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Alaska Fisheries Science Center
Resource Assessment and Conservation Engineering Division
Groundfish Assessment Program

Cruise and Backscatter Data Processing Report for the 2018 Gulf of Alaska Trawlability Study (GOATS)

SEPTEMBER 2020

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Cruise and Backscatter Data Processing Report for the 2018 Gulf of Alaska Trawlability Study (GOATS)

S. S. Intelmann[1], R. A. McConnaughey[1], and L. Huff[2]

[1]Alaska Fisheries Science Center
Resource Assessment and Conservation Engineering Division
7600 Sand Point Way NE
Seattle, WA 98115-6349

[2]LCHUFF Consultancy LLC
4048 Norbeck Square Dr
Rockville, MD 20853

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Abstract

This study investigates the utility of mission-appropriate hydrographic technology and advanced acoustic-processing methods to statistically discriminate T and UT habitats in the Gulf of Alaska (GOA) bottom-trawl survey area. Five selected "blocks", or groups, of stations were chosen to ensure efficient use of ship time and to cover areas that represent depths and slopes commonly encountered during the NMFS bottom-trawl survey. Additionally, International Hydrographic Organization quality bathymetry data were acquired and delivered for nautical chart updates thoughout the study area.

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Overview and Objective

Delineation of trawlable (T) and untrawlable (UT) areas of the seafloor is a major research and management issue in fisheries science. It is important because estimates of fish density from trawl surveys are expanded by the area of the survey region to obtain the estimates of abundance that are used to set harvest limits. We know, however, that all areas in the Gulf of Alaska (GOA) survey frame are not trawlable and that trawlable and untrawlable areas may support different populations of fish and crab. Ignoring these differences can lead to bias in estimates of abundance and resulting stock assessment outcomes. An accurate estimate of the (un)trawlable area is therefore crucial for sustainable management of stocks.

High-speed trackline surveys using hydrographic-quality sonars efficiently measure slope, roughness, and seabed hardness, and are in turn, also useful for discriminating T and UT areas. Similarly processed acoustic data have been shown to improve trawl-survey catchability models for snow crabs (Somerton et al. 2017) and species-distribution models for groundfish (e.g., McConnaughey and Syrjala 2009) on the Bering Sea shelf. In addition to providing these direct improvement to NMFS stock assessments, the acoustic data indirectly provide improvements to EFH definitions and identify vulnerabilities due to environmental change and bottom-contact fishing gears.

As such, the Gulf of Alaska Trawlability Study (GOATS) was designed to collect acoustic data and investigate their utility for statistically discriminating T and UT habitats in the GOA bottom-trawl survey area. Another objective, in collaboration with the NOAA Office of Coast Survey (OCS), was to deliver International Hydrographic Organization quality bathymetry for nautical chart updates in areas with outdated or non-existent information.

Vessels and Gear

Operations were conducted aboard NOAA ship *Fairweather*, a multi-mission hydrographic survey vessel capable of continuous sonar operations. The Kongsberg EM710 multibeam echosounder (MBES; 200/400 beams, 73-97 kHz), mounted to the keel of the ship, was used to survey various regions of the GOA in the general vicinity of Kodiak Island during the late summer of 2018. The objective of the EM710 backscatter measurements on the GOATS cruise was to obtain a "uniform" (realistic) set of backscatter data, as possible with the EM710, given its particular operational

capabilities. At a high level, the operational capabilities of the EM710 include a Single-Swath mode and a Dual-Swath mode. Within each of those swath modes, there are several depth modes, which are designed for optimal bathymetric and backscatter operation in a particular depth range.

For monitoring sound speed changes during the project, measurements were obtained from an AML Oceanographic MVP-200 system. The MVP-200 is capable of sampling water column profiles to approximately 200 m depth from a vessel moving at up to 12 knots, and to deeper depths at slower speeds. The system is self-contained, completely autonomous, and controlled by computer without the requirement for personnel on deck. The device consists of a single sensor free-fall fish, an integrated winch and hydraulic power unit, a towing boom, and a remotely located controller with user-interface computer. Within the tow body is an AML Oceanographic Micro-CTD sensor capable of acquiring a conductivity, temperature, and depth (CTD) profile to determine the speed of sound and absorption in the water column. These data were ultimately used to provide proper ray-tracing of the sonar beams from the EM710 MBES.

Pre-Cruise Gear Tests

Prior to executing the GOATS operational survey plan, deck operations and survey-gear readiness exercises were conducted in the sheltered waters of Chiniak Bay near Kodiak (Fig. 1). In addition to testing the sound velocity instruments and MBES, the Klein 7180 long-range side scan sonar (LRSS) towfish was launched and towed for several short passes along two predefined survey lines. The towfish contains multiple acoustic, environmental, and navigational sensors which, combined with topside processing electronics, efficiently collects, processes and archives quantitative data for use in characterizing the seabed. The purpose of this short LRSS deployment exercise was to assess the effectiveness of a variety of shore-side repairs, including replacement of the pitch actuator, motion sensor and numerous cable assemblies.

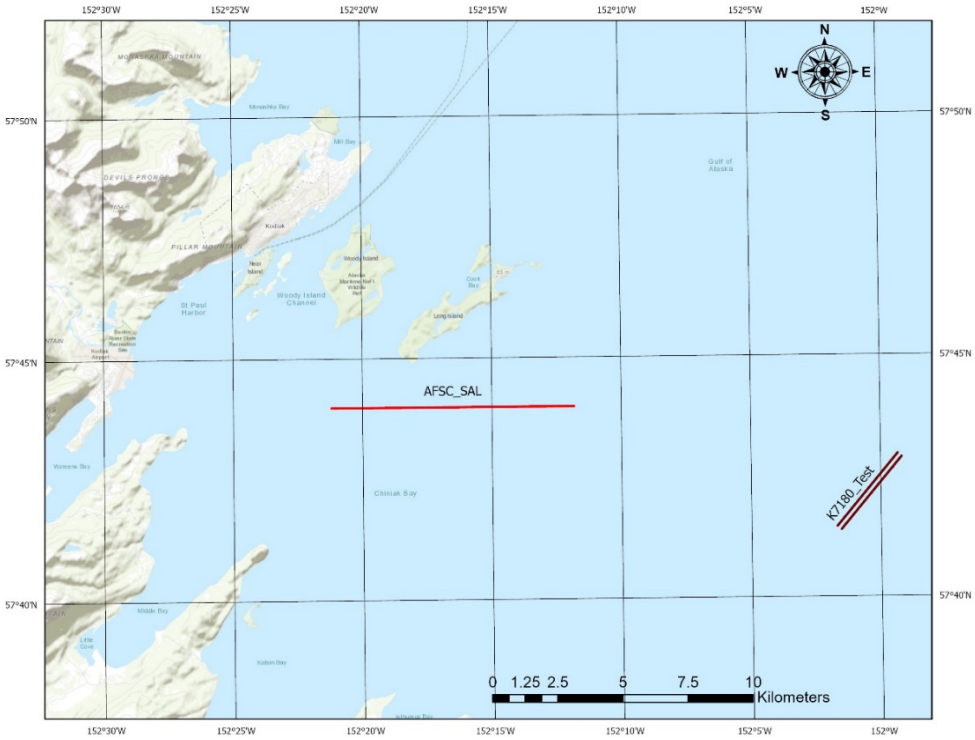


Figure 1. -- Project readiness test area in Chiniak Bay where the ship acquired MBES data along the AFSC standard acoustic line (SAL) shown in red, and the LRSS was reciprocally towed along two adjacent survey lines offset by 200 m (shown in brown).

For the LRSS assessment, a two-line survey plan was devised with passes being run on each planned line (Fig. 1) in reciprocal directions several times at varying speeds. The ship additionally acquired data along the AFSC-standard acoustic transect logging bathymetry and backscatter data with the ship's MBES as a calibration archive set.

Survey Design and Methods

Ship operations were designed to simultaneously, and continuously, acquire quantitative backscatter and bathymetric data from multiple areas with approximately equal numbers of T, UT, and undesignated stations (Fig. 2). These five selected "blocks", or groups, of stations were chosen to ensure efficient use of ship time (i.e., reduce non-survey transits) and to cover areas that represent depths and slopes commonly encountered during the NMFS bottom-trawl survey. Individual bottom trawl stations measured 5 × 5 km except along the outer boundary of the study area, which was defined by a 1,000 m isobath. For analysis, the 5 × 5 km blocks are further sub-divided into the standard NMFS groundfish stratums which are determined by a combination of management area location, water depth, and or distinctive bathymetric features.

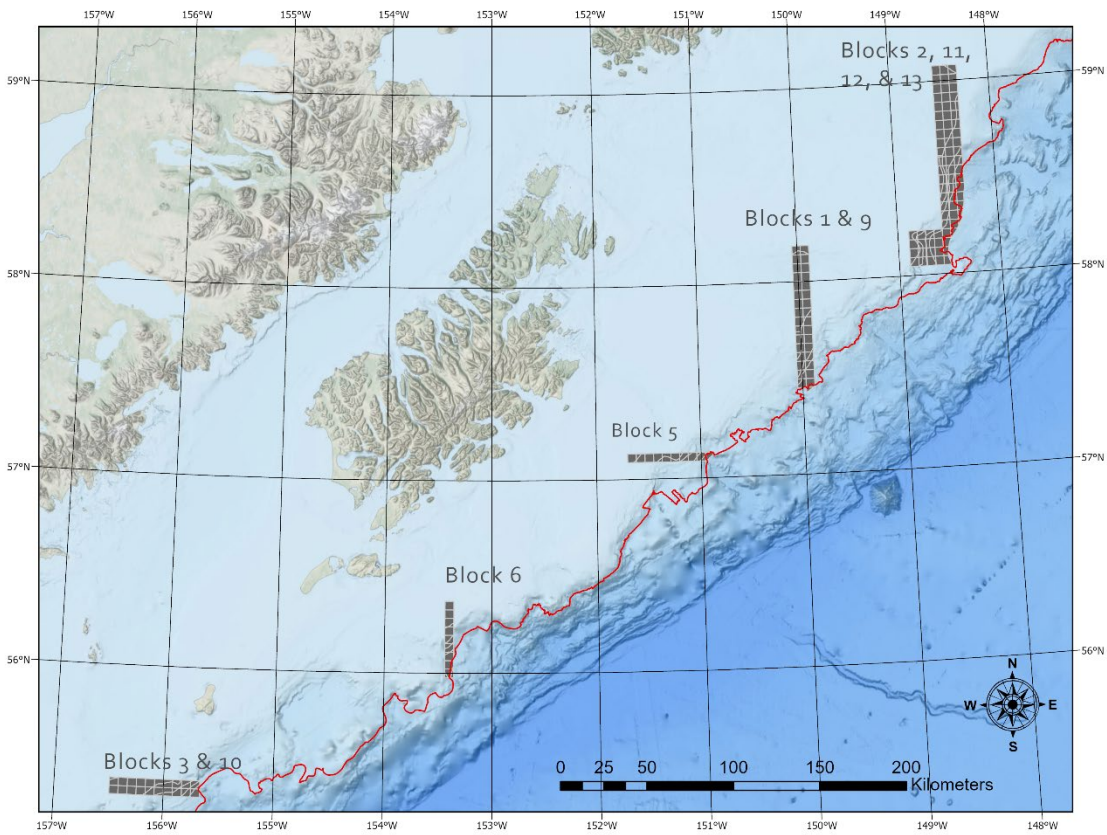


Figure 2. -- Location of the 149 trawl survey stations (and 287 stratum cells) mapped near Kodiak Island, shown with a 1,000-m isobath (in red).

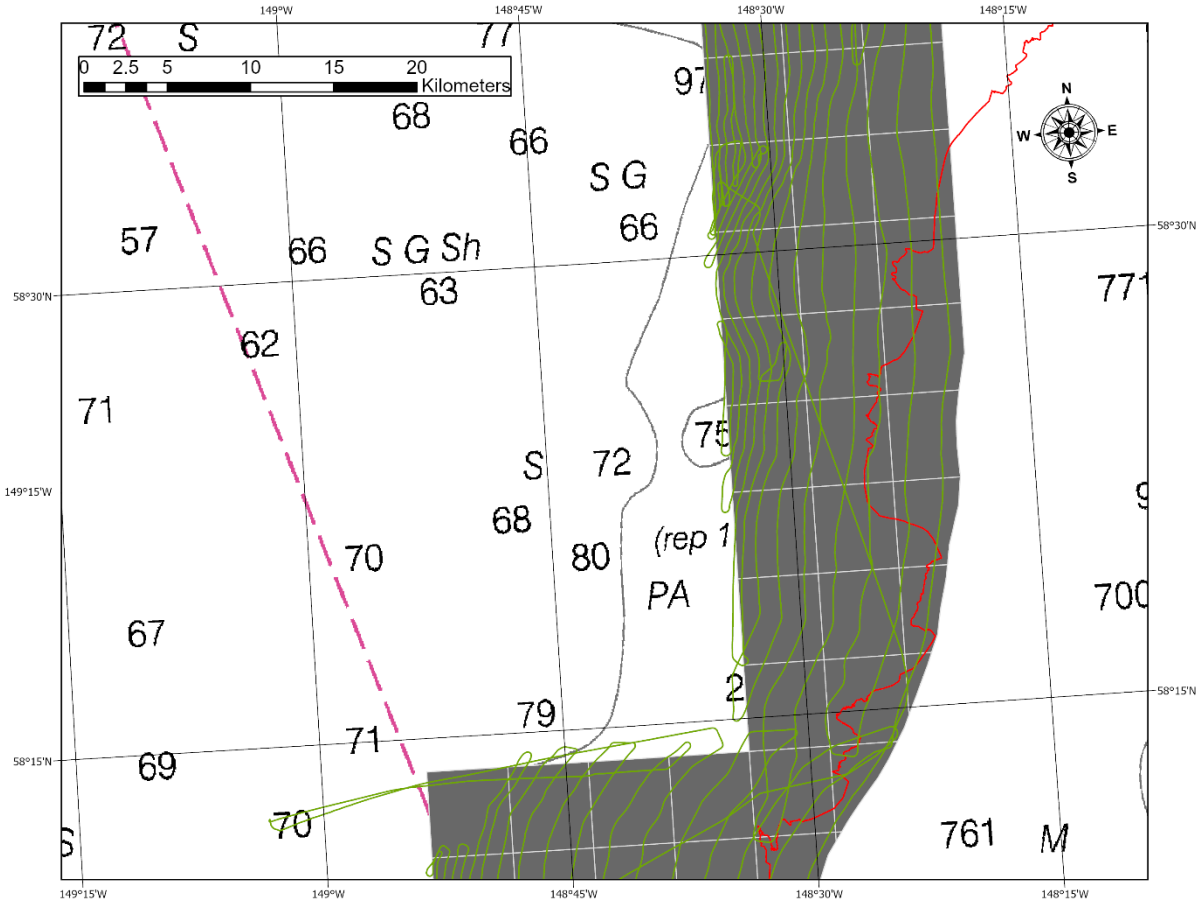


Figure 3. -- Free-form ship navigation, characteristic of a "paint the bottom" seafloor survey approach, shown as the circuitous green lines. Shoaler areas require tighter line spacing to achieve full bottom coverage, while the deeper areas near the 1,000 m isobath (shown in red) were covered with greater efficiency.

Survey speed was targeted at 10 knots under favorable conditions but was adjusted as necessary to ensure safe operating conditions and high-quality acoustic data. Sonar acquisition used the bottom painting method where real-time swath coverage was used to navigate the ship to effectively cover the seafloor using the previous, or adjacent soundings, as a pathway to achieve 100 % bottom coverage while still allowing enough overlap to filter the outer edges in post-processing (Fig. 3). This survey method was preferable to using traditional pre-planned survey lines since they often lead to more holes in the data coverage and require more survey time to backfill the gaps.

Device settings within the Kongsberg EM710 deviated from the standard NOAA tuning generally used by Coast Survey for bathymetric nautical charting. The EM710 has several operational depth

modes (Very Shallow, Shallow, Medium, Deep, Very Deep and Extra Deep) that employ different pulse lengths (0.2 ms to 120 ms) and different modulation of the transmit pulse (gated continuous wave and frequency modulated). It should also be noted the sonar manufacturer designed the Extra Deep depth mode specifically for optimal bathymetric operation, whereby the transmit pulse characteristics are uniquely altered and not explicitly specified to the end-user. As such the backscatter measurements in that mode are incapable of being calibrated like the others.
With that said, an operational plan was developed to allow the EM710 to "automatically" change between modes deeper than Medium but "manually" constraining the system from "automatically" moving from Medium into Shallow or Very Shallow modes in depths less than 200 m (shown in Table 3). The need for changing modes in deeper water was necessary since the higher frequencies associated with the shallower modes would be incapable of proper bottom detection. This selective use of "manual" and "automatic" switching between depth modes had the effect of keeping the range of acoustic frequencies as narrow as practical to "reduce" acoustic frequency as a factor responsible for spatial variations in backscatter since acoustic frequency changes between depth modes on this MBES. Dual Swath and FM (frequency modulation) were both enabled and pitch and yaw stabilization were also activated for the duration of the survey.

Sonar acquisition with the EM710 system included use of SIS (v. 4.31) and Hypack Hysweep (v. 2017a) to log all MBES data. The ship's Moving Vessel Profiler (MVP200) was the primary sound speed instrument used for the entire project and the data were processed using Pydro Explorer (v. 18.4). Data from all equipment were securely archived on redundant data drives.

Operations

During the project mobilization phase, RACE Habitat Research Group (HRG) installed a QINSY navigation logging suite and Trimble SPS 855 GNSS receiver with Zephyr2 GPS antenna on the ship. Ship's attitude from an Applanix POS M/V, heading from a Meridian Gyrocompass, and depth from the EM710 center beam were interfaced and logged in QINSY (v 9.0). The LRSS topside controllers were also integrated into the stand-alone scientific party navigation setup to accomplish the brief pre-cruise towfish operations described earlier.

Transit to the GOATS survey grounds began following completion of the readiness testing in Chiniak Bay on 27 August. Project activities were interrupted when the ship made a brief crew change in Kodiak on 5 September. The cruise ended in Kodiak on 11 September.

Itinerary

23 August	Vessel arrives in Kodiak, AK, and mobilization begins
27 August	Vessel departs Kodiak, gear readiness in Chiniak Bay
28 August – 11 September	Scientific operations
12 September	Demobilize vessel

Results

A total of 5,553 linear km of MBES data were collected across the five selected blocks and within 149 RACE bottom trawl stations (and 287 stratum cells), covering 3,801 km^2 of seafloor (Table 1). MBES data were also logged over an additional 1,415 km while transiting between survey sites. Over 162 sound velocity profiles were acquired with the MVP which were used for beam steering and post-processing ray tracing of the sonar data. Figure 4 provides an example of the sound velocity sampling distribution within one of the selected blocks of survey stations.

Table 1. -- Seafloor area (km^2), linear tracks (km), and number of trawl stations surveyed with the EM710 within each of the five selected survey blocks during the GOATS 2018 effort.

Survey Blocks (grouped Stations)	Station Count (5×5)	Stratum Count	Linear Tracklines (km)	Seafloor Area (km^2)
Blocks 1,9	33	52	1,652	895
Block 5	10	22	476	291
Block 6	9	20	767	255
Blocks 3,10	20	41	622	479
Blocks 2,11,12,13	77	152	2,036	1,881
Sum	149	287	5,553	3,801

Bathymetric data conversion, processing, and cleaning were accomplished using CARIS HIPS (v. 10.4) and processed and delivered to the Pacific Hydrographic Branch for final review and eventual incorporation into NOAA nautical charts. Separate reports describe the MBES bathymetry processing (M-P951-FA-18_DAPR and D00260_DR_memo, produced by Office of Coast Survey). Additional data processing by the AFSC HRG generated user-specified grids of slope and rugosity for analysis of morphological seabed traits that were derived from the bathymetry data. Acoustic backscatter was corrected for radiometric and geometric effects with aid of specialized software to produce multiple descriptive statistics (Table 2) that are consistent and comparable over the full study area. Processed mosaics and rendered digital terrain models (DTMs) for each group of survey blocks are provided in Appendix 1. A custom dbSEABED database of surficial-sediment properties for the GOA survey will also be incorporated into the analytical framework.

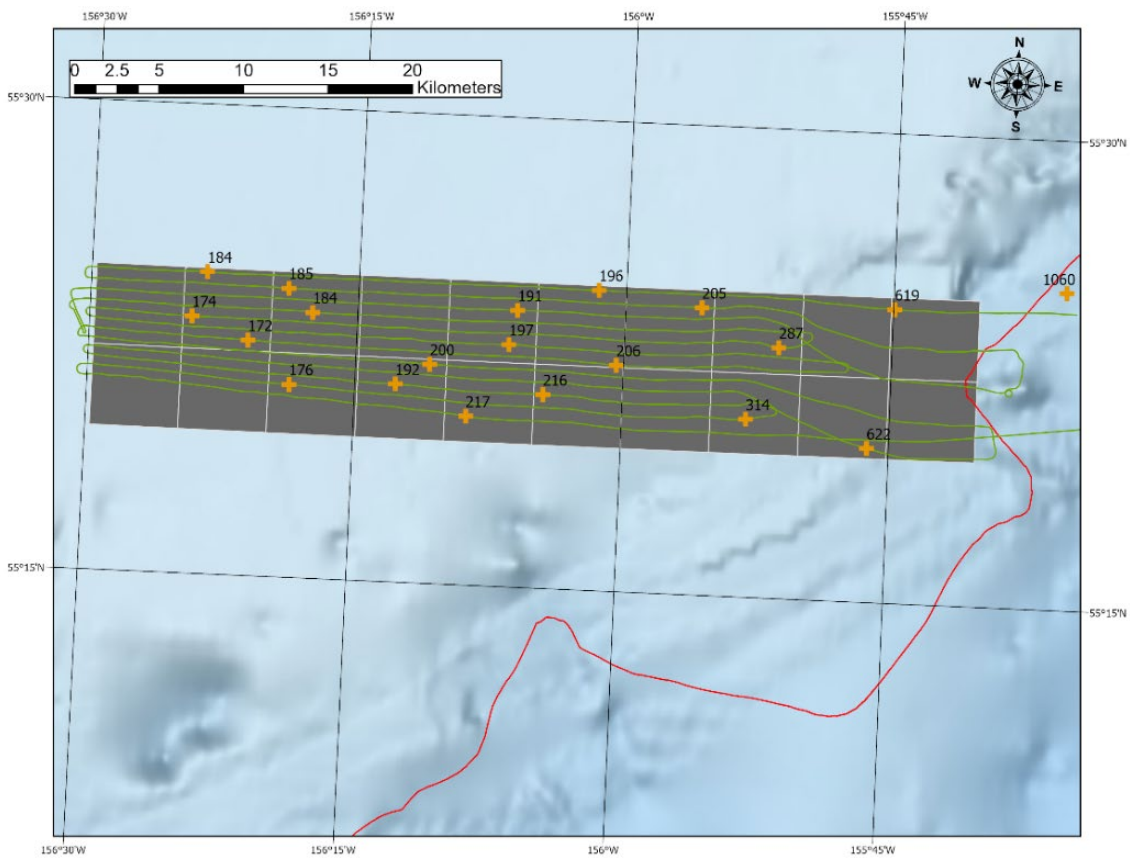


Figure 4. -- Orange cross-hair symbology showing MVP sampling dispersion across survey groups 3 and 10. Numbers at each location indicate water depth in meters. Green lines provide ship navigation path. The 1,000 m bathymetry contour is shown in red.

Table 2. -- Statistical derivative layers by gridded raster format type.

Floating Point-based Grids	Integer-based Grids
Kurtosis, Maximum, Mean	Grazing Angle
Median, Minimum, Mode	Number of Samples
10th, 25th, 75th, and 90th Percentiles	
Quartile Range, Skewness	
Standard Deviation	

Backscatter Processing

Backscatter processing relied on 1) Kongsberg *.all files, which contained the raw sonar files captured by the SIS acquisition system and 2), the subsequently converted and cleaned bathymetry data contained within the HIPS HDCS libraries. The processing software (QPS FMGT v. 7.9.2) is designed to visualize and analyze backscatter data from multibeam and side scan sonars. The processing of source files is designed to perform as many corrections as possible to maximize the information content within the backscatter signals. These corrections involve compensating for static gains, time-varying gains and sonar specific manufacturer corrections, along with correction for source level and transmit/receive beam patterns.

FMGT utilizes several processing stages that can involve navigation extraction, filter processing, frequency analysis, ARA processing (Fonseca and Mayer 2007), and statistics generation. The navigation processing stage initially extracts the swath coverage from each survey line. During the Backscatter/Adjust stage, the raw backscatter time series are extracted for each beam from the source file then all the potential adjustments are made to the data, including proper signal level shifts due to range and transmission loss, beam incidence angle and footprint area adjustments, Lambertian scattering adjustments, along with any other necessary adjustments particular to the chosen sonar (FMGT user manual). The time- and memory-intensive Filter Processing stage performs additional adjustments to the backscatter swath based on beam angle before implementing an antialiasing routine on the resulting swath. If chosen, an Angle Range Analysis (ARA) can also be undertaken to compute a modeled characterization of the underlying surface. Finally, the Statistics generation process computes a multi-layered surface with attributes and beam data from each mosaic cell feeding an intersection of a co-located statistics cell. As such, the resulting statistics

layers have a coarser resolution due to the need of the information from neighboring mosaic cells to compute values within each of the statistics cells.

It was important to ensure the HIPS data were properly cleaned of anomalies prior to backscatter conversion. The bathymetry cleaning process results in appropriately flagged soundings which are then carried over during the backscatter conversion and, as such, avoids the potential of mosaicking erroneous/rejected data.

Procedurally, individual FMGT projects were created for each survey block, with some ingesting multiple days (and thereby subfolders) of raw sonar data. Creating a new project within FMGT merely required selecting the menu item "Create Project…" on the dropdown menu from the "File" heading. Once selected, project name and path were provided, along with desired Horizontal Coordinate System. For the GOATS18 project, the NAD83 UTM Zone 5 North coordinate system was used for georeferencing all processing project files.

Prior to file backscatter extraction, various required "Processing Parameters" were specified within the "Settings" drop-down menu in FMGT. The Adjust Tab was configured as in Figure 5, to specify Beam Angle Cutoffs as a range of 15-55 (per recommendation from a pre-project BSCorr Analysis – Appendix 4); "Absorption" was left as null (since values are calculated real-time through MVP input feeding SIS during acquisition and is thereby captured in the .all files); and "Head 1 Bias" (see Appendix 2 for more details) was set to 5. The "Filter", "Navigation", and "Plug-in Configuration" tabs were left as default settings. Within the "Sonar Defaults" tab, the Sonar Type was set to Simrad EM710 MBES Model 710. Of note, the Head 1dB Bias value in the Adjust tab is subtracted from the Head 1dB Reference value within the Sonar Defaults tab. Under the "Statistics" tab, the Linear Space amplitude selection was checked.

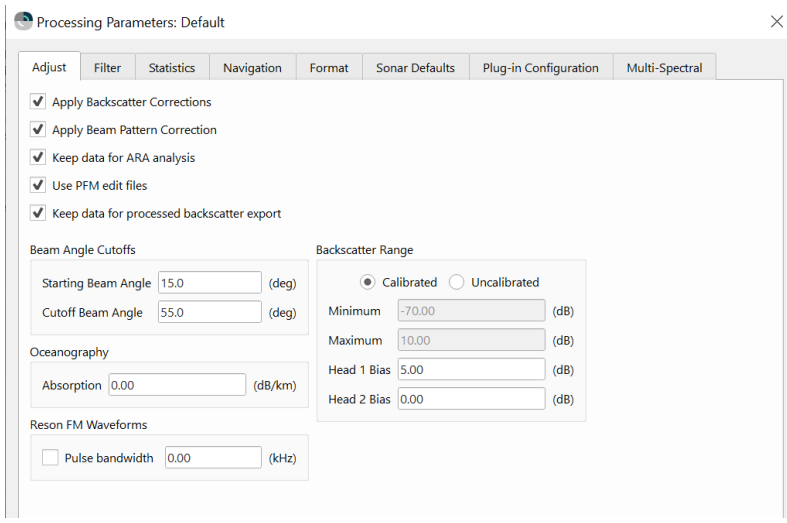


Figure 5. -- Beam angle cutoffs, absorption, and Head 1 Bias settings applied to the processing parameters.

The EM710 uses multiple swath modes and depth modes (Table 3) designed for optimal bathymetric and backscatter operation within a particular depth range. Frequencies within 73 to 97 kHz are used and the transmit pulse length increases with depth, from 0.2 ms CW to 2 ms CW, and up to 120 ms as FM. By project design, operation of the EM710 was removed from automatic ping mode and manually constrained to operate nearest the Medium depth mode to avoid varying frequencies and pulse lengths which would ultimately change the characteristics of the backscatter return. However, when depths exceeded the systems internal auto crossover depth zone, the system was manually bumped up to the next depth mode in order to maintain a proper bottom detect.

Table 3. -- Crossover depths associated with the various EM710 ping modes, when operated in Automatic Depth Mode. The "Mode Action" describes how the sonar was locked to Medium Ping Mode in all depth less than 300 m and allowed to Auto Shift as depths increased. For example, as water depths exceeded 301 m, the sonar was allowed to transition into Deep mode, etc.

Ping Mode	Crossover Depth	Mode Action
Very Shallow	n/a	
Shallow	100	
Medium	200	Manual Lock
Deep	300	Auto Shift
Very Deep	500	
Extra Deep	1,000	

Shifts in dB levels between the differing modes can result in mosaic artifacts where the sonars change mode. As such, QPS introduced a Ping Mode Correction option in FMGT to allow the user to specify a dB offset to match the response levels between different sonar ping modes specific to the EM710. In practice, the software allows the user to click on patches in the mosaic map view to reveal the sonar ping mode at that time. By clicking on a bundle of pings between one sonar mode and another, the delta dB between the survey modes are revealed and can be entered in the Ping Mode Corrections section within the Format tab of the Processing Parameters (Fig. 6).

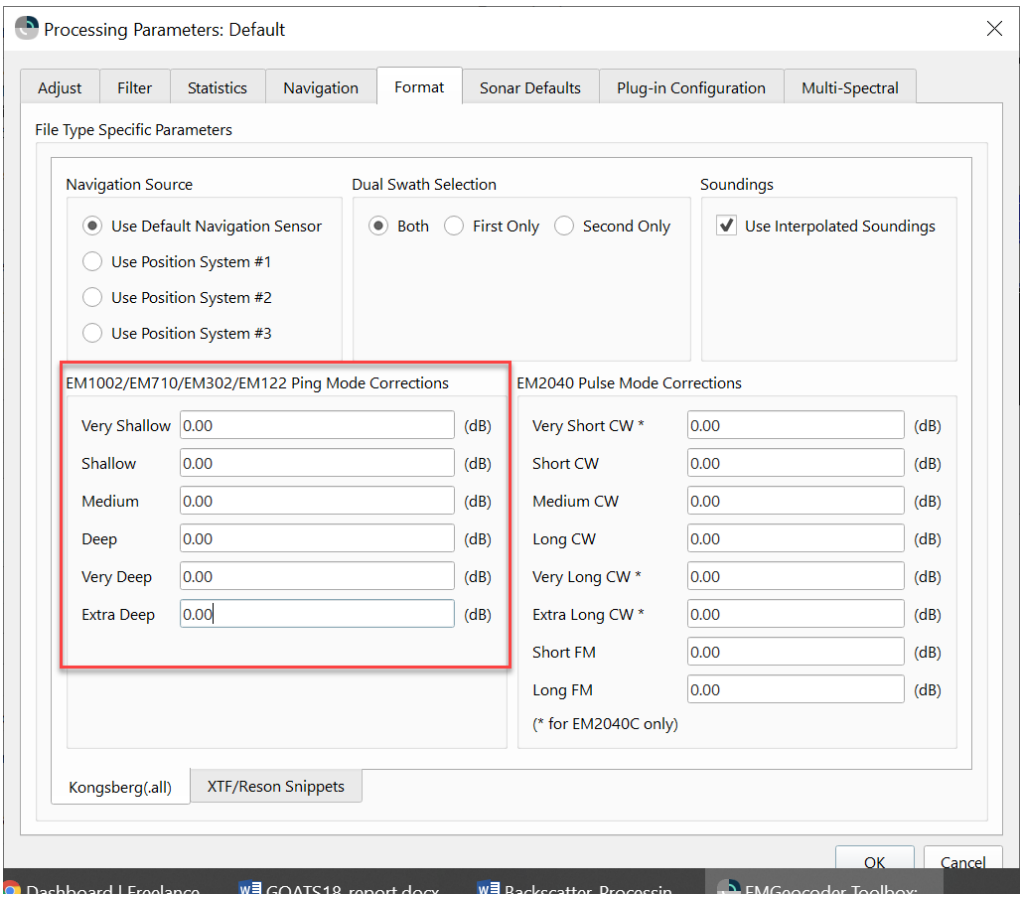


Figure 6. -- Kongsberg EM710 Ping Mode correction entry section (outlined in red box) within the Processing Parameters of FMGT. Note, however, the values used for each survey block during the GOATS project are presented in Table 4 as they differed for each block.

Every effort was made to keep the EM710 operating in Medium Mode or deeper when possible during survey. However, at various times during the cruise the system would hang and have to be rebooted. Upon reboot, SIS would revert back to the default setting of Automatic Ping Mode. If left

unnoticed, and the ship was in shallower water than the crossover zone shown in Table 3, the echosounder would default to a shallower mode until altered back to manual mode and reset to Medium. Careful examination of converted files produced the ping mode correctors calculated in FMGT for each survey block as shown in Table 4.

Table 4. -- Ping mode delta dB values entered into the EMxx correction section within the FMGT processing parameters. Values presented are for each survey block processed in 2018.

Ping Mode	*Blk1n9*	*Blk3n10*	*Blk2to13*	*Blk5*	*Blk6*
Very Shallow	0.0	0.0	1.6	0.0	0.0
Shallow	-2.0	0.0	-2.0	0.0	-1.2
Medium	0.0	0.0	0.0	0.0	0.0
Deep	0.2	0.2	-0.3	0.2	-1.5
Very Deep	3.4	2.6	2.9	5.0	1.1
*Extra Deep**	6.9	5.1	5.5	8.0	3.5

*Note: Extra Deep mode was not designed to be properly calibrated but these numbers seemed to generate "visually" close matches with adjacent Ping Mode bundles.

After the processing parameters were populated within each FMGT project, source files were then imported by activating the dropdown menu from the "File" heading and selecting the menu item "Add Source/Paired Files". The import process involved pairing the appropriate Kongsberg *.all file directory structure containing the backscatter datagrams with the Caris HIPS bathymetry library files previously cleaned of anomalous sounding artifacts. Data from the two sources were merged together into a new Generic Sensor Format (GSF) file, where the FMGT pairing process used ping and beam numbers to match each HIPS "ProcessedDepths" file residing within every logged line folder with the similarly named Kongsberg SIS files. The end result allowed the Caris HIPS rejected sounding flags to be carried over to the merged GSF for subsequent acknowledgment in the backscatter processing stage by FMGT.

Mosaic and statistical surface resolutions were generated at 5 and 32 m squared, respectively. It should be noted the mosaic resolution setting controls the size of both the Mosaic and Statistical layer output resolutions, and often requires the procedure to be run once for each output. Setting a desired statistical resolution in FMGT requires setting the Mosaic resolution at 1/20th the desired Statistic size. For example, a 1.6 m mosaic setting produces the 32 m statistical bins used in this project.

Additionally, though not needed for this project, the Mosaic Tiles feature could be useful for overcoming memory requirements when generating mosaics and statistics when large areas are surveyed or when long track lines surveys are employed that result in a high number of null raster cells within a particular survey boundary. In these cases, the Mosaic Memory display (Fig. 7) can be used to help determine the extent of tiling required. When digits in the Mosaic Memory box are displayed in green, the Mosaic Memory used is theoretically small enough to facilitate processing. In general, size of Mosaic Tiles should be chosen with an effort to minimize number of tiles while still achieving green numbers in the Mosaic Memory window when set at the desired output resolution. Tiling extent would be adjusted by selecting the size of each tile in pixels from the Mosaic Tiles drop-down menu.

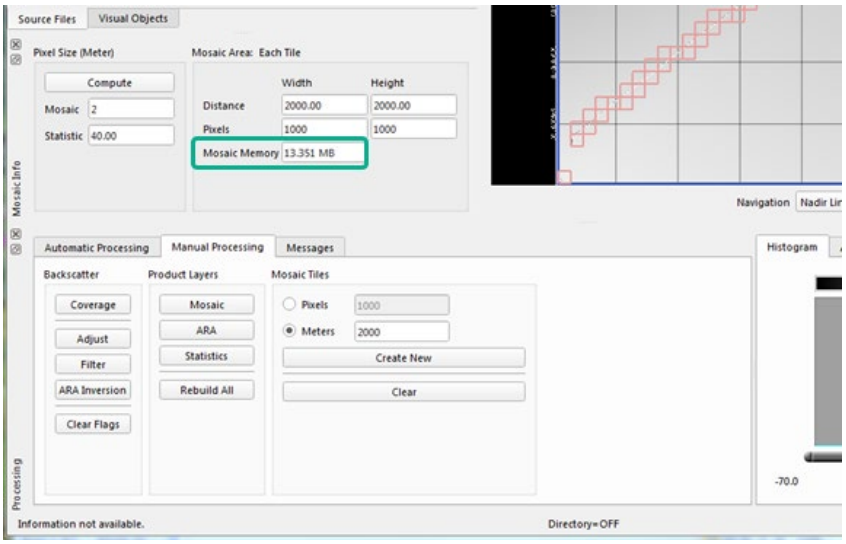


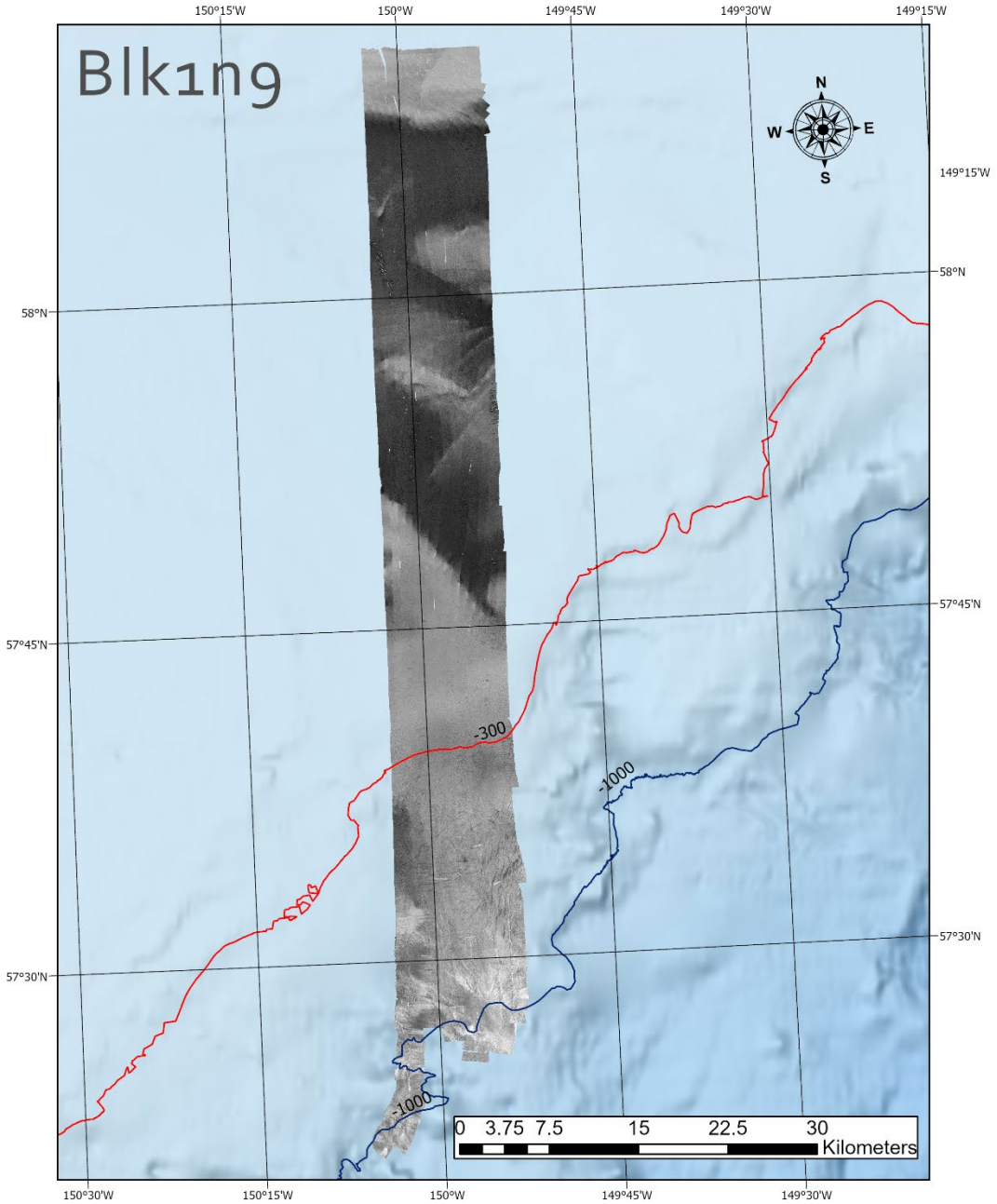
Figure 7. -- The Mosaic Memory field is used to determine whether the rendering of a mosaic (or statistics) at a chosen resolution is possible. If the digits are red then more intensive tiling is required until they change to the color green.

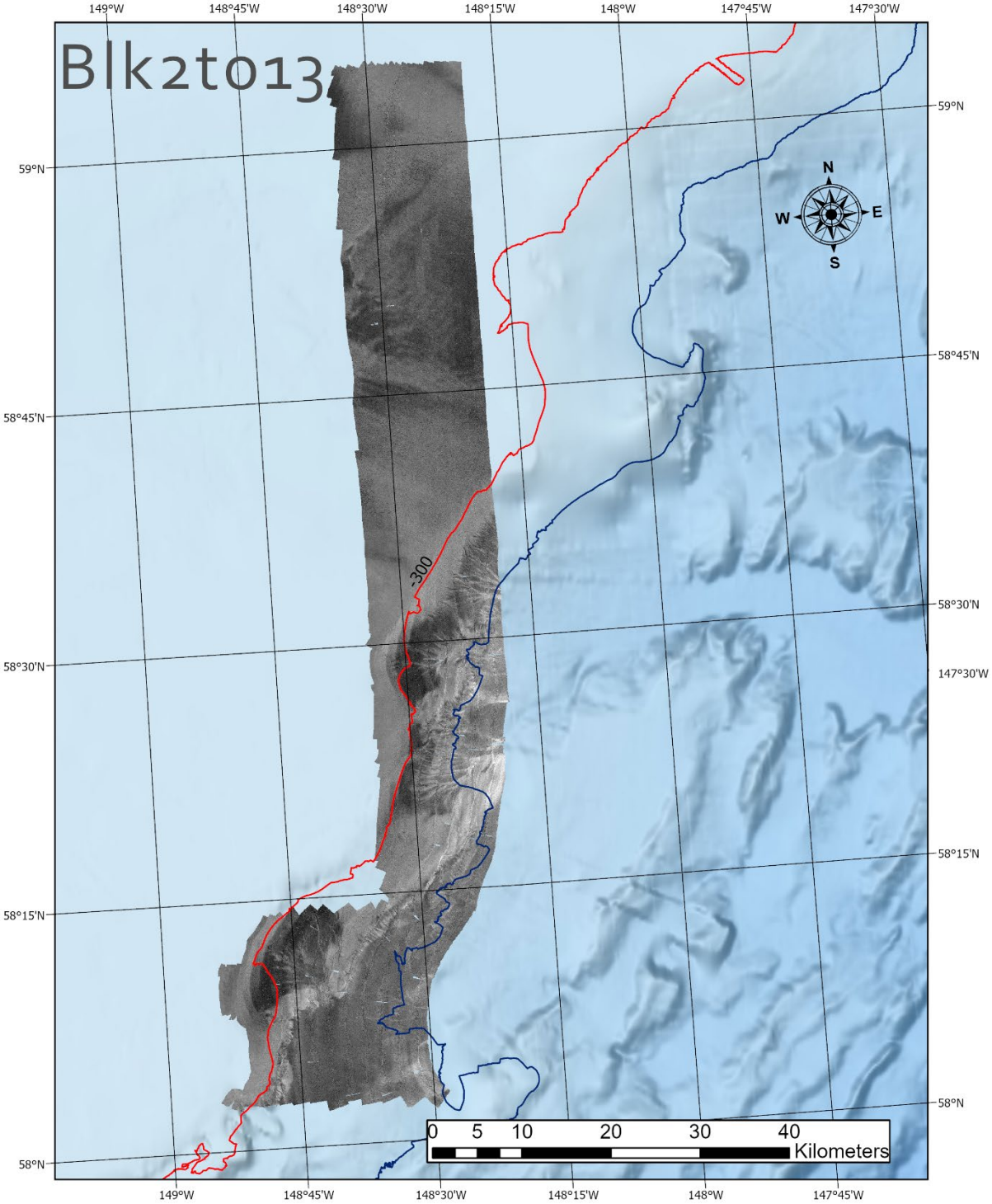
Processed mosaics (5 m) were exported as 8-bit greyscale geotiff images and then imported into an ArcGIS geodatabase for each survey group/project. Statistical derivatives were exported from FMGT using the "Ascii Stat Details" option, and unchecking "include Raw Histogram". This export function created an Excel spreadsheet with columns of statistical values that were then converted

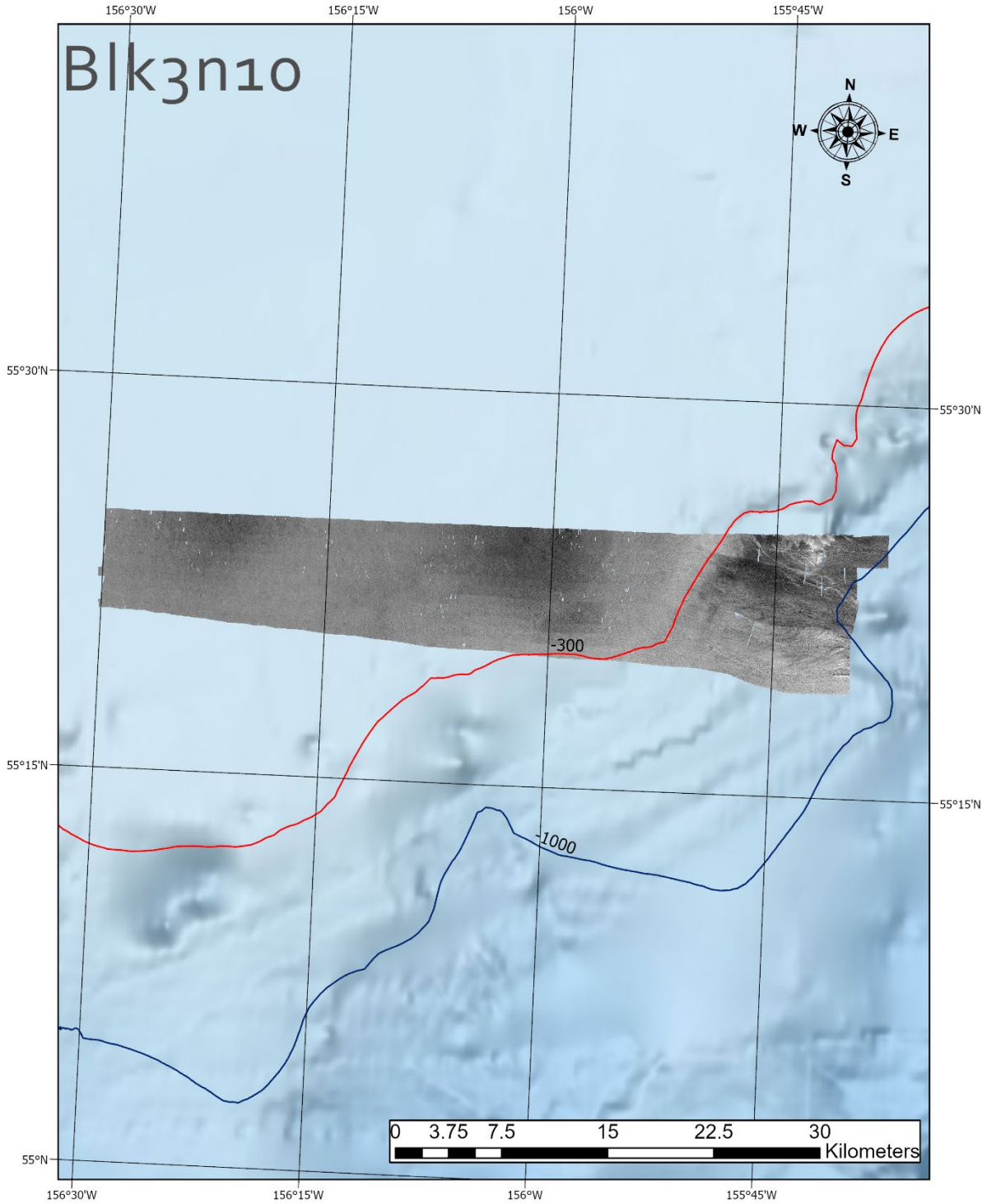
into georeferenced raster files using the custom Python script “FMGT Stats to Raster”. Final products were archived in both raster catalogs and in NETCDF structure.

Appendix 1 – Backscatter Mosaics

Backscatter mosaics (5 m resolution) for each survey group. Bathymetry contours for the 300 and 1,000 m isobaths are shown in red and blue, respectively. Higher acoustic returns (i.e., harder bottoms) are lighter shades of grey.




Blk2to13
149°W
148°45'W
148°30'W
148°15'W
148°W
147°45'W
147°30'W
59°N
58°45'N
58°30'N
58°15'N
58°N
-300
N
W
E
S
0 5 10 20 30 40
Kilometers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156°W
155°45'W
55°30'N
55°15'N
55°N
N
W
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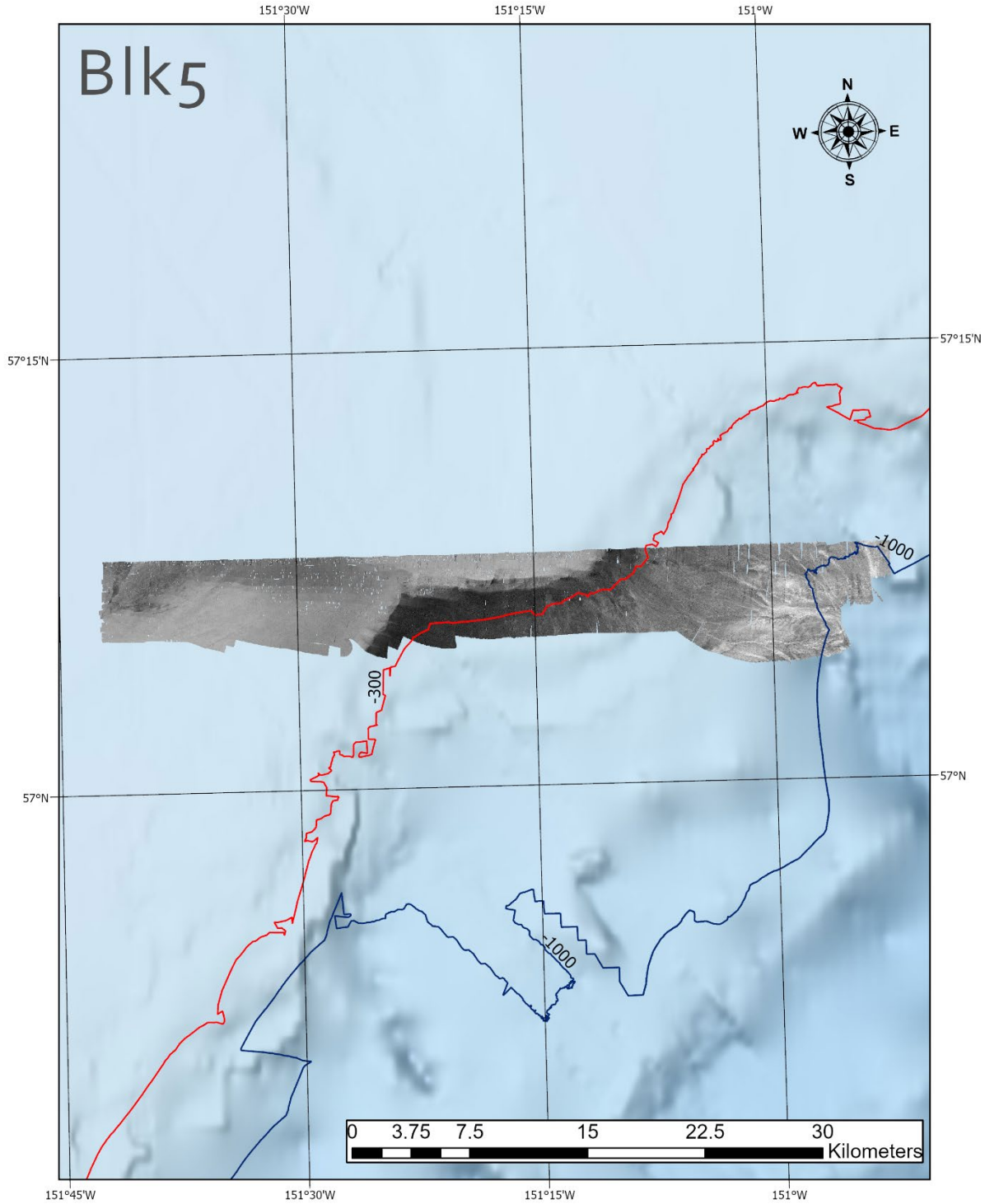
S
-300
-1000
0 3.75 7.5 15 22.5 30
Kilometers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57°15'N
57°N
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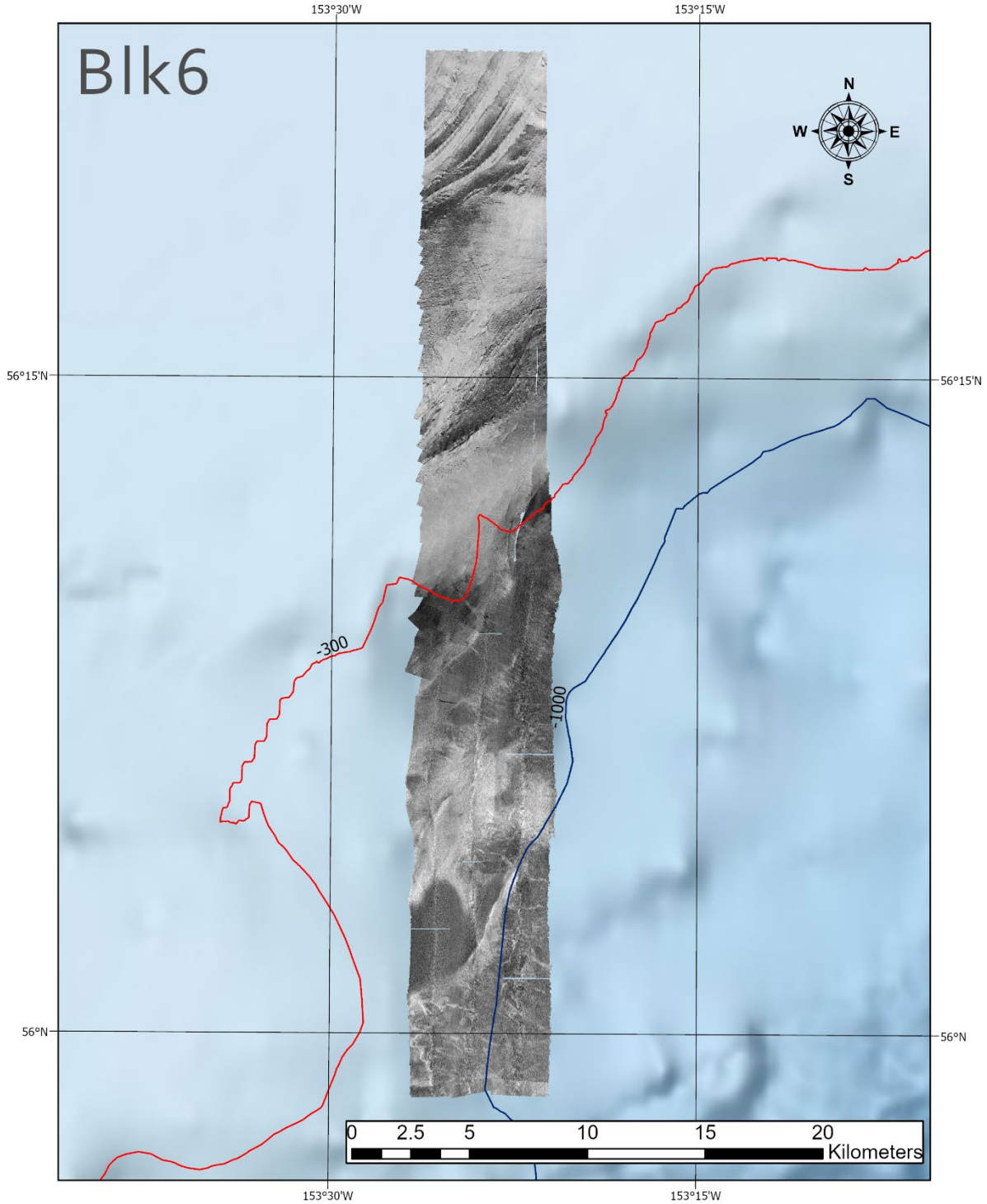
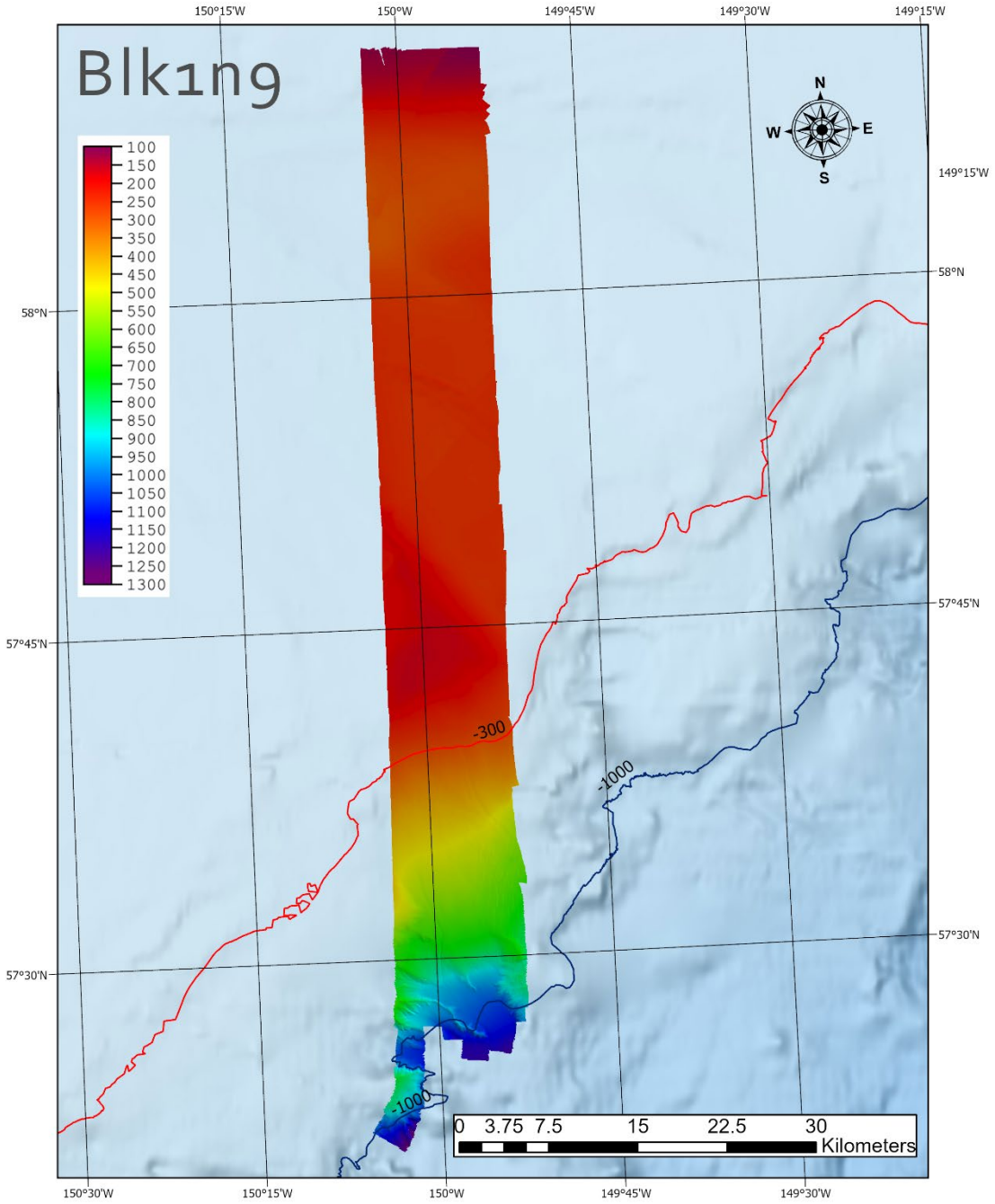
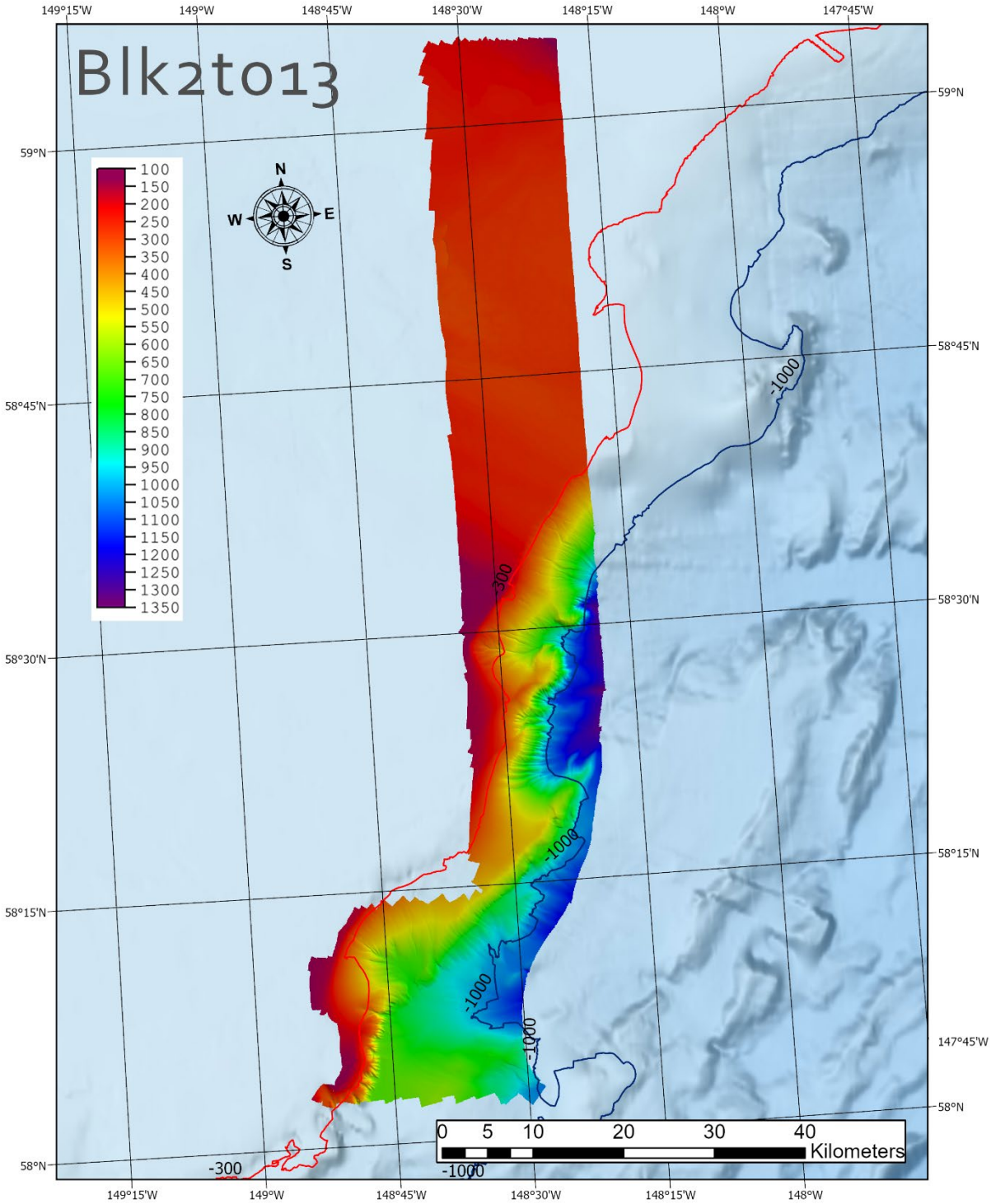
151°30'W
151°15'W
151°W


Blk6
153°30'W
153°15'W
56°15'N
56°N
N
W
E
S
-300
-1000
0
2.5
5
10
15
20
Kilometers

Appendix 2 – Bathymetry Surfaces

Bathymetry surfaces (32 m resolution) for each survey group. Bathymetry contours for the 300 and 1,000 m isobaths are shown in red and blue, respectively.




Blk2to13
149°15'W
149°W
148°45'W
148°30'W
148°15'W
148°W
147°45'W
59°N
58°45'N
58°30'N
58°15'N
58°N
147°45'W
100
150
200
250
300
350
400
450
500
550
600
650
700
750
800
850
900
950
1000
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1100
1150
1200
1250
1300
1350
N
W
E
S
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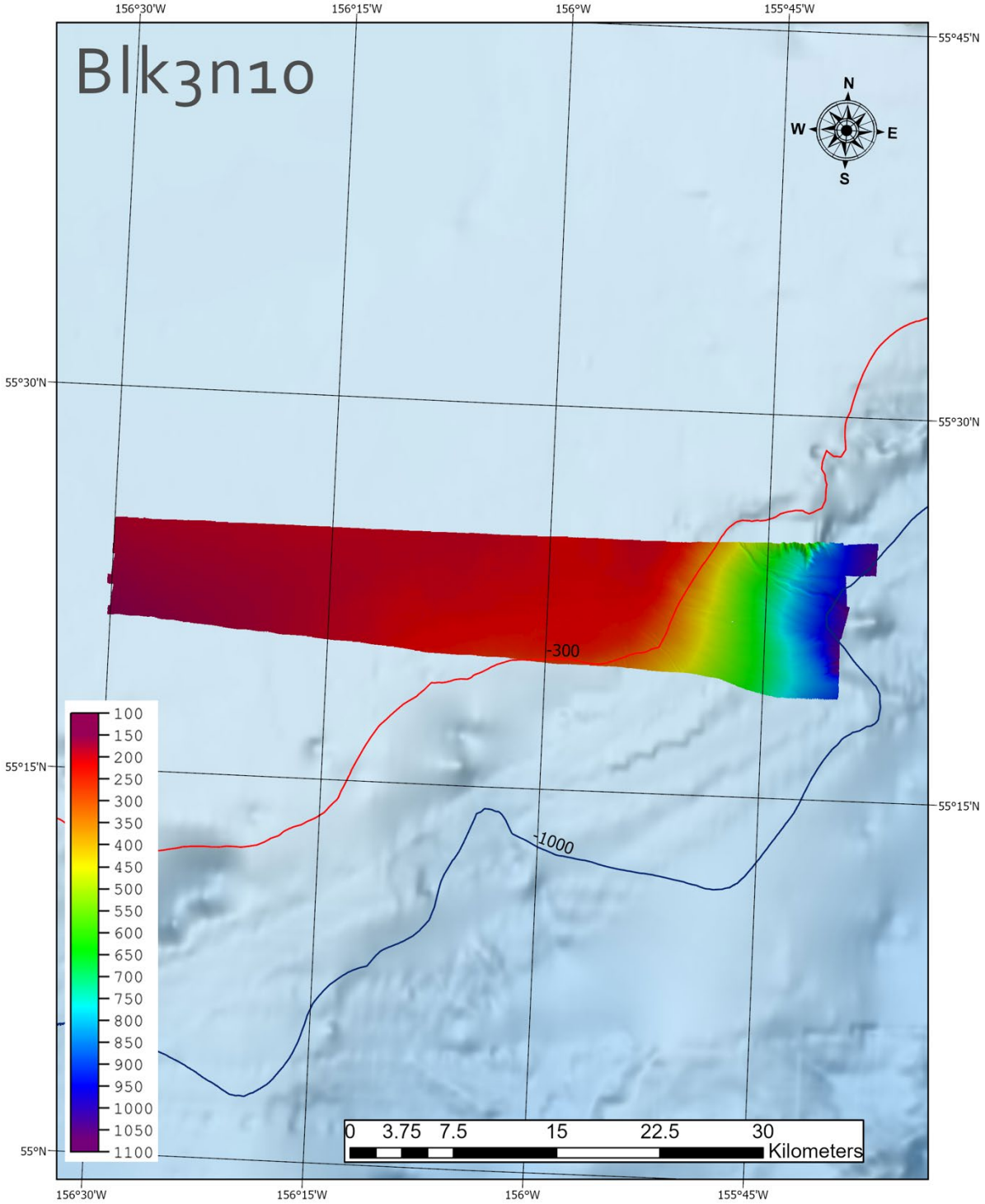
-1000
0 5 10 20 30 40
Kilometers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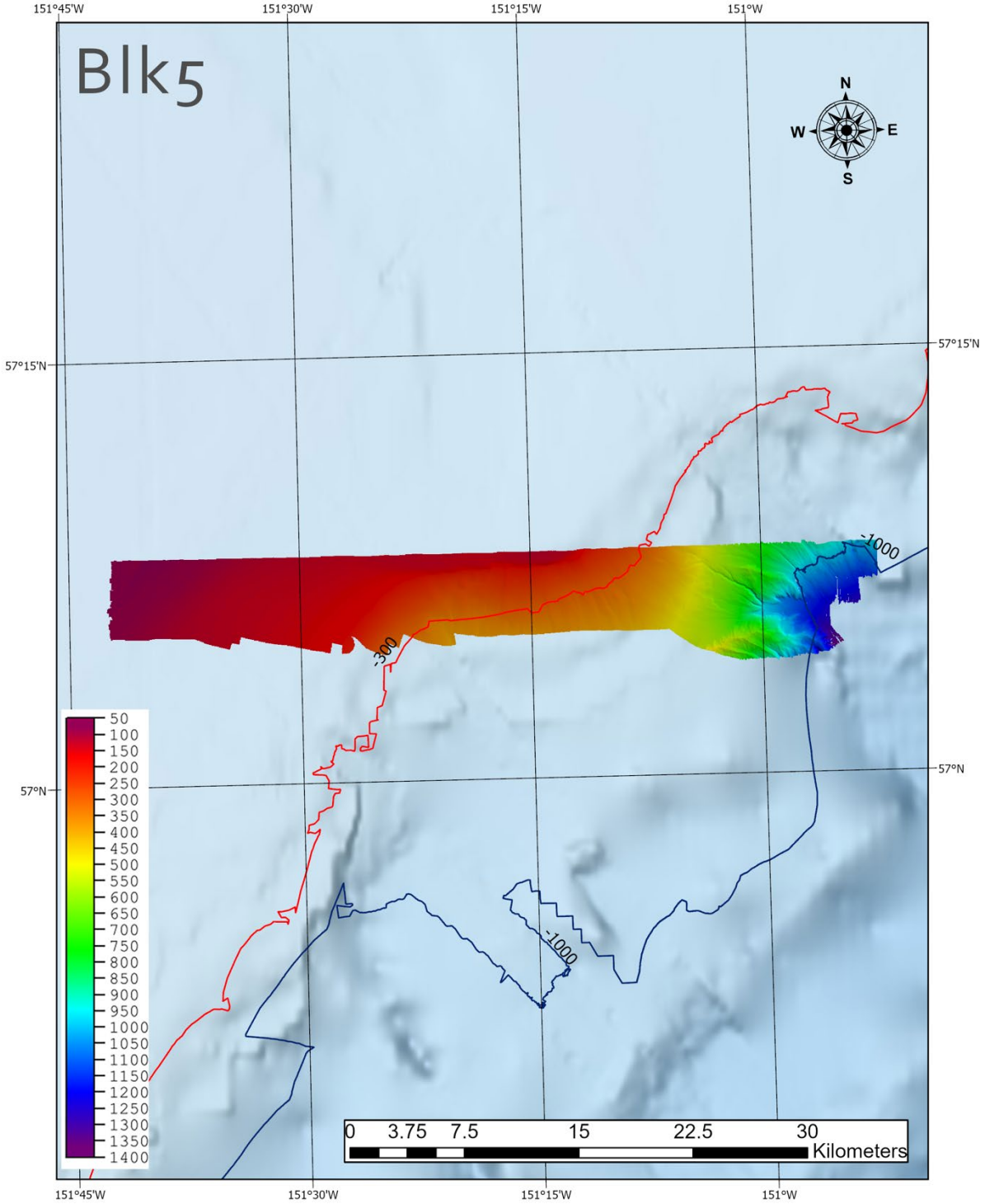
Kilometers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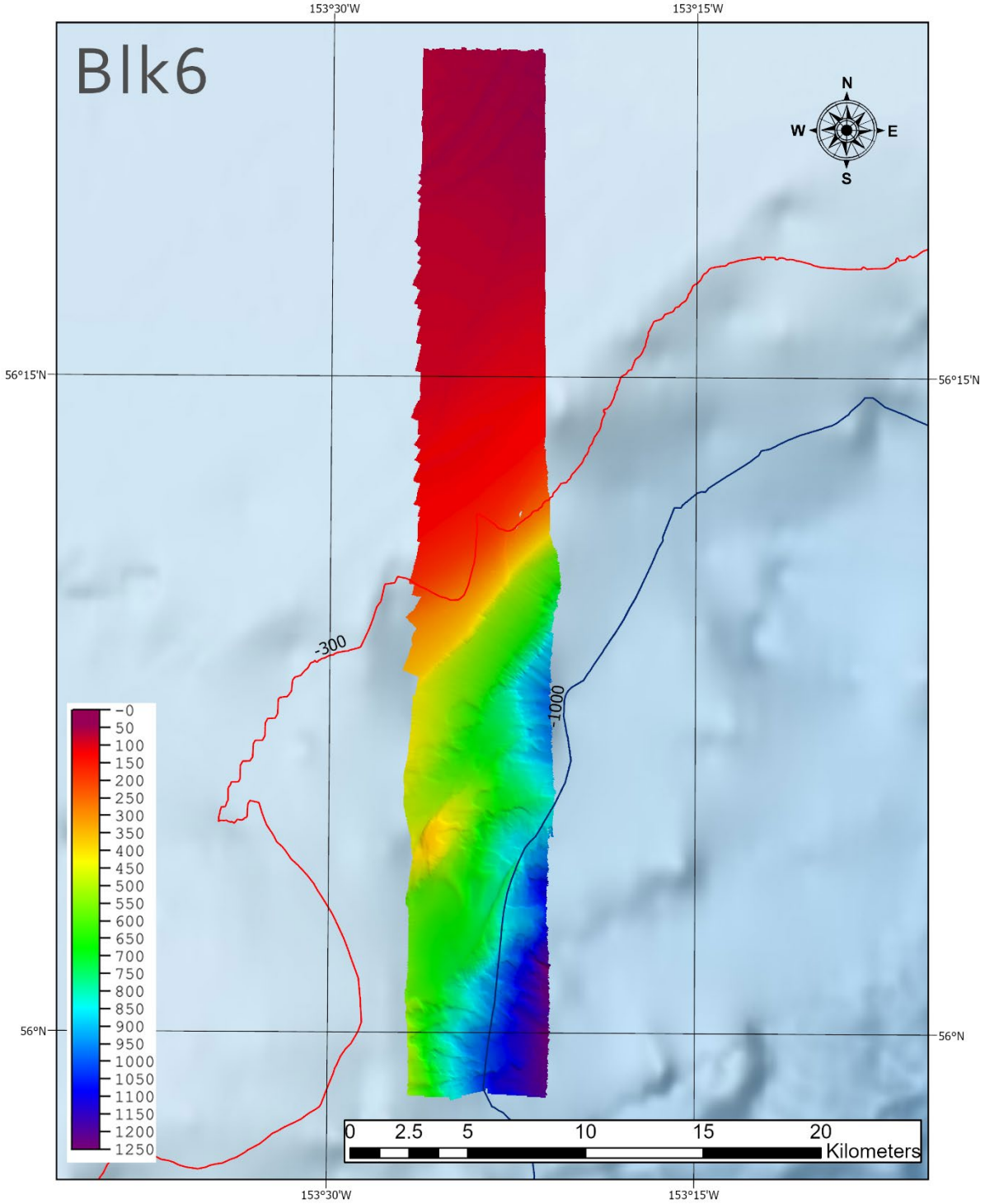
1400
0
3.75
7.5
15
22.5
30
Kilometers


Blk6
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153°15'W
56°15'N
56°N
N
W
E
S
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-1000
-0
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150
200
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300
350
400
450
500
550
600
650
700
750
800
850
900
950
1000
1050
1100
1150
1200
1250
0
2.5
5
10
15
20
Kilometers

Appendix 3 – Head 1 Bias Calculation

A benefit of many modern MBES' is the simultaneous acquisition of precisely coincident georeferenced backscatter. But rarely are MBES' put through a calibration procedure, and as such produce relative backscatter. A calibration procedure would become important, for example, in instances where data from multiple echosounders would be compared or used in a common survey area, in a time series scenario, or perhaps when a transducer has been replaced. Since acoustic calibrations are generally accomplished at an established facility within a tank using some known target source level, they are costly and not always feasible since it involves removal of the system from the vessel.

To approach handling this situation in FMGT, upon selecting the Sonar Type within the sonar processing parameters, the software automatically populates various parameters specific to the chosen echosounder, which includes a Head 1 dB reference value (Fig. 8). Head 1 dB is a magical internal pre-defined value generated from expert knowledge by the software engineers and the acoustic community. It is treated as a constant that is essentially added to the raw signal to get a particular echosounder to output the range of backscatter (in dB domain) values near accepted sediment response curve levels (J. Beaudoin, Quality Positioning Services, pers. comm., 2020).

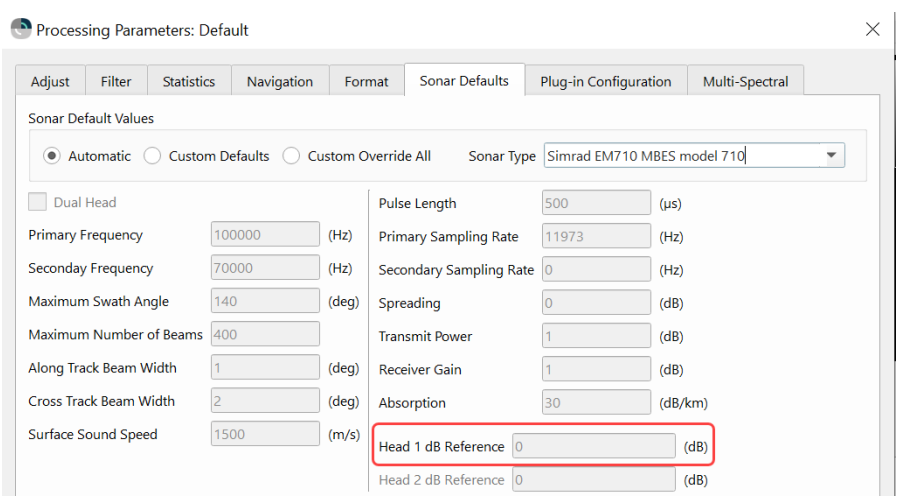

Figure 8. -- Sonar Type configuration within the FMGT processing parameters, highlighting the Head 1 dB reference entry.

However, the Head 1dB Bias value, found in the Adjust Tab (Fig. 5) allows the user to set an additional bias that will get added (or subtracted) on top of all the other initial correctors stated in the Backscatter Processing section. Minor adjustments of this bias value permit the user to shift the

data in an effort to match output levels produced between completely different survey vessels, for example, or perhaps accommodate different performance from the same vessel as the behavior of a particular transducer changes over time due to fatigue in the piezo-ceramic material.
Since the Head 1 dB Reference value is purely a best guess constant to get the data somewhat close to an accepted backscatter value found in sediment response curves, we attempted to go a bit further by using the Head 1 Bias value in a creative way to provide some degree of pseudo-calibration for the backscatter data in lieu of a highly costly and time consuming tank calibration procedure. To that end, we leveraged the modeled phi output produced by the Angular Range Analysis (ARA) in FMGT to shift the dataset to closely approximate sediment grain-size distribution as determined from in situ sediment grab samples and data classified using the Krumbein phi scale. During a 2016 project in the Bering Sea, 13 grab samples were acquired with a VanVeen grab sampler attached to the Seaboss or with a Shipek sampling device. Three of these 13 samples were excluded from analysis as they were acquired in areas where the sonar mode was set to operate in a different ping setting thereby making them less comparable to data acquired at the other sites. The grab samples were attempted to be acquired within or near an area of seafloor recently surveyed with the EM710. Unfortunately, in several cases the ship drifted away from the defined MBES swath coverage for the grab sampling exercise (Table 5). However, due to the extreme low number of available samples (n = 10) for averaging phi values, the samples were still included in the adjustment exercise under the assumption that the Bering Sea is generally considered flat and featureless and that frequent local changes in sediment types are unlikely (Smith and McConnaughey 1999). The grab samples were later processed by SedTrend using a Malvern Masterizer 2000 optical unit with a Malvern Hydro 2000G sample-handling unit to obtain various sediment grain size characteristics including a quantitative mean phi based on the Krumbein scale.

Within FMGT, an ARA was computed from the raw sonar files at each sampling site and the modeled phi value was recorded (Table 5) from the pixel of interest (i.e., at the sample site). Where the sample was obtained outside the swath coverage, the closest pixel was selected. This procedure was run multiple times, altering the Head 1 dB bias setting from the default setting of 0 to various values. In each instance the modeled phi value from the output at each sample site was recorded.

Thereafter, the difference of squared phi values between the in-situ phi and modeled ARA phi was calculated as:

$$\text{Squared Phi Diff} = (\text{Grab Phi} - \text{ARA phi})^2.$$

From this step, the average sum of squared differences from all the grab sample sites was then calculated for each Head 1 dB Bias offset value (Table 6). The Head 1 dB value corresponding to the minimum difference value was used for processing the entire sonar data set for the GOATS survey. In this case, a Head 1 dB bias offset of 5 dB was determined to minimize the sum of square differences between the in-situ phi and ARA modeled phi values and was entered into the FMGT adjust tab (Fig. 5). Since no grab samples were acquired during the 2018 effort, the same Head 1 dB offset value calculated from the 2016 survey effort was likewise used for processing of the 2018 backscatter data.

Table 5. – In situ phi (Grab Phi) and modeled ARA phi values calculated at each of the 10 grab sample sites. ARA was conducted after altering the Head 1 dB Bias from 0 to 3, 4, 5, 6 and 7 dB. distOff is the distance in meters from the actual in situ grab sample and the MBES swath coverage at a particular site. For example, 0 means the sample was taken within the swath coverage and 1800 indicates the ship had drifted nearly 2 km away by the time a grab sample was successfully acquired.

Station	*grabPhi*	*distOff*	*0 hdb*	*3 hdb*	*4 hdb*	*5 hdb*	*6 hdb*	*7 hdb*
TX2	0.818	1800	3.48	1.83	1.35	0.83	0.06	-0.67
TX3	1.657	1200	6.05	3.58	3.27	2.71	1.83	1.49
TX4	1.770	1200	3.15	2.44	2.19	1.77	1.39	1.08
TX5	1.474	1100	2.01	0.24	-0.87	-1.00	-1.00	-1.00
TX6	1.853	1500	3.38	2.18	1.71	1.30	0.57	-0.54
TX7	2.027	0	3.18	2.48	2.24	1.95	1.62	1.16
TX9	3.632	35	4.14	3.30	2.73	2.44	1.82	1.32
TX10	1.867	0	5.51	3.43	2.70	2.15	1.66	1.23
TX11	3.305	800	9	3.84	3.13	2.67	2.24	2.17
TX12	2.162	1100	4.2	3.25	2.79	2.52	1.81	1.34

Table 6. -- Average sum of squared differences between in-situ grab phi and ARA modeled phi for all 10 sample sites by various Head 1 dB Bias settings. Note a Head 1 dB value of 5 minimized the average sum of squared differences.

Head1 dB Value	Average Sum of Squared Differences
0	82.354
3	11.029
4	10.554
5	**9.574**
6	13.266
7	23.032

Appendix 4 – BSCor Analysis

The following cursory review of the EM710 BSCor file used on the NOAA ship *Fairweather* installation was provided by Dr. Lloyd Huff -- July 2018.

Overview of the EM710 Principles

The EM710 works on the scheme of crossed beams, wherein the transmitted acoustic energy that propagates from the system to the seabed is confined within a fan-shaped volume that is wide in the cross-track direction and narrow in the along-track direction. That statement might evoke a mental image of a Mills Cross array that is used in many multi-beam bathymetric system, where there is single fan beam, that is nominally 120 degrees wide in the cross-track direction. However, the EM710 is closer to the bathymetric subsystem (ENAS) of the Klein 7180 Long Range Sonar System, than to a standard Mills Cross system. That is because the transmit fan beam in the EM710 is actually made up of three separate, but slightly overlapping, fan beams, all of which, transmit at the same time. The three transmit fans of the EM710 are pointed in different directions, namely to port of nadir, toward nadir and to starboard of nadir. That pattern provides the EM710 with directivity diversity.

Each of the three fan-shaped beams are nominally 60 degrees wide in cross-track and their combination has a nominal cross-track spread of 150 degrees. Due to the overlap between the three fan-shaped beams, directivity diversity is insufficient to provide the beam-to-beam isolation that is necessary for high quality measurements of backscatter and bathymetry. Therefore, the EM710 employs frequency diversity, in addition to directivity diversity. The frequencies used for any particular fan-shaped beam sector and operating mode vary between 73 kHz and 97 kHz. In some operating modes, the acoustic pulse is a short (0.2 to 2 ms) CW segment of a continuous sinewave (in the frequency range between 73 and 97 kHz). In other operating modes, the acoustic pulse is a relatively long (20 to 120 ms) frequency modulated sinewave, centered in the frequency range of 73 to 79 kHz.

Given that the physical dimension of the EM710 transmit transducers are fixed, the dimension of the EM710 transmit transducers, expressed in terms of acoustic wavelength, is not fixed, therefore the exact beam pattern and directivity gain of the EM710 transmit transducers will change with acoustic frequency and sound speed at the face of the transducers.

Acoustic backscatter is an important measurement parameter of the EM710. The sonar equation is used to estimate the acoustic backscatter strength of the seabed based on the measurements of acoustic pressures (echoes) that are sensed by the EM710 receivers in a narrow time-window, centered on the point-in-time the EM710 determines to coincide with the two-way travel time of the transmit pulse(s) to each particular area of a wide cross-track swath of the seabed, and return.
The sonar equation employs: 1) the source level and beam pattern of the transmit transducer; 2) refraction in the water column; 3) spreading in the water column; 4) absorption in the water column; and 5) the receive sensitivity and beam pattern of the receive transducer, to estimate the acoustic backscatter strength of the sea bed.

Review of the BSCor Entries for NOAA Ship Fairweather

It is possible to combine the impacts that the transmit and receive beam patterns (both of which vary with frequency) have on the estimation of acoustic backscatter. A table of "dB adjustments" as a function of off-nadir angle is sufficient to remove the impact of the transmit and receive beam patterns, and thereby "normalize" the acoustic backscatter.

The EM710's BSCor file is essentially such a table of adjustments for several different off-nadir angles for each of its three fan-shaped beams and 14 different operating modes. The BSCor file also contains 42 entries for Source Level; one for each of its three fan-shaped beams in each of its 14 operating modes (Very Shallow - Extra Deep).

In the EM710's twelve operating modes associated with the Very Shallow thru Deep modes, the system will normally use the center fan-shaped beam and its associated BSCor values to report backscatter values in the off-nadir angular range from -40 to 40 degrees. Under the same twelve operating modes, the backscatter values reported from off-nadir angles less than -40 degrees will normally use the starboard fan-shaped beam and its associated BSCor values. Under the same twelve operating modes, the backscatter values reported from off-nadir angles greater than 40 degrees will normally use the port fan-shaped beam and its associated BSCor values.

The frequency diversity of the EM710 is also such that in any particular fan-shaped beam sector, several different operating modes may employ the same frequency. The combined impact of the transmit and receive beam patterns in any particular fan-shaped beam sector is a function of

frequency. **Therefore, one would expect that the BSCor file entries for repeat occurrences of a particular combination of fan-shaped beam sector and frequency should be identical**. This important point provides a means of assessing, not the accuracy, but the precision of the BSCor file entries for the EM710 installation on the NOAA ship *Fairweather*.

Figure 9 shows that the diversity combination of 73 kHz and PORT SECTOR is used 10 times. The most of any combination of a particular sector and a particular frequency. This composite of BSCor file entries for 73 kHz & the PORT SECTOR shows the expectation that **repeat occurrences of a particular combination of fan-shaped beam sector and frequency should be identical, is not met.**

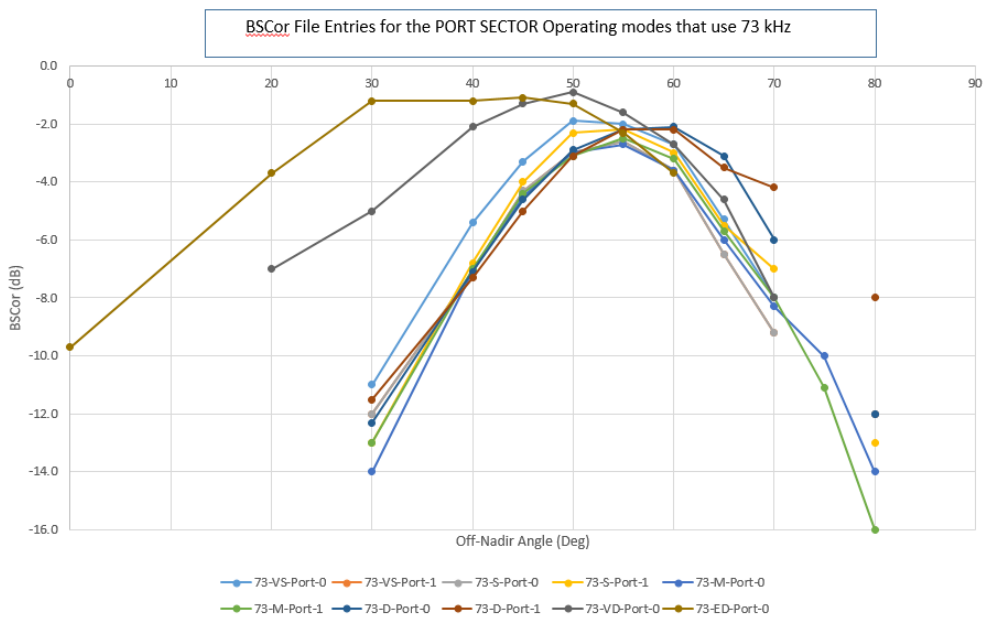

Figure 9. -- Plot of the various Port Sector BSCorr entries using the 73 kHz frequency. VS = Very shallow, S = Shallow, M = Medium, D = Deep, VD = Very Deep, ED = Extra Deep; 0 = single ping mode, and 1 = first of two pings in dual ping mode

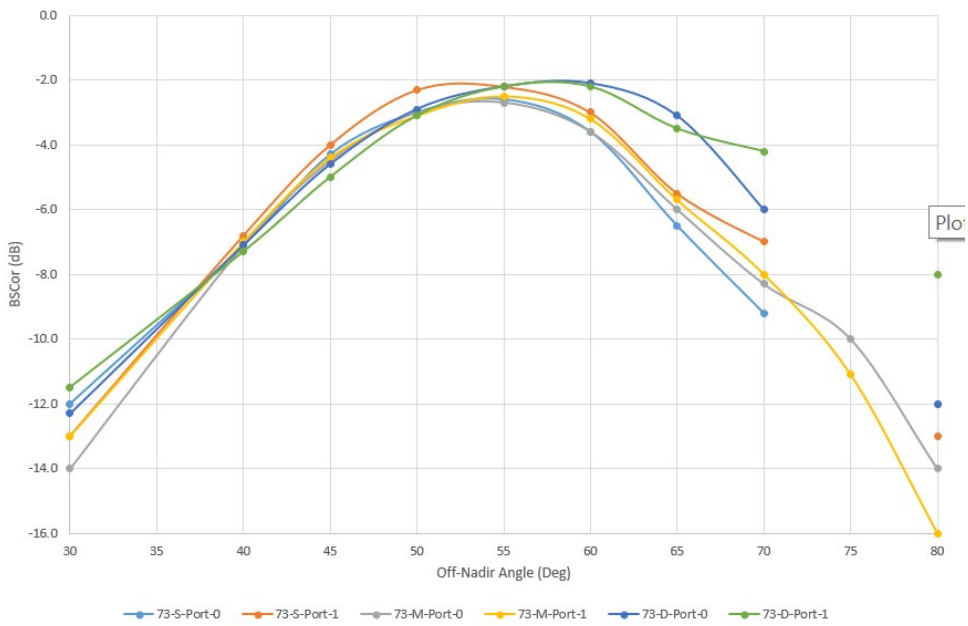

Figure 10. -- Composite of the 73 kHz BSCor values from ONLY the modes expected to be used during the 2018 GOATS projected (adjusted for source level).

When the composite of 73 kHz BSCor file entries is reduced to only the depth modes that are expected to be used during the 2018 GOATS cruise (Fig. 10), the curves are clustered more tightly. Within the applicable angular sector (40 to 65 degrees), there is up to a 3 dB spread between the several different curves for the PORT SECTOR at 73 kHz (Fig. 11). Therefore, any spread in the 73 kHz PORT SECTOR BSCor file entries will introduce uncertainty in all applications of Backscatter measurements that are reported from the EM710's PORT SECTOR. The maximum off-nadir angle for backscatter that will be utilized for the Gulf of Alaska Cruise in August-September 2018, is 65 degrees.

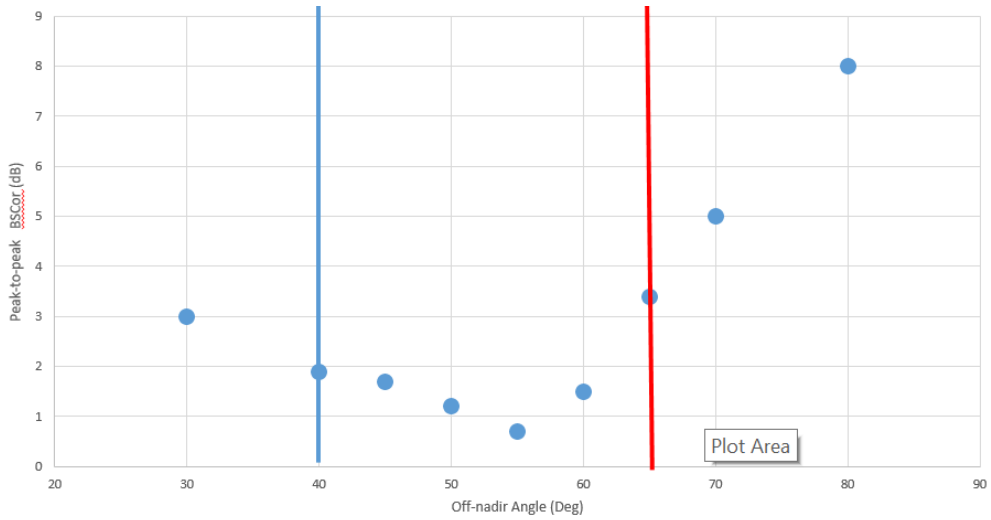

Figure 11. -- Peak-to-Peak spread among BSCor values for 8 different Port Sector Operating Modes at 73 kHz.

The Starboard Sector employs 3 different frequencies (73, 75 and 76 kHz) in its suite of frequency diversity. Again in the applicable angular sector -40 to -65 degrees off-nadir, there are discrepancies up to 3 dB (Figs. 12-14). Any uncertainty in the Starboard Sector BSCor file entries will introduce uncertainty in all applications of Backscatter measurements that are reported from the EM710's Starboard Sector.

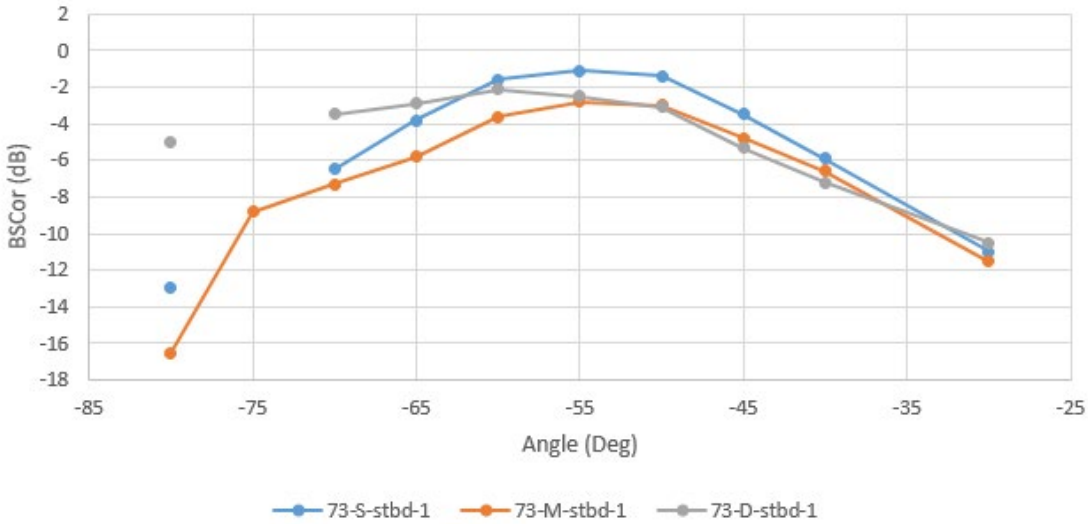

Figure 12. -- Starboard Sector BSCorr values at 73 kHz (adjusted for source level) for the S = shallow, M = Medium, and D = Deep single ping mode.

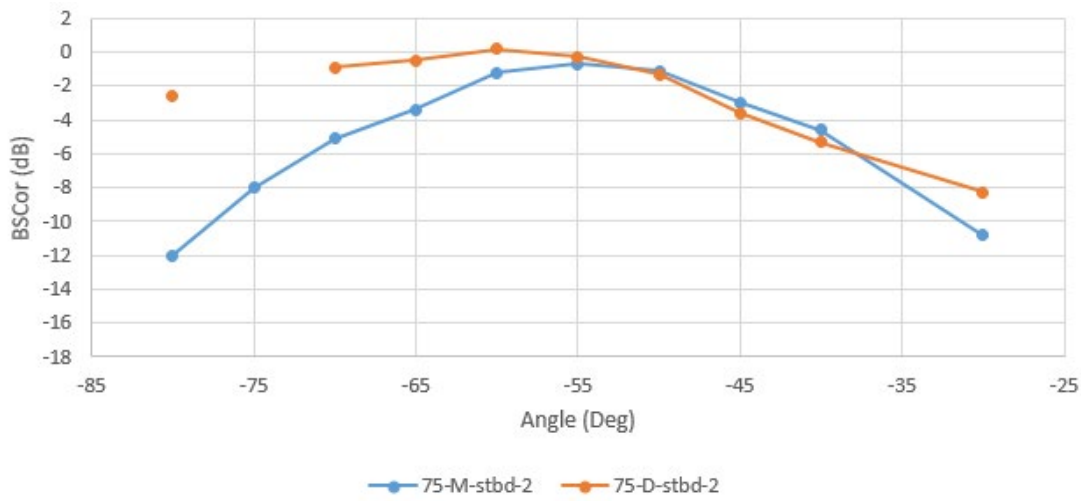

Figure 13. -- Starboard Sector BSCorr values at 75 kHz (adjusted for source level) for the M=Medium, and D=Deep single ping mode.

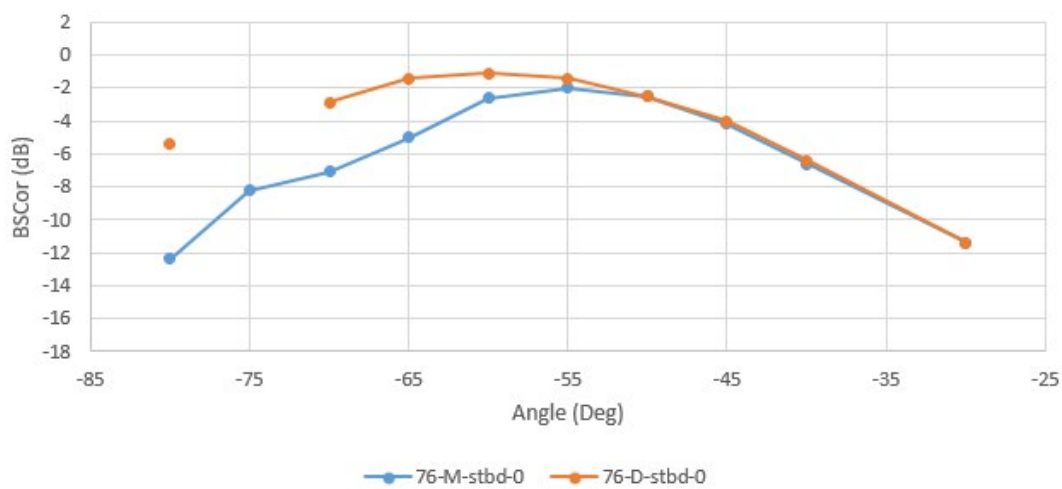

Figure 14. -- Starboard Sector BSCorr values at 76 kHz (adjusted for source level) for the M = Medium, and D = Deep single ping mode.

The CENTER SECTOR has four different frequencies (77, 79, 81, and 85 kHz) in its suite of frequency diversity. 81 kHz occurs only once, so there can be no intra-comparison at that frequency, as there are at the other three frequencies.

In the angular sector -40 to 40 degrees off-nadir, there are discrepancies up to 3 dB. Any uncertainty in the Center Sector BSCor file entries will introduce uncertainty in all applications of Backscatter measurements that are reported from the EM710's Center Sector.

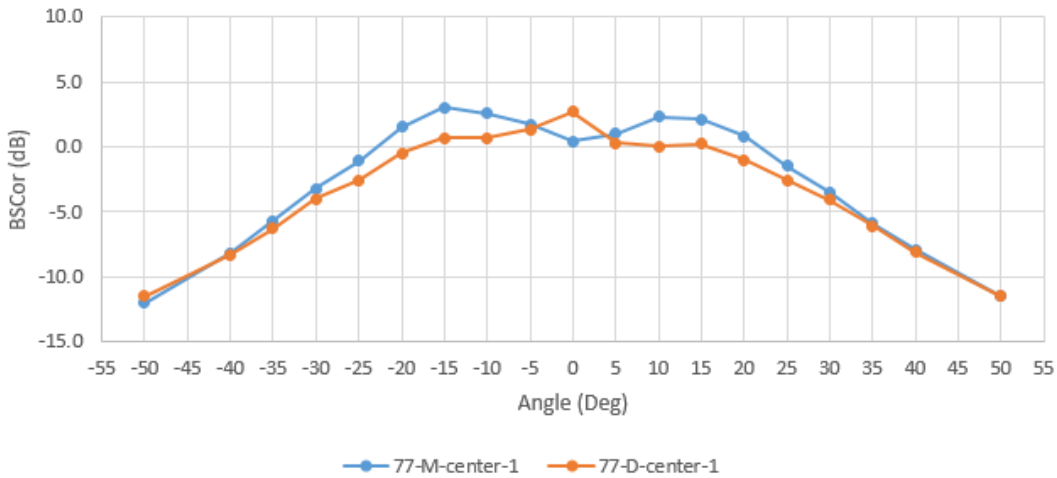

Figure 15. -- Center Sector BSCorr values at 77 kHz (adjusted for source level) for the M = Medium, and D = Deep.

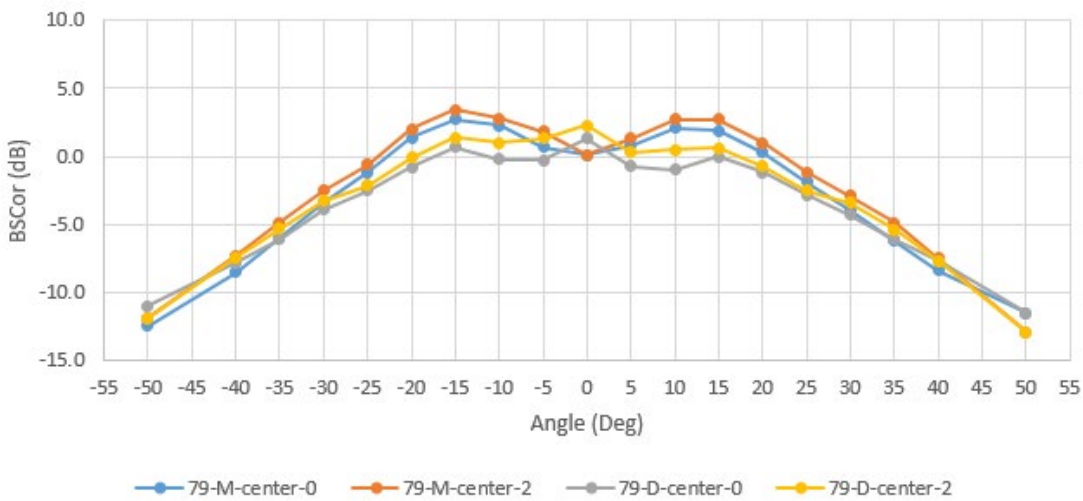

Figure 16. -- Center Sector BSCorr values at 79 kHz (adjusted for source level) for the M = Medium, and D = Deep; 0 = single ping mode and 2 = second ping of dual ping mode.

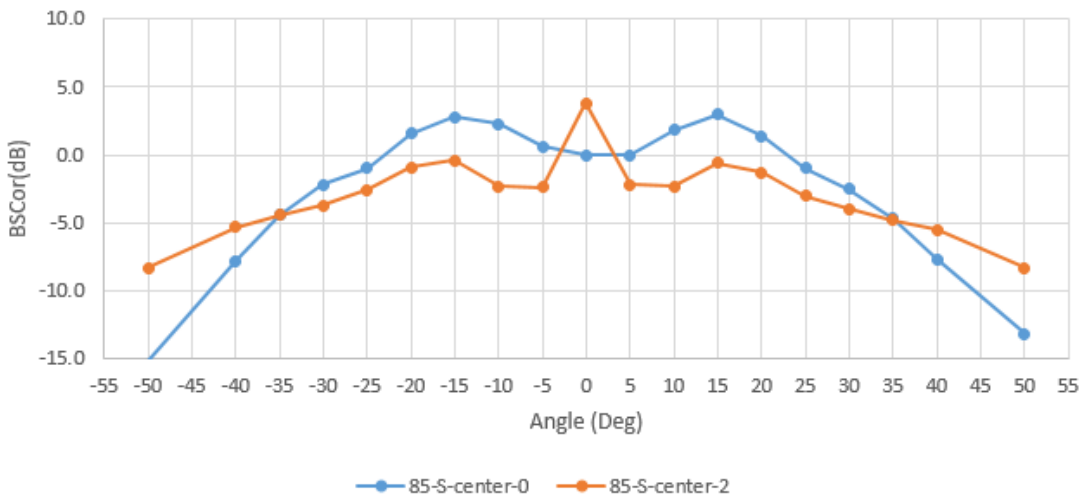

Figure 17. -- Center Sector BSCorr values at 85 kHz (adjusted for source level) for the S = shallow; 0 = single ping mode and 2 = second ping of dual ping mode.

Finally, Figure 18 provides a composite of the Center Sector BSCor values and might be interpreted as showing the impact of frequency on the transmit and/or the receive beam patterns, but the range of frequencies is only about 10% of the nominal frequency, therefore that interpretation should probably be discounted.

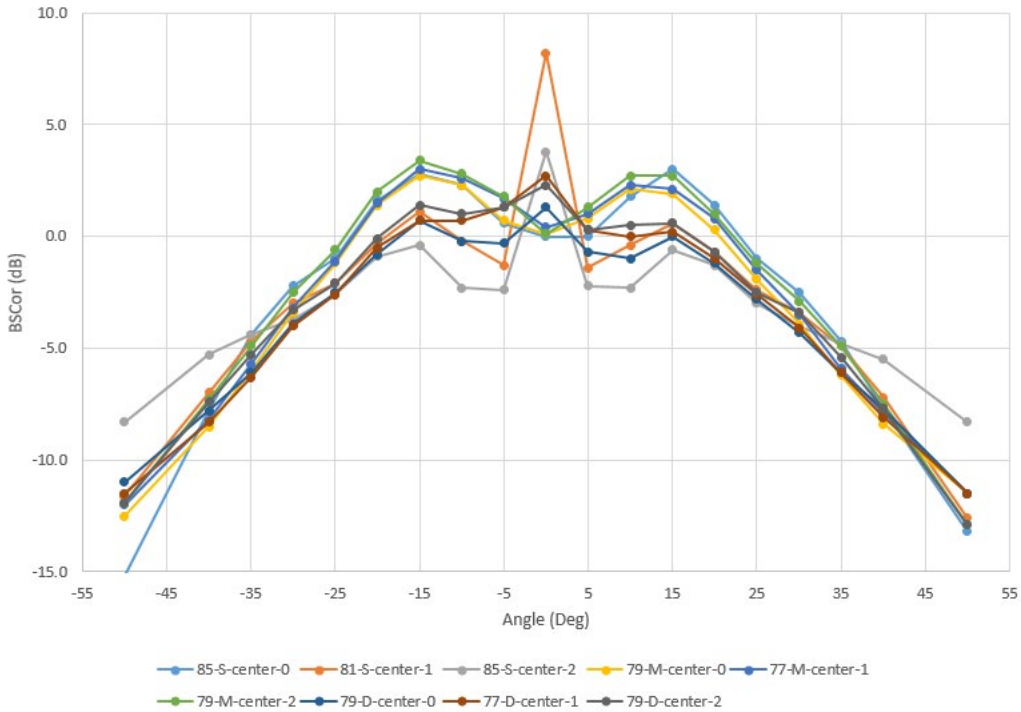

Figure 18. -- Center Sector Composite of BSCor entries (adjusted for source level) at 77, 79, and 85 kHz for the S = Shallow, M = Medium, and D = Deep modes; 0 =s ingle ping mode, 1 = first ping of dual ping mode, and 2 = second ping of dual ping mode.

Based on Figure 18, even if one decided to exclude any backscatter data within 15 degrees either side of nadir, there would still be in excess of 3 dB uncertainty in backscatter from the Center Sector. Based on past experiences, one might more readily accept the 77-M-Center-1, 79-M-Center-0, 79-M-Center-2 and 85-S-Center-0 curves, than the other curves.

BSCorr Conclusion

This cursory examination of the BSCor file entries for the EM710 on the NOAA Ship *Fairweather* has brought to light issues that should cause one to be cautious about the confidence that is assigned to the backscatter values, especially when the system changes its operating mode. This cursory examination has also shown that one should be cautious about the confidence that is assigned to the backscatter values reported either from within +/-15 degrees of nadir, or from beyond 55 degrees to either side of nadir. There also appears to be up to 3 dB discrepancies in all three sectors, and any uncertainty in the BSCor file entries will introduce uncertainty in all applications of Backscatter measurements that are reported from the EM710.

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U.S. Secretary of Commerce
Wilbur L. Ross, Jr.

Acting Under Secretary of Commerce
for Oceans and Atmosphere
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