted from the vehicle logs (using a Matlab script supplied by Andrew Westwell–Roper, MacDonald Dettwiler and Associates), but by the end of the trial on Nov 4, these positions were being correctly incorporated in the sonar data files as written and it was possible to geocode the sonar data as received without modification.

It is more convenient to summarize the data conditioning issues by topic, as in the following subsections.

4.2.1 Altitude and Sound Speed

As mentioned earlier (in the discussion of data conditioning issues on April 12th, Build 2), the DVL altitude in the vehicle logs was low by almost 20% at the beginning of the trial. It was discovered that a slant range–to–vertical distance correction for the 30° beam angle was incorrectly being reapplied. This was remedied on October 31. In addition, the DVL default sound speed of 1500 m/s was initially being used in the range calculations by its onboard processor. From October 30 onward, the daily measured sound speed was used. Prior to these improvements, it was found to be most convenient to simply multiply the DVL altitude values by a factor of 1.185, determined by comparison with the first bottom return in the raw sonar data. Note that applying a factor of 1/cos30° (= 1.155) did not bring the low altitude values up to what would be expected from the raw sonar data, i.e. the DVL altitude values were consistently low. A reason for this has not been determined beyond speculation about sound speed values, or the effect of towfish roll and pitch motions on the (proprietary) algorithms used by the DVL onboard processor to determine range–to–bottom along the beams.

4.2.2 Heading

Heading information was available from several sensors on both the towfish and vehicle. Figure 9 illustrates examples of the output from some of these sensors through a turn. The "course true" is determined from the vehicle course by the GPS processor and has been considered to be accurate and reliable. The vehicle heading from the OCTANS system compares well with the GPS–determined heading. Two of the three towfish sensors report less reliable heading. The Watson magnetic compass heading seems to be offset by about –20°, and the DVL magnetic compass heading has a similar offset with an additional offset of –105° in a band between about 315° and 360°. The towfish INS heading appeared to be the most reliable of

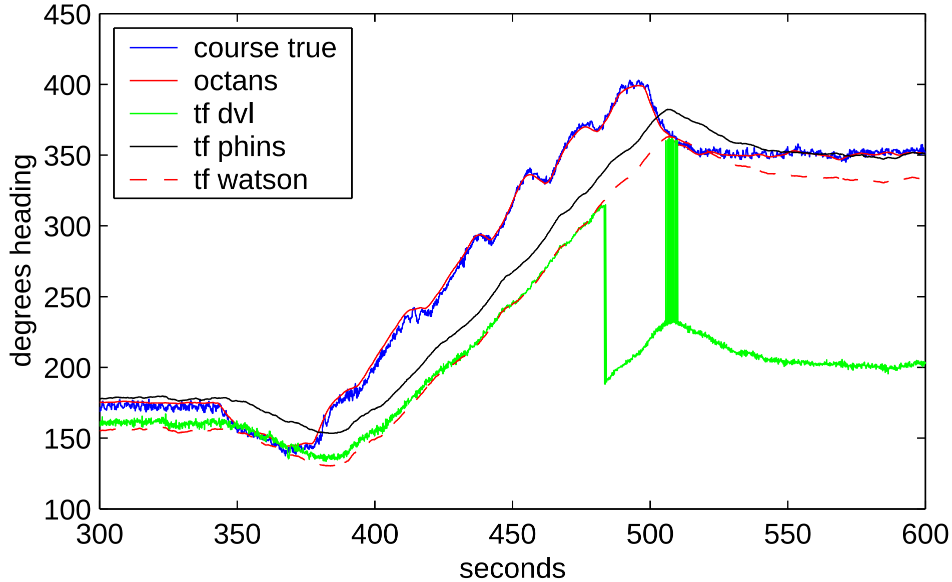

Figure 9: *Output of the various heading sensors on the vehicle and towfish through a turn (Oct 31).*

the towfish sensors and this was used when geocoding all Build 3 sonar data, with the exception of one case where some vehicle logs are missing and the GPS course true was used instead (last leg of second survey on Oct 28). Note that a time lag between changes in vehicle heading and towfish heading, as seen in Figure 8, is what would be expected since the vehicle is negotiating the 180° turn with approximately 100 m of cable to the towfish. This illustrates one reason why the straight–cable towfish following model gives incorrect towfish position near turns.

4.2.3 Towfish and Vehicle Position

The sidescan sonar data for Build 3 were geocoded using the towfish position determined by the INS system. During part of the trial, towfish positions determined using a Global Integrated Buoy System (GIBS) were also available, as well as positions determined using a Short Baseline (SBL) acoustic towfish tracking system. These additional sources of navigation information have not been used in this analysis, however MDA (Westwell–Roper) has analysed positioning accuracy using combinations of the various towfish position measurements [2] and found the resulting rms target positioning error to be comparable to the results for Build 2 that are presented here (< 5 m). Recall that the GPS–determined vehicle position during both Builds was not differentially corrected.

5 Results of Target Positioning Analysis, Build 3

The Build 3 target positions have been analyzed similarly to the Build 2 data, with the same aims in mind. As mentioned, the Build 3 sonar data was geocoded using the INS navigation data for the towfish position, in contrast to the Build 2 data where a simple straight–cable model was used to determine towfish position from vehicle position.

Table 7, Annex B, lists the mean positions and deviations (rms Easting and Northing and mean and rms across and along track) for the target positions in the Build 3 processed data. The rms deviations in the Easting/Northing and along/acrosstrack directions are equivalent at about 8 m. This indicates there was no systematic consistent positioning error, though as before, bear in mind that gross positioning offsets will not be evident when comparing to the mean target positions. That the magnitude of the rms deviations are larger for Build 3 than Build 2 is a source of concern which will be discussed in following sections.

Table 4: *Deviations of Build 3 '88 Array target positions from the DREP positions.*

TARGET	$\langle \Delta E \rangle$	$\langle \Delta N \rangle$	ΔE_{rms}	ΔN_{rms}
H1	-7.2	3.4	8.6	8.3
H2	-7.1	2.4	8.3	8.5
H3	-8.4	3.8	8.2	8.5
H4	-9.1	6.1	10.1	8.5
H5	-7.6	3.6	9.6	8.8
H6	-10.8	0.3	11.4	9.1
V1	-7.4	3.4	7.1	8.9
V2	-1.4	3.6	11.5	8.7
V3	-10.0	2.5	8.7	8.4
V4	-10.7	3.9	9.4	8.7
V5	-9.5	3.4	8.6	8.1
V6	-6.8	1.3	11.1	8.5
V7	-10.4	2.5	10.5	9.1
RT	-0.0	1.5	10.2	8.1
Mean	-7.6	3.0	9.5	8.6

5.1 '88 Array Target Positions

Table 4 lists the deviations of the Build 3 mean '88 Array target positions from the DREP positions that were listed in Table 2. The Build 3 mean positions are consistently to the West and North of the DREP '88 Array positions. Figure 10 illustrates the mean positions for each target for both Builds, with Easting and Northing error bars equal to 1 standard deviation in each direction. Each mean position is the average of 10 to 15 positions. There appears to be consistent offsets

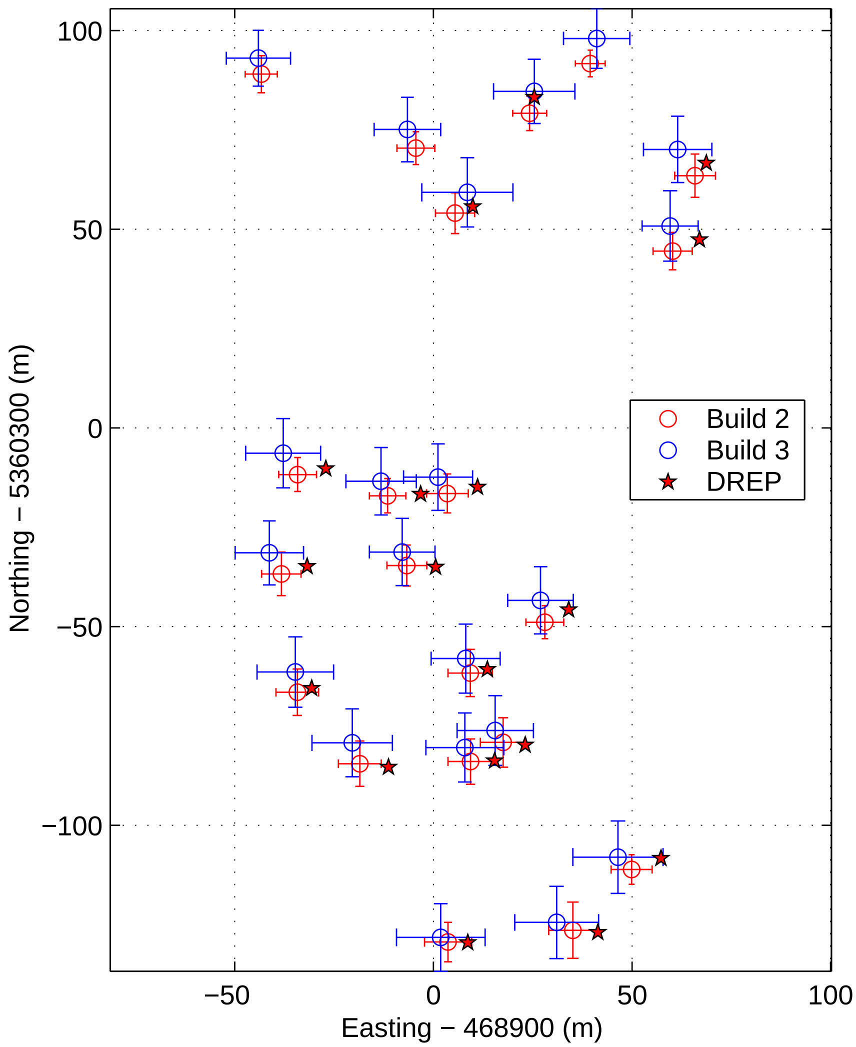

Figure 10: *Comparison of Build 2 and 3 '88 Array mean target positions (error bars are +/- 1 standard deviation) and DREP positions.*

between the average target positions between the two Builds and between the Builds and the DREP positions. The error bars show smaller variability among the Build 2 target positions. This will be discussed further in the following section.

5.2 INS Towfish Positioning vs. Straight–Cable Model

As noted, the variation of the target positions determined from the INS towfish navigation data was larger than for positions determined from the straight–cable model. To help determine a reason for this, the survey data from Oct 31 has been reprocessed using the straight–cable model for towfish position, and the targets located in the resulting geocoded images. Figure 11 illustrates the scatter in the position deviations for the '88 Array target positions in the two sets of geocoded data, rela-

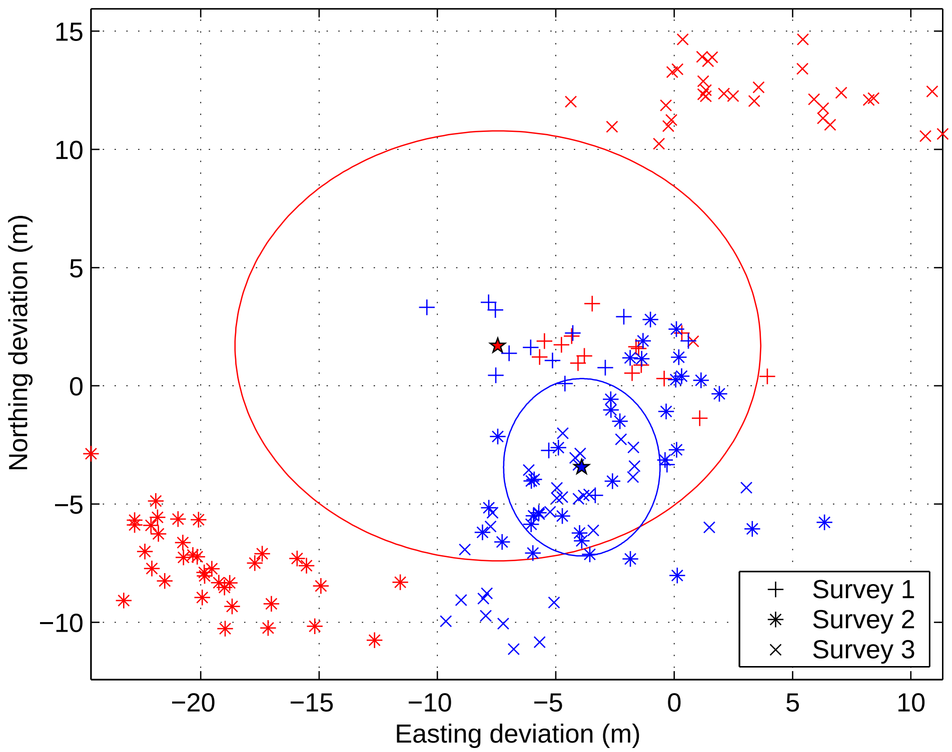

Figure 11: *Comparison of October 31 '88 Array target position deviations for sonar data geocoded using INS (red symbols) and straight-cable model (blue symbols) towfish positions. All positions are relative to the DREP '88 array positions.*

tive to the DREP positions. The ellipses have axes equal to 2 standard deviations in the Easting and Northing directions and are centred on the overall mean deviations shown by the star symbols. The target locations in the INS geocoded data (red symbols) cluster in three groups which correspond to the three surveys that day. In contrast, the straight–cable model positions (blue symbols) group more closely, with less separation between the surveys. The mean deviation of the straight–cable model positions is to the South–East of the mean for the INS geocoded positions, closer to the Build 2 results (see Figure 10).

Figure 12 shows the distance between the vehicle (GPS position) and the towfish (as determined by the INS) as the vehicle is negotiating the 2nd, 3rd and 4th legs of the second survey on Oct 31. Also shown for comparison are the cable length and the horizontal component of that length (layback), determined using the towfish depth, part of the straight–cable following model. During the 2nd and 4th roughly Northward legs, the distance between the vehicle and INS towfish position is larger than the length of cable out, and during the Southward leg, is significantly less than the calculated layback. This explains the Southerly offset of the cluster of target positions for that survey shown in Figure 11. Compared to the vehicle track when plotted in plan view, shown in Figure 13, the towfish track shows a rotation of

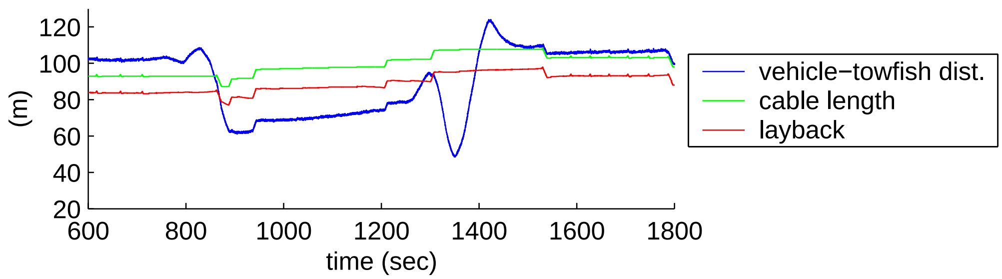

Figure 12: *Distance between the vehicle (GPS position) and towfish (INS position) through legs 2, 3 and 4 of survey 2, Oct 31, with cable length and layback shown for comparison.*

the entire survey pattern by a few degrees clockwise, which explains the Westerly offset of the cluster. Though the towfish appears to be tracking the vehicle more closely at the North end of the lines, the distance between the vehicle and towfish is incorrect. The overshoots in vehicle–towfish separation during the turns (800–900 and 1300–1400 s, Figure 12) may indicate an INS system tuning problem, such that positioning error was accumulated through turns. This behaviour has been referred to as "drift" of the INS. "Figure–8" patterns intended for INS alignment were run prior to each of the surveys on Oct 31, but this does not seem to have been effective.

An analysis of the '88 Array target locations by MDA (Westwell–Roper) using raw sonar and navigation data shows the positioning error with the INS to be significantly larger at > 30 m rms relative to the DREP positions. It is unclear why this is the case. That analysis was performed with fewer target locations, and not with geocoded data. Some of the individual target locations in the MDA analysis are more than 100 m from the DREP locations, where the same sonar data when geocoded for the analysis presented here have deviations < 10 m. Their analysis has the value, however, of being more representative of a truly operational situation, where post–processed (geocoded) data will not be available in real time.

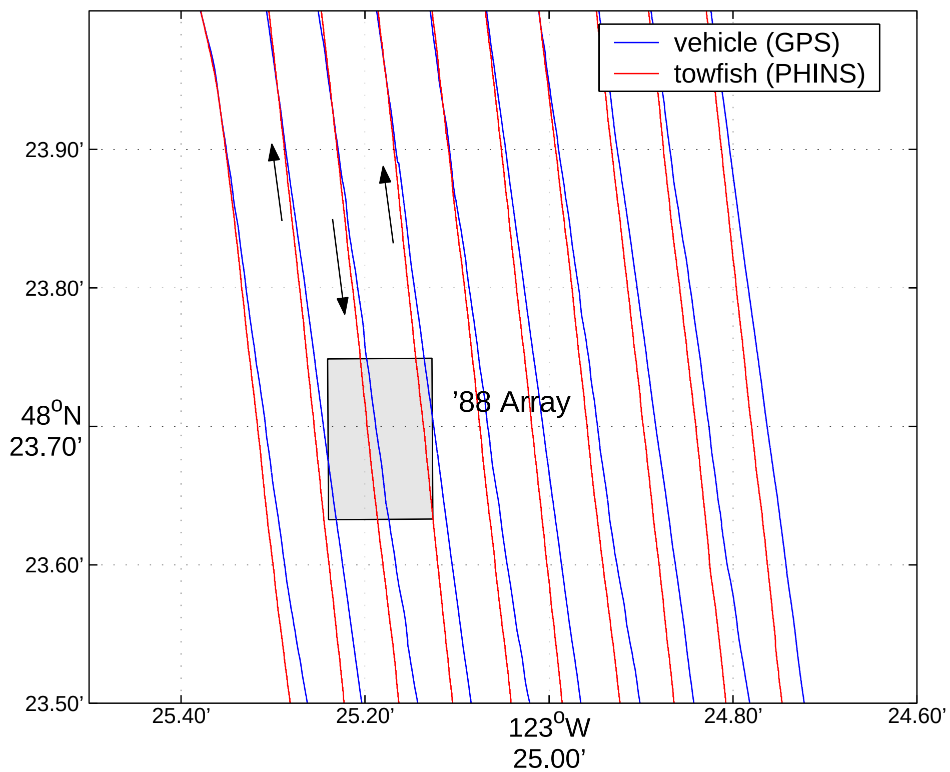

Figure 13: *Vehicle and towfish tracks during survey 2, Oct 31. The vehicle heading on the 3 legs shown in Figure 12 is indicated by the arrows.*

6 Conclusions

The overall positioning errors determined from geocoded data for the two Builds are summarized in Table 5, where "#" refers to the number of target image positions included in the statistical calculations, "ΔE_{rms}" and "ΔN_{rms}" refer to the rms positioning error in the Easting and Northing directions, and "ΔX_{rms}" and "ΔY_{rms}" refer to the rms positioning error in the along and across track directions.

Table 5: *Overall target positioning error determined for Builds 2 and 3.*

	# OF TGTS	ΔE_{rms}	ΔN_{rms}	ΔX_{rms}	ΔY_{rms}
Build 2	597	5.0	5.0	4.8	4.8
Build 3	337	8.5	7.7	8.5	7.6

For a Build, the positioning errors were calculated relative to the mean of all the positions in the data set for that target for that Build. This means that gross persistent positioning errors will not be evident.

The Build 2 sonar data was geocoded using a simple straight–cable model to determine towfish position. This has given marginally better positioning accuracy for the targets than the towfish INS in Build 3, though both sets of results fall well within the initial project criteria of < 10 m rms. The larger deviation of the Build 3 positioning results is probably due to the observed wander of the INS, as discussion in Section 5.2. That the along/across track positioning errors are not significantly different than the Easting/Northing errors indicates there is no consistent systematic error, and in particular for Build 2, there is no significant additional error introduced by using the straight–cable model for towfish position. The GPS–determined vehicle position for both Builds was not differentially corrected, and the magnitudes of the target positioning errors are comparable to uncorrected GPS positioning error.

That the straight–cable model appears to perform better for positioning the targets is not the point here. Both methods yield processed sonar data products that meet the original project specifications. This degree of positioning accuracy is difficult to achieve with any current Inertial Navigation System technology. It is most surprising that the straight–cable model performs as well as it does, and perhaps such a method can be considered as a real–time "sanity check" while the INS is in operation.

7 References

1. Remote Minehunting System Technology Demonstrator Contract, Annex C, Technical System Concept (Draft), Technology Demonstrator for Remote Minehunting System, PWGSC File No. 03SV.W8477–9–0010.

2. Build 3 Trials Report for Remote Minehunting System (RMS) Technology Demonstrator (TD), MacDonald Dettwiler and Associates Ltd., July 2003.

3. Crawford, A. M., 2002, Methods for Determining Towfish Location for Improvement of Sidescan Sonar Image Positioning, DREA TM 2002–019, Defence R&D Canada – Atlantic.

Annex 1: Target Position Data, Build 2

Table 6 contains position information for all targets from data geocoded using the straight–cable model for towfish position. The columns are: the number of instances located in the sonar data (#), the mean Easting and Northing position ($\langle E \rangle$, $\langle N \rangle$), the root–mean–squared deviations from the mean position (ΔE_{rms}, ΔN_{rms}).

Along and across track errors were calculated by resolving the Easting and Northing deviations of individual target locations from the mean target location into components parallel and perpendicular to the mean vehicle heading through the 1–minute data file containing the target. Table 6 lists the mean along and across track deviations ($\langle \Delta X \rangle$, $\langle \Delta Y \rangle$), and the root–mean–squared along and across track deviations (ΔX_{rms}, ΔY_{rms}). Negative along track error places a target behind the mean position, and negative across track error is to the port side.

Following Table 6 are scatter plots of the target positions relative to the mean positions, and for the '88 Array targets, the DREP surveyed positions (Figures 14–18). The red star symbols denote the DREP survey position where applicable, and the green stars denote the mean target location at (0,0) since the axes units (meters Easting and Northing) are made relative to that position.

Table 6: *Target positions determined from processed sonar images, Build 2.*

TARGET	#	$\langle E\rangle$	$\langle N\rangle$	ΔE_{rms}	ΔN_{rms}	$\langle\Delta X\rangle$	$\langle\Delta Y\rangle$	ΔX_{rms}	ΔY_{rms}
B1	9	468354.8	5361144.7	4.0	6.2	1.8	0.1	6.6	3.1
B2	9	468355.2	5361125.9	3.4	6.4	1.2	0.8	6.4	3.4
B3	10	468361.9	5361126.9	4.4	6.9	1.0	2.3	6.2	5.4
B4	10	468382.1	5361141.2	5.3	4.4	3.8	2.4	4.9	4.8
B5	10	468368.2	5361125.0	4.5	6.7	0.5	2.6	5.9	5.4
B6	10	468373.2	5361114.3	4.1	5.5	0.9	2.8	4.3	5.3
B7	9	468379.6	5361108.7	4.4	4.7	1.5	2.8	4.3	4.8
B8	10	468397.0	5361074.3	3.9	2.4	0.6	2.1	2.0	4.1
B9	10	468401.2	5361061.9	3.9	2.6	0.5	2.3	2.2	4.1
B10	10	468409.8	5361048.5	3.3	2.4	0.5	2.1	2.0	3.6
B11	10	468412.4	5361041.3	3.4	2.4	0.6	2.2	2.0	3.6
B12	9	468393.7	5361116.1	4.3	2.7	-2.2	2.2	3.6	3.9
B13	9	468409.0	5361080.2	4.0	2.4	0.8	2.0	2.4	4.0
B14	9	468413.1	5361083.2	4.0	2.4	0.7	2.0	2.4	4.0
B15	8	468425.1	5361061.6	4.0	2.2	-0.2	1.9	2.1	4.1
B16	9	468430.7	5361047.9	3.6	2.6	0.7	2.1	2.8	3.5
H1	18	468965.9	5360363.5	5.0	5.3	-0.4	0.4	4.8	5.5
H2	19	468928.1	5360251.1	4.6	4.0	0.8	-0.5	4.1	4.5
H3	22	468893.3	5360265.4	4.9	5.0	-0.1	0.3	4.9	5.0
H4	19	468881.5	5360215.5	5.3	5.5	1.8	0.7	5.5	5.4
H5	16	468917.6	5360220.8	5.6	6.0	1.4	0.5	5.9	5.7
H6	19	468949.9	5360188.9	5.0	3.6	1.5	-1.7	4.2	4.6
V1	20	468960.2	5360344.5	4.8	4.6	0.2	-0.2	4.5	4.9
V2	23	468905.4	5360354.1	4.8	5.0	0.7	0.1	5.0	4.8
V3	23	468903.5	5360283.5	5.1	4.8	0.9	0.0	4.7	5.2
V4	21	468865.8	5360288.3	4.6	4.2	1.3	1.0	4.1	4.7
V5	21	468861.7	5360263.3	4.9	5.4	1.2	0.5	5.3	5.0
V6	17	468903.7	5360170.6	5.8	4.8	1.0	0.4	4.5	6.0
V7	17	468935.1	5360173.6	5.9	6.9	2.6	-0.7	6.7	6.1
RT	22	468924.2	5360379.2	4.2	4.2	0.7	0.3	4.3	4.2
poslog	18	468909.4	5360216.0	5.5	5.5	1.6	0.2	5.5	5.5
steel1	19	468909.3	5360238.3	5.4	5.8	0.8	0.6	5.6	5.7
steel2	21	468888.5	5360282.9	4.5	4.2	0.6	0.7	4.1	4.6
stove	18	468865.7	5360233.5	5.2	5.7	1.9	0.7	5.7	5.2
box1	17	468895.6	5360370.4	4.6	4.0	0.5	0.1	4.2	4.4
box2	9	468939.5	5360391.7	3.5	3.2	1.3	-1.2	3.7	3.0
box3	15	468856.7	5360389.1	3.9	4.5	-0.3	-1.0	4.0	4.5
Mk56	8	468626.6	5359642.2	4.9	3.8	0.5	-0.8	2.5	5.7
Mk36	7	468719.7	5359616.3	4.5	6.2	1.9	-1.2	5.1	5.7
Mk62	6	468809.6	5359579.6	2.4	3.3	0.5	-0.2	3.8	1.4
Mk6	15	467692.5	5359968.6	5.3	5.1	5.7	1.0	6.8	2.8
WASP	16	467878.4	5360109.7	5.2	4.3	5.7	0.4	6.2	2.8
ALL				5.0	5.0	1.2	0.6	4.8	4.8

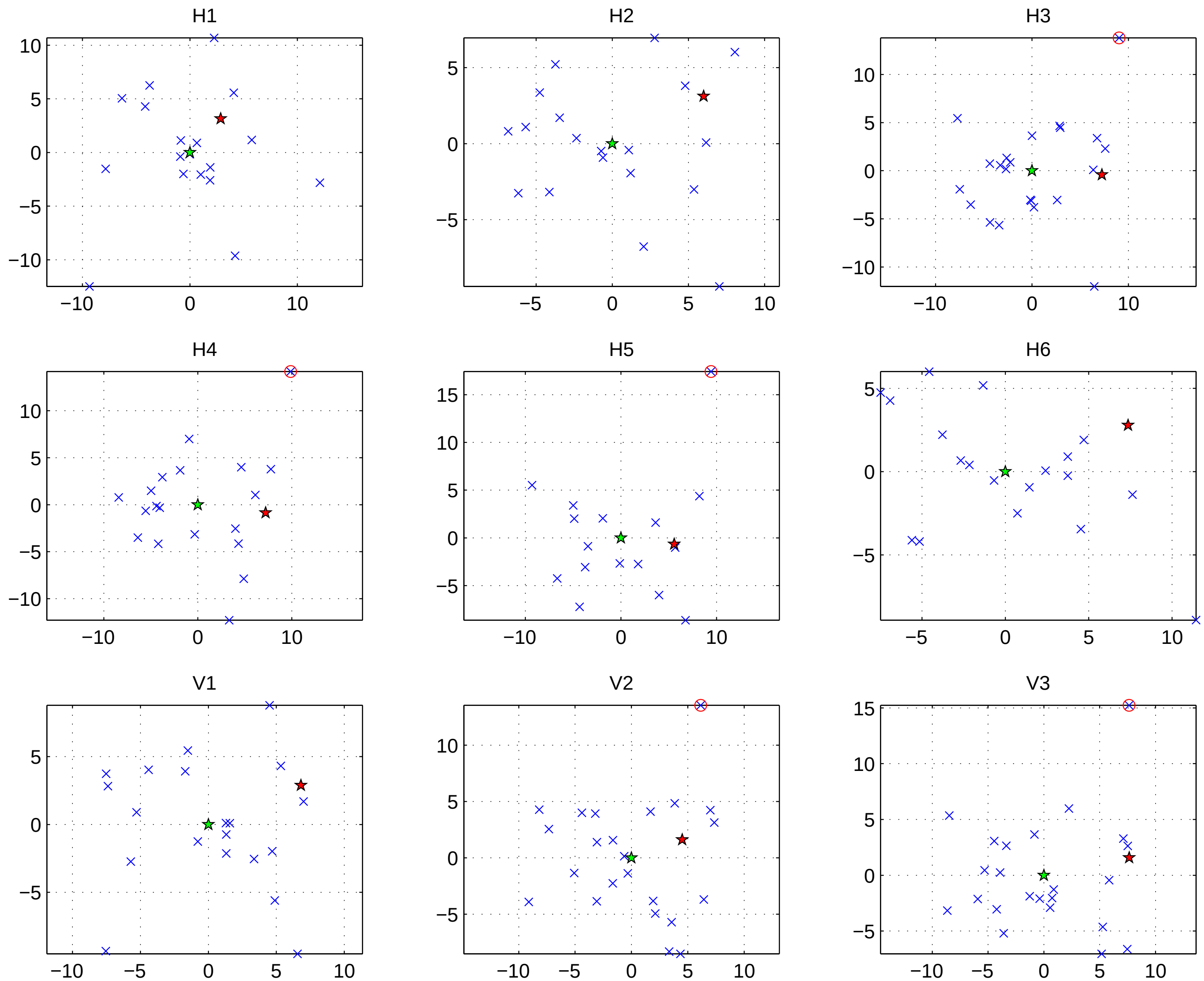

Figure 14: *Scatter plots of target positions around the mean position (targets H1–H6, V1–V3). Red circled positions are from the April 12th survey (see discussion, section 3.2).*

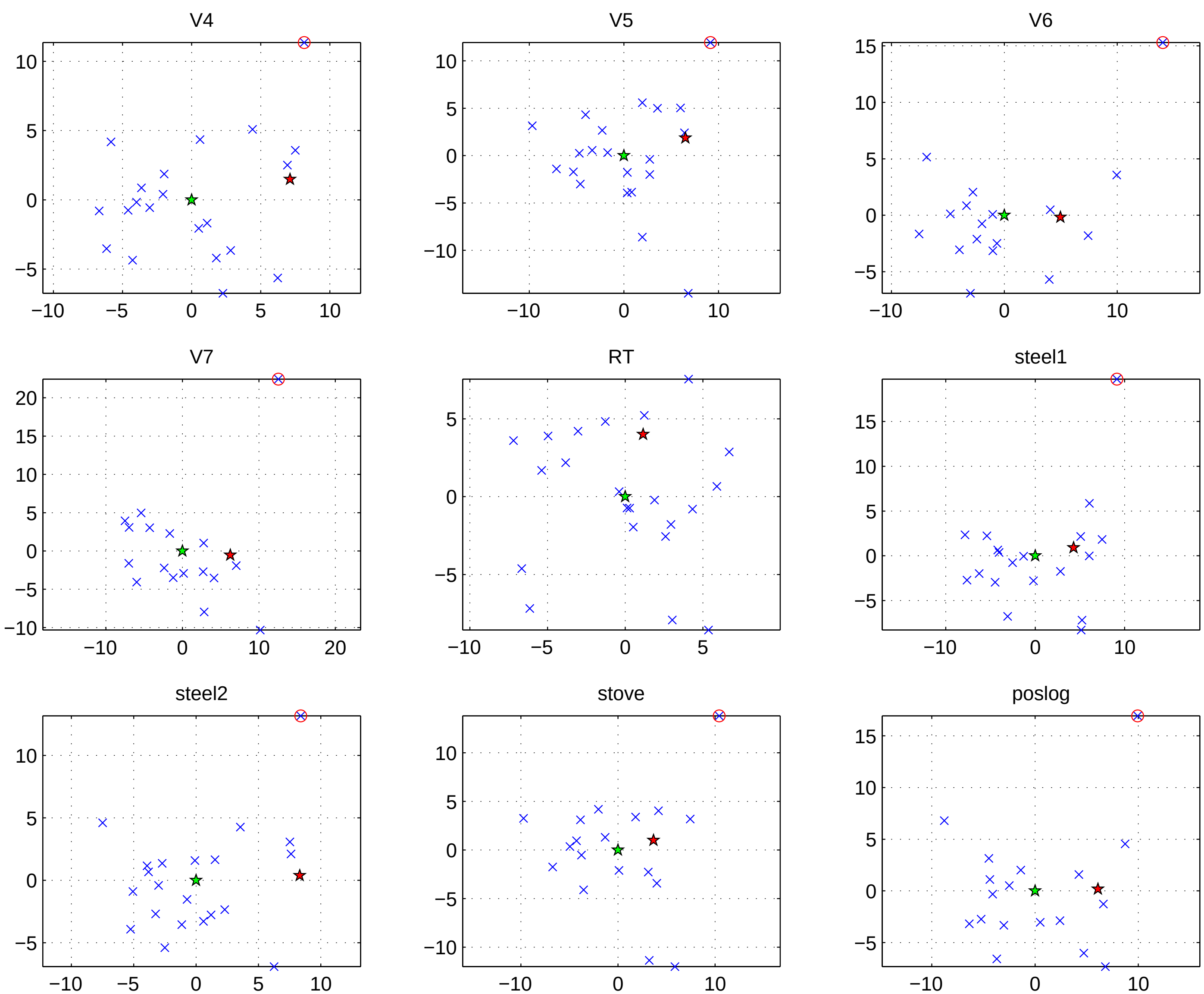

Figure 15: *Scatter plots of target positions around the mean position (targets V4–V7, RT, steel1, steel2, stove and poslog). Red circled positions are from the April 12th survey (see discussion, section 3.2).*

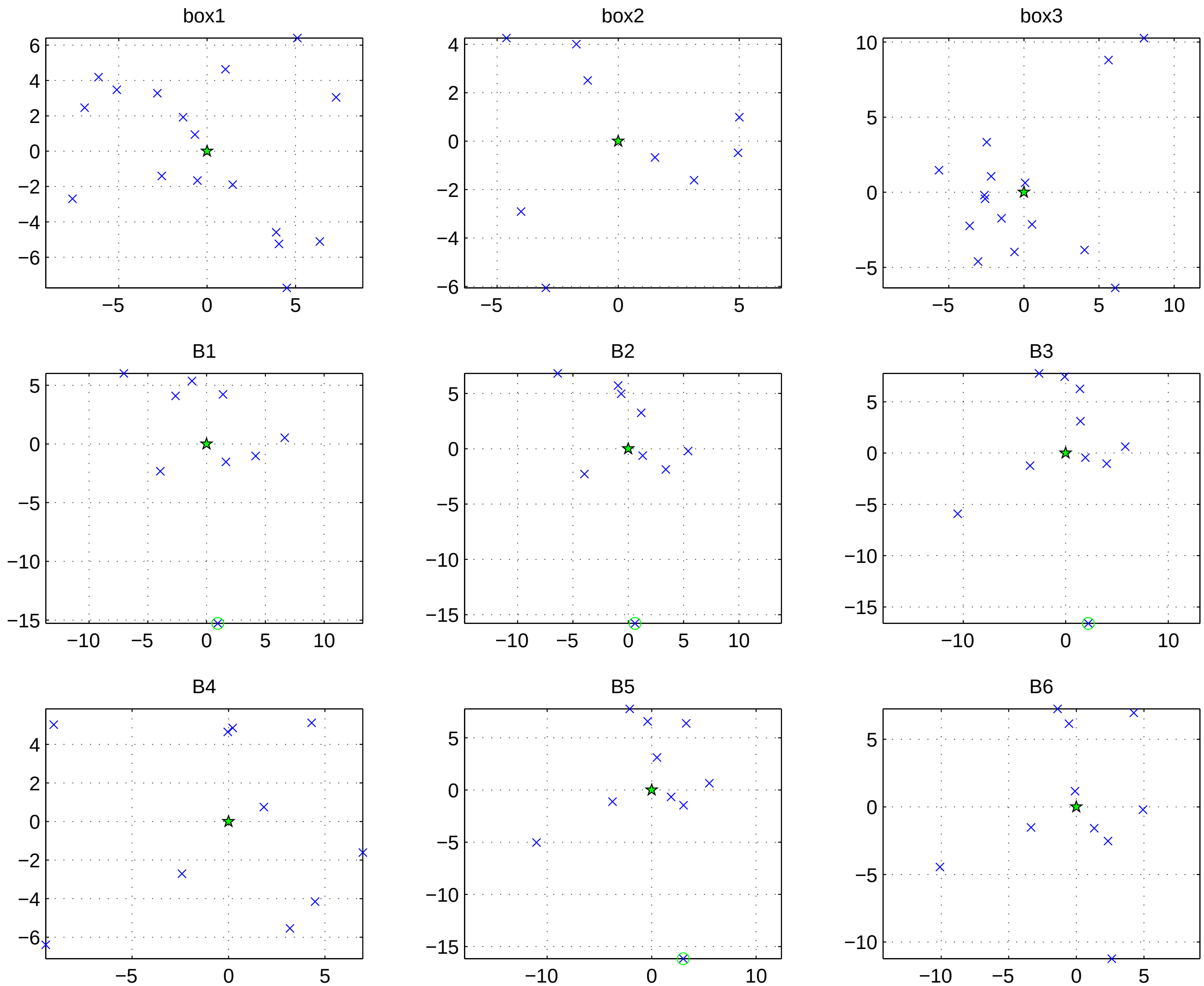

Figure 16: *Scatter plots of target positions around the mean position (targets box1, box2, box3, B1–B6). Green circled positions are from survey data near a turn (see discussion, section 3.3).*

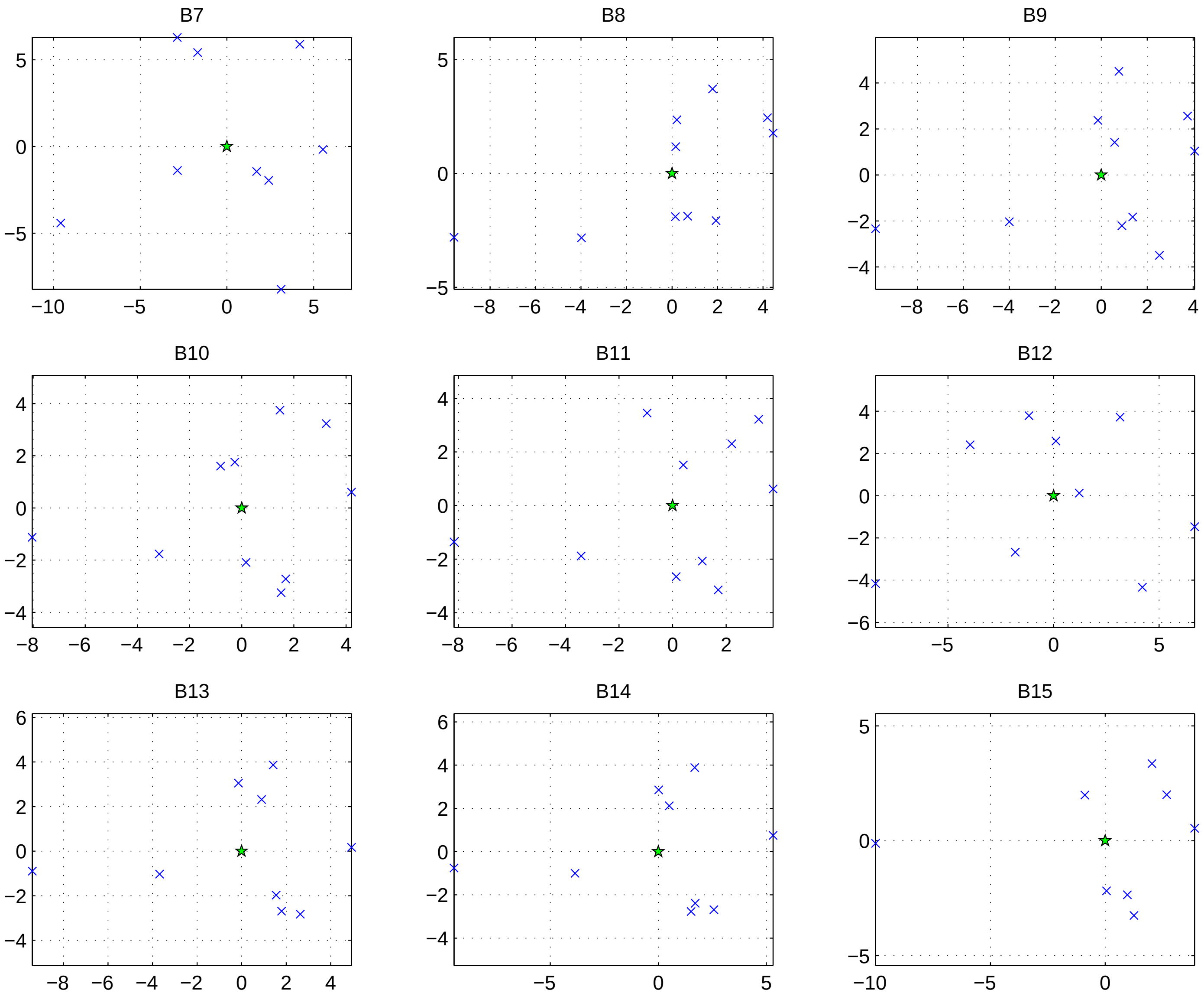

Figure 17: *Scatter plots of target positions around the mean position (targets B7-B15).*

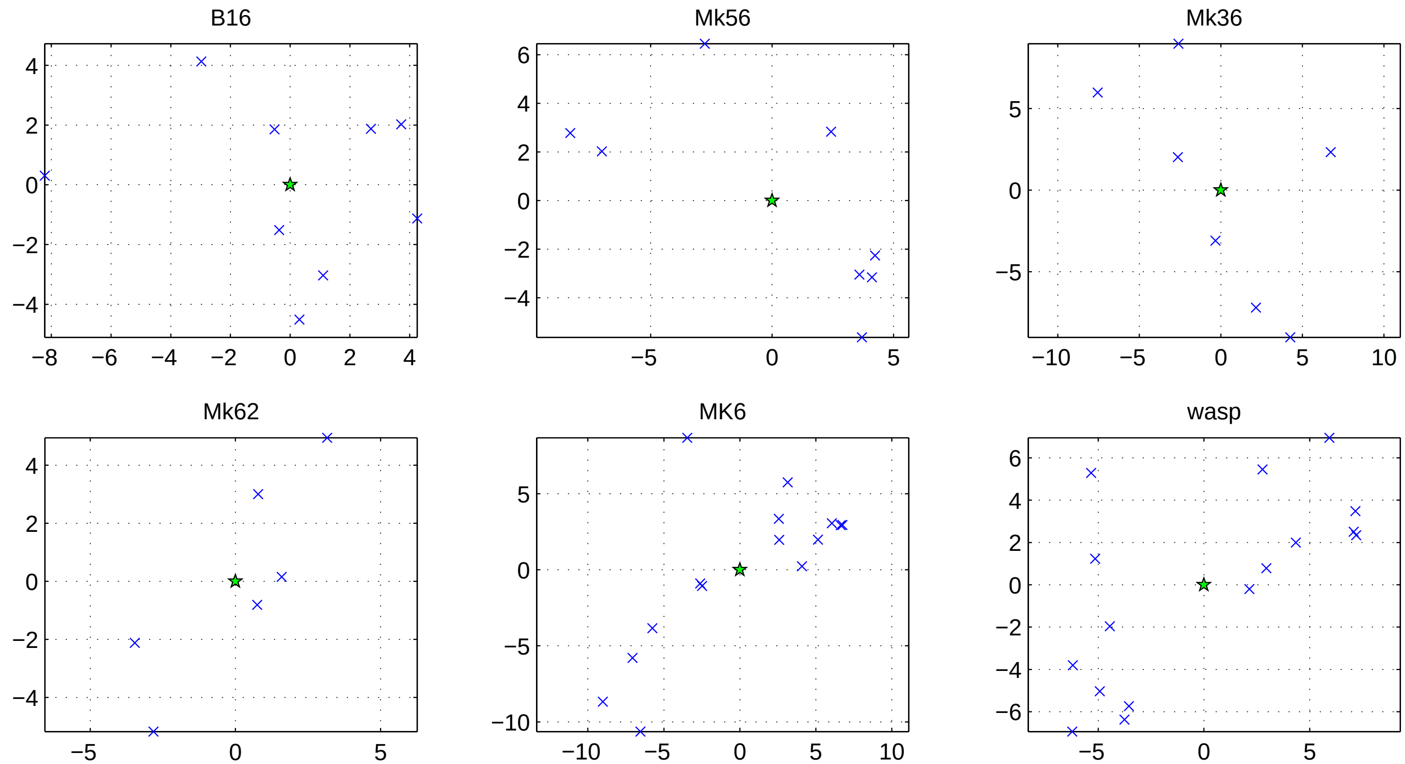

Figure 18: *Scatter plots of target positions around the mean position (targets B16, Mk56, Mk36, Mk62, Mk6 and WASP mooring).*

Annex 2: Target Position Data, Build 3

Table 7 contains position information for all targets from data geocoded using PHINS towfish position. The columns are: the number of instances located in the sonar data (#), the mean Easting and Northing position ($\langle E \rangle$, $\langle N \rangle$), the root-mean-squared deviations from the mean position (ΔE_{rms}, ΔN_{rms}), the mean along and across track deviations ($\langle \Delta X \rangle$, $\langle \Delta Y \rangle$), and the root-mean-squared along and across track deviations(ΔX_{rms}, ΔY_{rms}), calculated as described in Annex 1. Negative along track error places a target behind the mean position, and negative across track error is to the port side.

Following Table 7 are scatter plots of the target positions relative to the mean positions, and for the '88 Array targets, the DREP surveyed positions (Figures 19–22). All axes units are meters Easting and Northing made relative to the mean position.

Table 7: *Target positions determined from processed sonar images, Build 3.*

TARGET	#	$\langle E \rangle$	$\langle N \rangle$	ΔE_{rms}	ΔN_{rms}	$\langle \Delta X \rangle$	$\langle \Delta Y \rangle$	ΔX_{rms}	ΔY_{rms}
H1	12	468961.5	5360370.1	8.3	8.0	-0.1	-0.8	9.6	6.3
H2	11	468927.0	5360256.6	7.9	8.1	0.6	0.6	7.6	8.4
H3	11	468892.2	5360268.8	7.9	8.1	0.5	0.6	7.1	8.8
H4	10	468879.6	5360220.7	9.6	8.1	0.8	1.0	8.1	9.6
H5	10	468915.6	5360223.8	9.1	8.3	0.7	0.5	8.1	9.3
H6	6	468946.5	5360192.0	10.4	8.3	-4.0	-5.8	8.1	10.5
V1	10	468959.6	5360350.8	6.7	8.4	0.3	-0.4	7.6	7.6
V2	13	468908.6	5360359.3	11.0	8.4	-1.6	-0.9	10.6	8.9
V3	12	468901.2	5360287.6	8.3	8.0	-1.0	0.7	8.2	8.2
V4	8	468862.2	5360293.6	8.8	8.1	-1.6	1.0	9.8	7.0
V5	7	468858.7	5360268.6	8.0	7.5	1.0	0.4	7.5	7.9
V6	8	468901.9	5360171.7	10.4	8.0	-2.5	-1.5	8.1	10.3
V7	7	468931.0	5360175.5	9.8	8.4	-3.0	-4.1	8.7	9.5
RT	13	468925.4	5360384.7	9.8	7.8	-2.6	-0.8	9.8	7.9
poslog	10	468907.9	5360219.5	9.3	8.3	0.9	0.4	8.1	9.4
steel1	11	468908.1	5360241.9	8.3	8.3	0.5	0.5	7.4	9.1
steel2	12	468886.8	5360286.6	8.5	8.1	-1.1	0.6	8.4	8.3
stove	10	468865.2	5360238.5	9.2	8.4	0.6	0.9	7.6	9.8
box1	12	468893.5	5360375.1	8.0	7.8	-0.6	-1.0	9.0	6.6
box2	12	468941.1	5360398.0	8.0	7.2	0.7	-1.4	8.5	6.6
box3	12	468856.0	5360393.1	7.7	6.7	0.2	-0.3	8.4	5.9
Mk25–1	16	468983.0	5360620.7	7.3	6.9	-0.4	0.1	8.4	5.5
Mk25–2	14	469125.2	5360520.8	8.4	7.2	-0.8	1.0	9.3	6.0
Mk36–1	14	469108.6	5360581.2	6.8	7.0	-2.1	-0.4	7.8	5.7
Mk52–1	12	469005.8	5360738.6	8.5	5.0	-1.6	0.5	9.2	3.5
Mk56–1	9	468971.6	5360920.2	7.7	5.1	1.3	0.6	7.2	5.8
Mk56–2	16	469002.4	5360660.7	8.1	6.5	0.5	0.2	9.2	4.9
Mk62–1	8	468994.7	5360672.6	5.1	8.9	-0.1	-0.0	8.2	6.1
Mk62–2	4	469158.0	5360325.8	9.4	7.0	-4.2	3.0	9.7	6.6
Manta–1	13	469015.4	5360837.4	8.3	6.8	-0.5	-0.5	9.8	4.5
Manta–2	14	469159.4	5360429.7	9.7	10.0	2.6	1.5	9.7	10.0
ALL				8.5	7.7	-0.5	-0.1	8.5	7.6

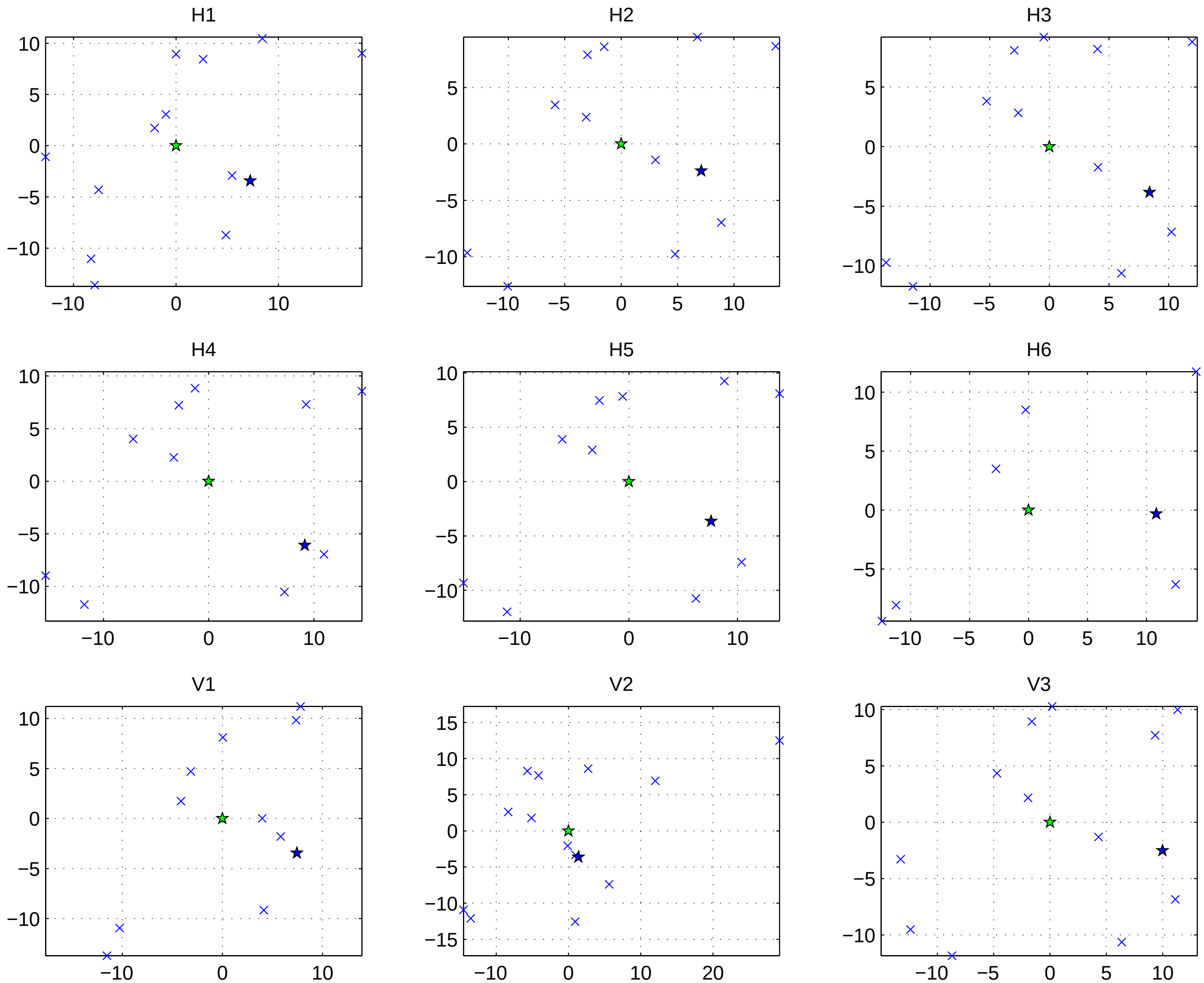

Figure 19: *Scatter plots of target positions around the mean position (targets H1–H6, V1–V3).*

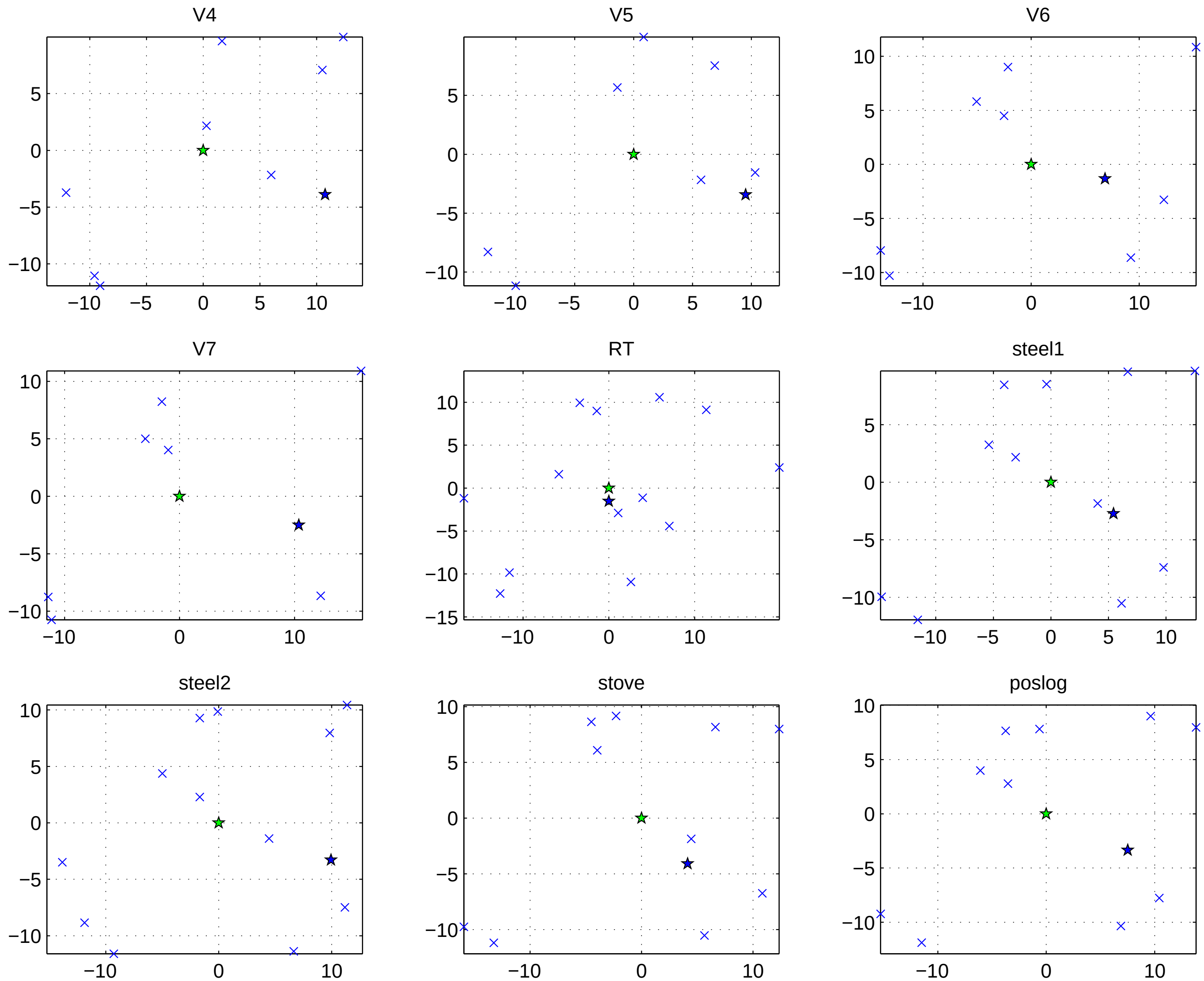

Figure 20: *Scatter plots of target positions around the mean position (targets V4–V7, RT, steel1, steel2, stove and poslog).*

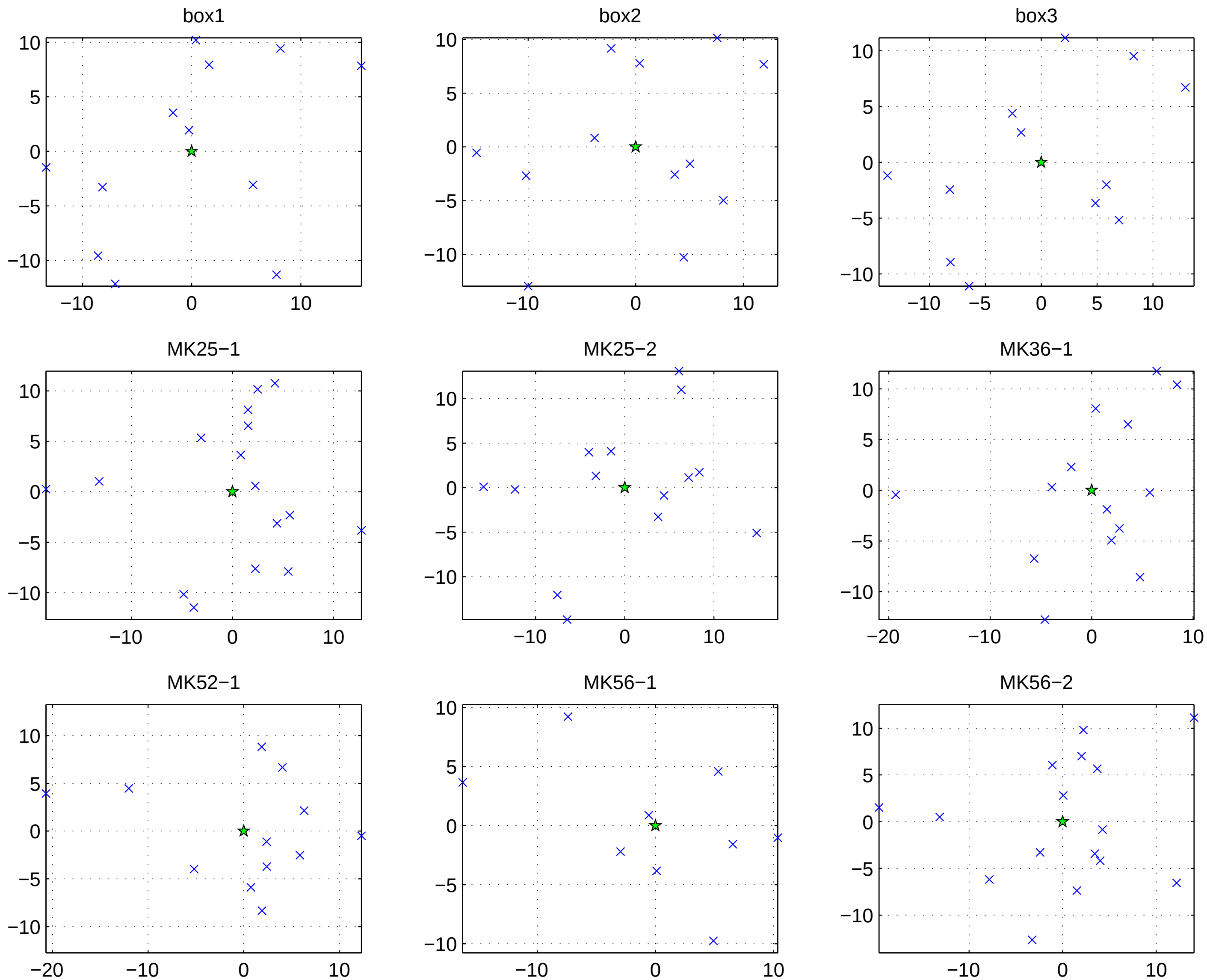

Figure 21: *Scatter plots of target positions around the mean position (box1–3, Mk25–1, Mk25–2, Mk36–1, Mk52–1, Mk56–1, Mk56–2).*

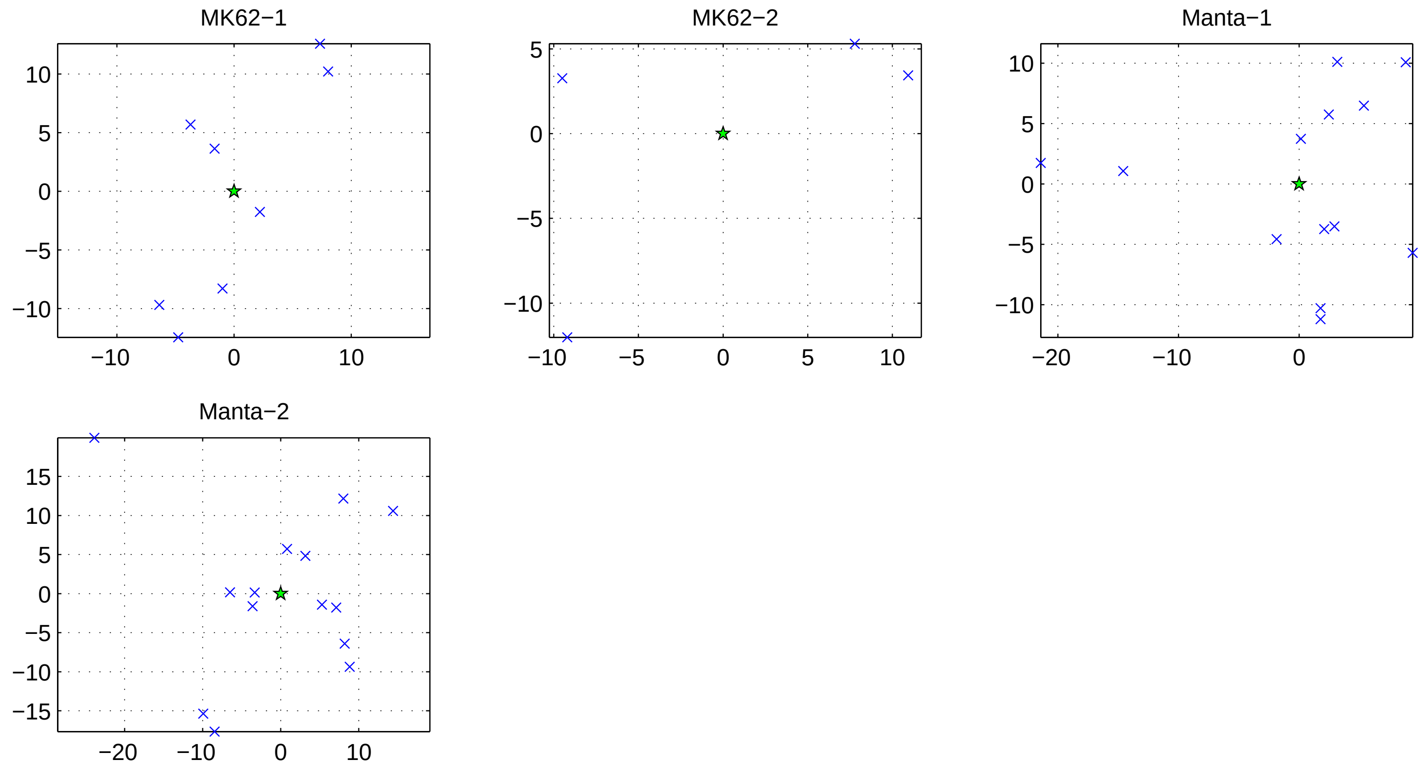

Figure 22: *Scatter plots of target positions around the mean position (targets Mk62–1, Mk62–2, Manta–1 and Manta–2).*

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(U) The Remote Minehunting System Technology Demonstrator Project (RMS TDP) was a three-year program with the goal of providing recommendations to the Canadian Navy on semi-submersible-based minehunting technology. A key component of the project was a series of sea trials during which ongoing improvements to design and operation were tested. During the second and third of these trials, Builds 2 and 3, a quantity of sidescan sonar data over deployed and pre-existing target arrays was collected. The subsequent analysis of this data provides a method for assessing the RMS performance in meeting the critical initial specifications on target positioning accuracy of <10 m rms.

(U) The results of this analysis using geo-referenced sonar data show positioning accuracy that meets the specifications, with Build 2 having a positioning accuracy of 5 m rms, and Build 3, marginally larger at 7-8 m rms. An important difference between the results for the Builds is that for Build 2, the sidescan sonar data were geo-referenced using a simple straight-cable model to determine towfish position, where the Build 3 analysis used towfish position determined by an onboard Inertial Navigation System (INS). The only slightly poorer positioning accuracy for Build 3 is due to observed wander of the towfish INS, however attaining this level of positioning accuracy with any such system is noteworthy.

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