DSSV Pressure Drop: Descriptive Report

South Sandwich Trench
And
Agulhas Fracture Zone

February 2019

Report developed for Five Deeps Expedition by Cassie Bongiovanni

Internal Use Only

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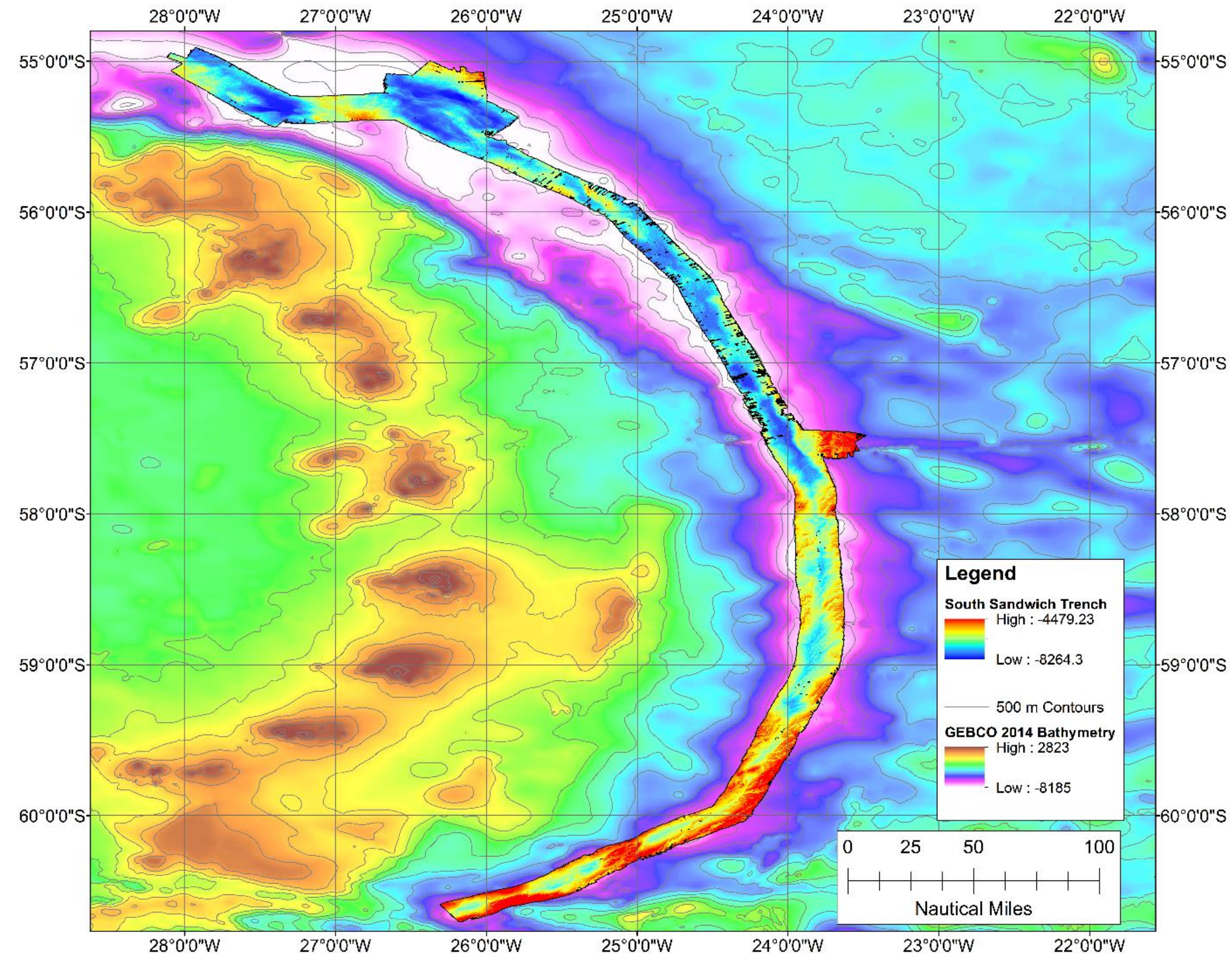

Figure 1: South Sandwich Trench (SST) bathymetry collected with the Kongsberg EM 124 over GEBCO 2014 estimated bathymetry.

The South Sandwich Trench (Figure 1) was surveyed with a Kongsberg EM 124 gondola-mounted to the hull of the 225-foot DSSV Pressure Drop. The survey was conducted over the course of seven days – February 2-9, 2019. The data meet the requirements for IHO Special Order standards.

The South Sandwich Trench (SST) is within the following limits:

Northwest Limit	Southeast Limit
54°45'57.073"S	60°43'43.099"S
28°10'10.49"W	23°29'38.4"W

Table 1: Survey Limits

0.1.2 Agulhas Fracture Zone

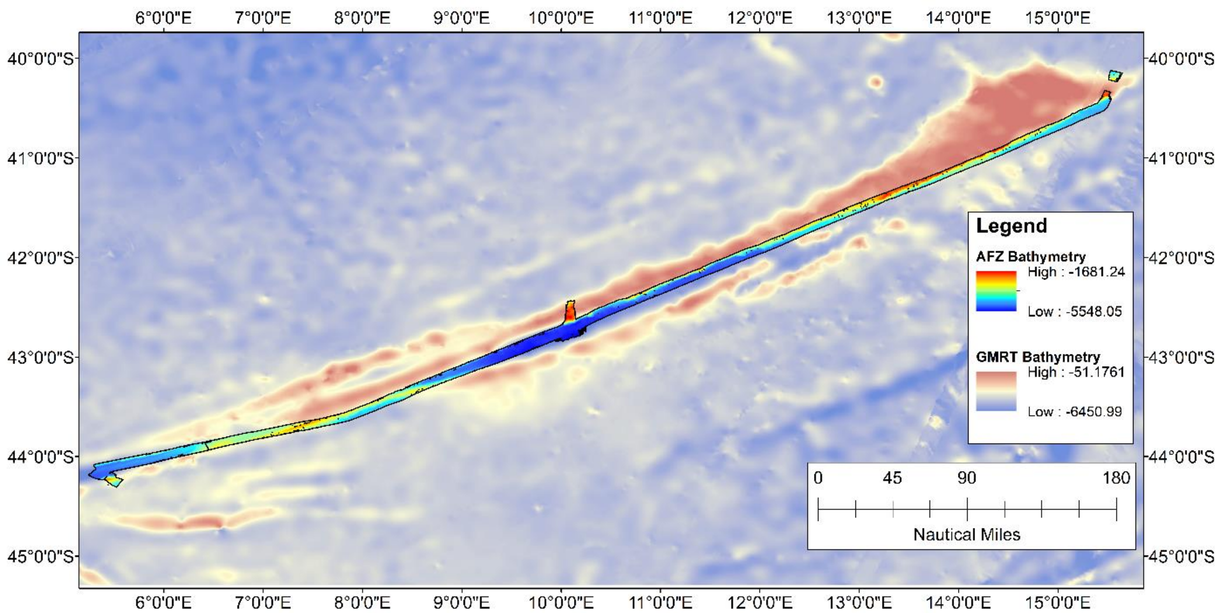

Figure 2: Agulhas Fracture Zone EM 124 collected bathymetry over GMRT bathymetry.

The Agulhas Fracture Zone (Figure 2) was surveyed with a Kongsberg EM 124 gondola-mounted to the hull of the 225-foot DSSV Pressure Drop. The survey was conducted over the course of four days – February 16-20, 2019. The data meet the requirements for IHO Special Order standards.

The Agulhas Fracture Zone (AFZ) is within the following limits:

Northwest Limit	Southeast Limit
39°51'28.648"S	44°32'26.653"S
4°53'29.489"E	15°41'5.136"E

Table 2: Survey Limits

0.2 Survey Purpose

Multibeam data were acquired by the DSSV Pressure Drop as part of the 5 Deeps Expedition. These data were collected to determine the deepest point in the Southern Ocean with the specific intention for a manned submersible to dive to it. Additional data were collected in the Agulhas Fracture Zone (AFZ) for scientific exploration. It is anticipated that all these data will help the greater scientific understanding of the area and contribute to the international effort to create a complete high-resolution map of the oceans (i.e. GEBCO 2030).

0.3 Survey Plan

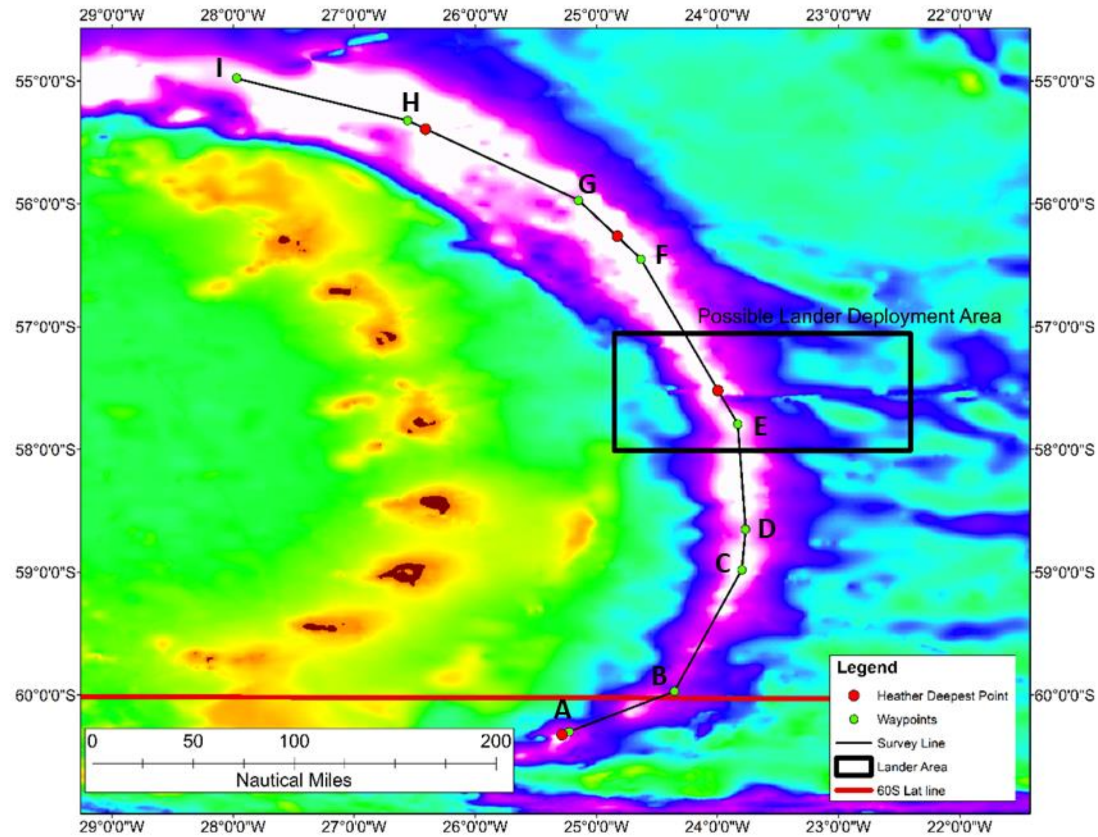

Figure 3: South Sandwich Trench area with NOAA ETOPO1 bathymetry and possible deeps identified by Stewart and Jaimeson (red points) (2018) SST line plan with waypoints (green points) and scientific lander deployment location (black box).

Stewart and Jaimeson (2018) identified multiple possible deep locations in the northern part of the SST as shown in Figure 3, all of which could have been the Meteor Deep. However, only one proposed deepest point was thought to be below 60°S. To identify the location of the deepest point below 60°S with the highest degree of certainty, we did two passes over the southern portion of the trench (Figure 4). It was found that the more central basin was where the deepest point was located, rather than the northern one. The final line plans are shown in Figure 4 and the final dive and science lander locations in Figure 5.

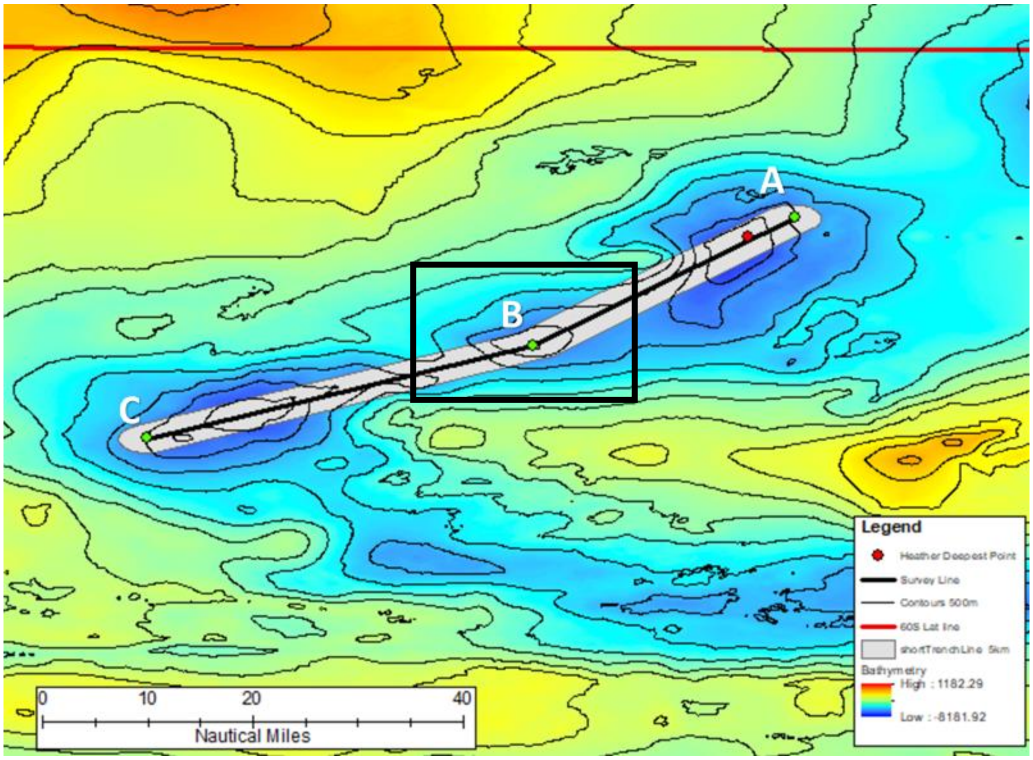

Figure 4: SST mapping plan. Black outline shows the deepest area (> 7,430 m). Black line indicates the line plan, a second line was run parallel and offset by 5 km. Red line is the 60S latitude line. Waypoints in green and proposed deepest point indicated in red. A 15km swath was estimated for this mission the bounds of which are in grey.

We approached the survey area from the Northwest near the 60^{o}S line coming from South Georgia and the South Sandwich Islands at 12 knots. Upon entry to the trench, the line plan was run as expected with minor deviations to avoid icebergs at a survey speed of 8 knots. A second pass was completed along a parallel but offset line running from waypoint C back up to A. This line was offset by about 5 km. The deepest point was identified near waypoint B. Once the location was identified, the ship transited back to that site. Lander locations were determined based on the 7000, 6500, and 6000 meter contours.

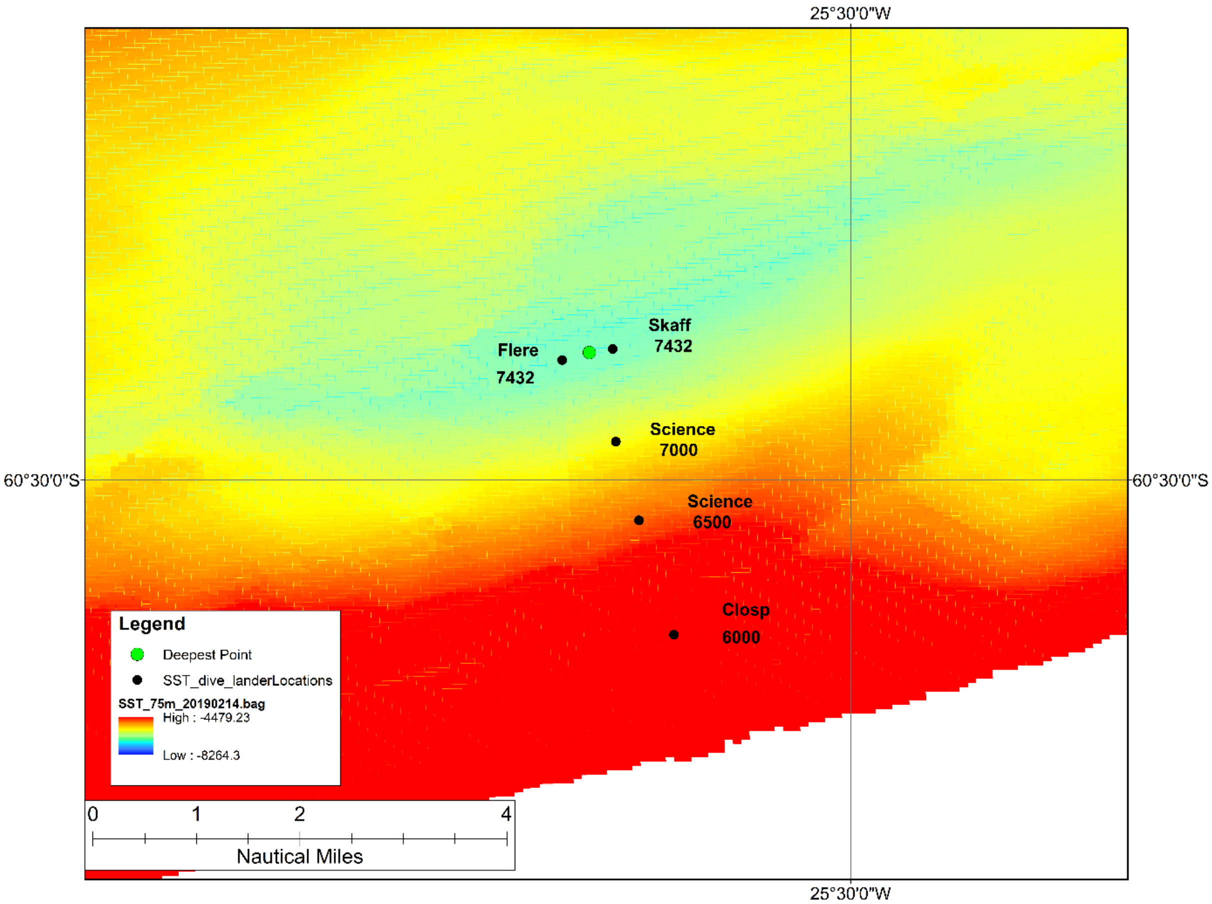

Figure 5: Final SST dive location and lander deployment locations.

Once on location, all landers were deployed. The successful mission brought validation to the depth we identified with a difference of less than a meter, well within the limits of the sonar.

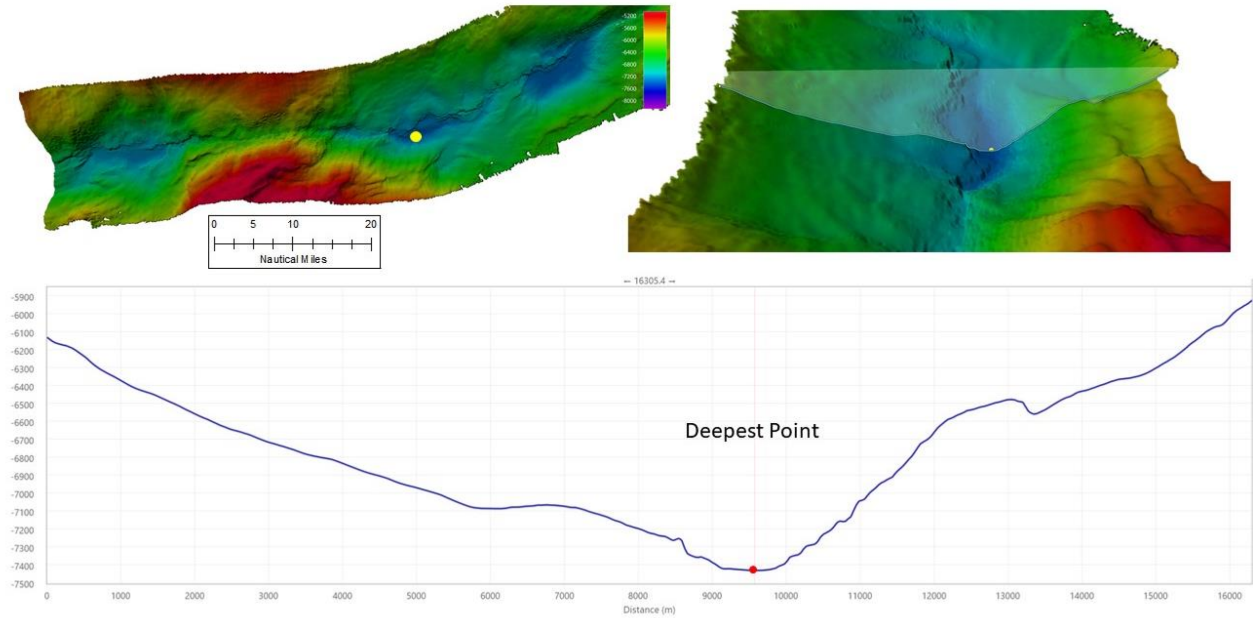

Figure 6: Verification of dive location in SST

The final dive location was: 60°28'46.213"S, 25°32'31.48"W.

The official final depth was recorded as: 7433.6 m.

0.4 Survey Quality

All data meet IHO Special Order specifications and should supersede any prior data for all intents and purposes.

0.5 Survey Coverage

Complete coverage was achieved for the south of 60ºS portion of the SST data collection. However, we hit a rough weather patch at about 57º 30’ S which continued for a day or two once we were north of 60ºS. We still managed to get ~7km swath widths, though it wasn’t consistent on either side of nadir and left some small gaps here and there. In the AFZ, complete coverage was obtained with 16-18km swath widths.

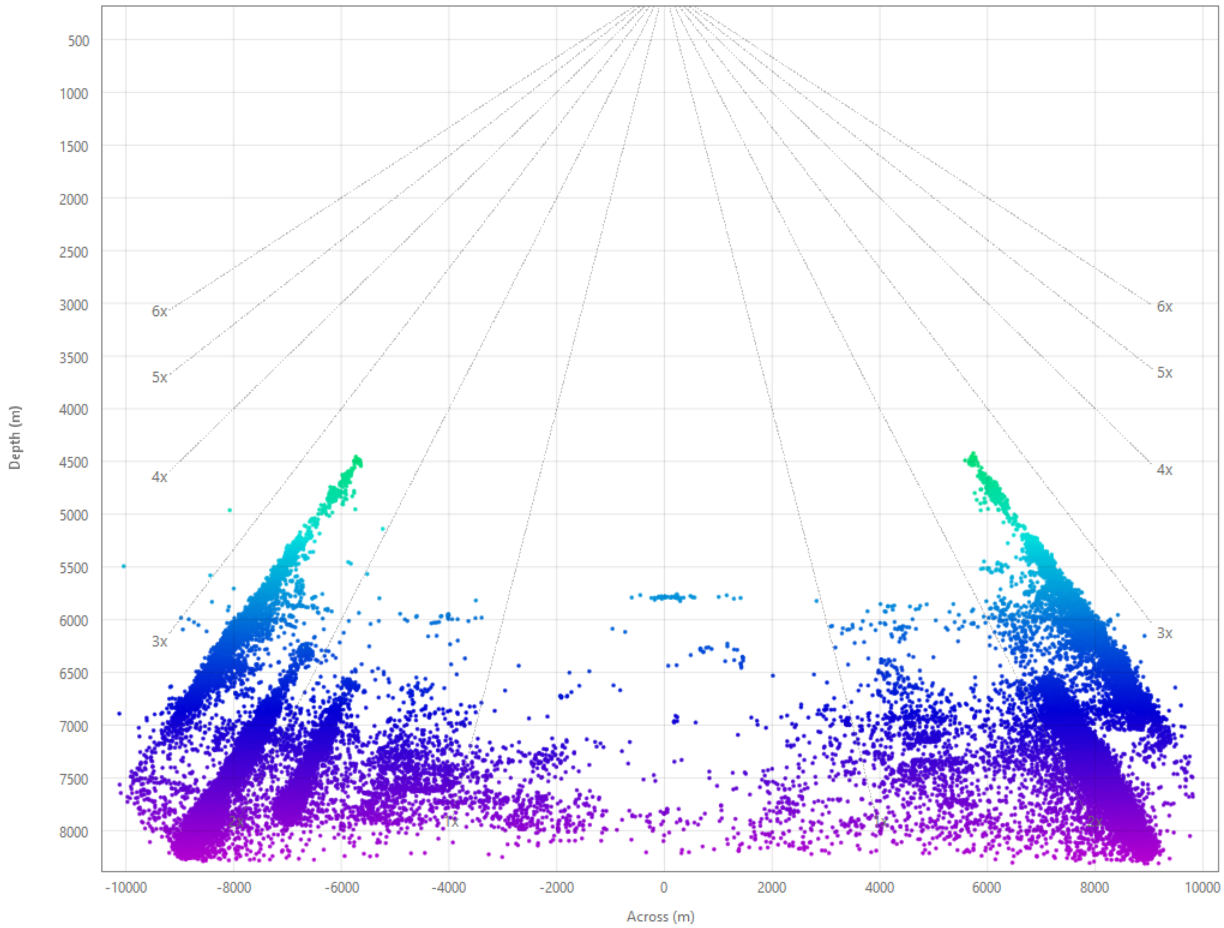

Figure 7: EM 124 SST survey extinction plot.

Inside the trench, we achieved swath widths around 17-18 km with 50-55° coverage on either side of nadir – just over 2x water depth (Figure 7). During the sonar installation, Kongsberg technicians determined that the DSSV Pressure Drop inherently produces 60 dB of noise which can contribute to the smaller swath widths. Additionally, the Southern Ocean is notorious for poor weather conditions which was a huge factor for a number of days.

0.6 Survey Statistics

0.6.1 South Sandwich Trench

The following tables lists the survey mileage for this survey:

	Vessel	Total (km)
	SBES Mainscheme	0

Line Type	MBES Mainscheme	263
	SBES/MBES Combo	0
	MBES Crosslines	0
Number of Bottom Samples		0
Survey Area (KM^2)		15,220.7

Table 3: SST Survey Statistics

The following table lists the specific dates of data acquisition for this survey:

Date	Julian Day
02-02-2019	33
02-09-2019	40

Table 4: Julian Day, survey dates for SST

Survey lines were run with a 12 kHz multibeam echosounder. Statistics were calculated in ESRI ArcGIS 10.6.1 (*personal license*).

0.6.2 Agulhas Fracture Zone

The following tables lists the survey mileage for this survey:

	Vessel	Total (km)
Line Type	SBES Mainscheme	0
	MBES Mainscheme	148
	SBES/MBES Combo	0
	MBES Crosslines	0
Number of Bottom Samples		0
Survey Area (KM^2)		18,302.1

Table 5: AFZ Survey Statistics

The following table lists the specific dates of data acquisition for this survey:

Date	Julian Day
02-16-2019	47
02-19-2019	50

Table 6: Julian Day, survey dates for AFZ

Survey lines were run with a 12 kHz multibeam echosounder. Statistics were calculated in ESRI ArcGIS 10.6.1 (*personal license*).

1. Data Acquisition and Processing

1.1 Equipment and Vessel

Refer to the Data Acquisition and Processing Report (DAPR) for a complete description of data acquisition and processing systems, survey vessels, quality controls, and processing methods. Additional information will be discussed in the following sections.

The following vessels were used for data acquisition during this survey:

Vessel	DSSV Pressure Drop
LOA	72.6 meters
Draft	4.18 meters

Table 7: Vessel Used

The following systems were used for data acquisition during this survey:

Manufacturer	Model	Purpose
Kongsberg	EM 124	Multibeam Echosounder (MBES)
Kongsberg	Seapath 380+	Positioning and Attitude System
Reson	SVP70	Fixed Mount Sound Speed
Seabird	SBE49 Fast Cat CTD	Sound Speed/CTD System
AML	Minos X SVP	Sound Speed System

Table 8: Systems used during data acquisition

The DSSV Pressure Drop single beam echosounder (SBES) was turned off during data acquisition as interference becomes visible in the MBES due to the frequency of the two signals. The Seabird CTD was attached to the Limiting Factor submarine vehicle. These data were collected during the deep dive and were used during post-processing for ray-path corrections.

1.2 Crosslines

No crosslines were obtained for either the SST or AFZ data sets.

1.3 Uncertainty

Total propagated uncertainty values were derived from fixed values with instrumental detailed in the DAPR, vessel characteristics, and uncertainty associated with the sound speed measurement and data processing (Table 9). The Seabird SBE49 derived sound velocity from temperature and conductivity sensors.

MANUFACTURER	SOURCE	CONTRIBUTION
QIMERA	Roll & Pitch	0.01°
	Heading	0.01°
	Heave Fixed	0.05m
	Heave Variable	5%

	Roll Offset	0.05°
	Pitch Offset	0.05°
	Heading Offset	0.05°
SEABIRD	Conductivity Accuracy	± 0.0003 S/m
	Temperature Accuracy	± 0.002 °C
	Pressure Accuracy	± 0.1% of full-scale range
AML	Sound Velocity Accuracy	0.5 m/s
	Conductivity Accuracy	± 0.010psu
	Density Accuracy	± 0.027 kg/m^3
	Depth Accuracy	± 3 dbar

Table 9: Uncertainties associated with processing and sound velocity measurements.

1.3.1 South Sandwich Trench

For Special Order surveys, the maximum allowable horizontal uncertainty is 2 m at 95% confidence while the maximum allowable vertical uncertainty is $\pm\sqrt{(0.25)^2 + (0.0075 \times d)^2}$ of a given depth (d) at 95% confidence. The SST survey area has a depth range between 4,479-8,264 m. With these values, the range of allowable TPU is ± 33.5-62 m at 95% confidence.

TPU statistics were generated for the Qimera CUBE uncertainty surface in the ESRI ArcGIS.

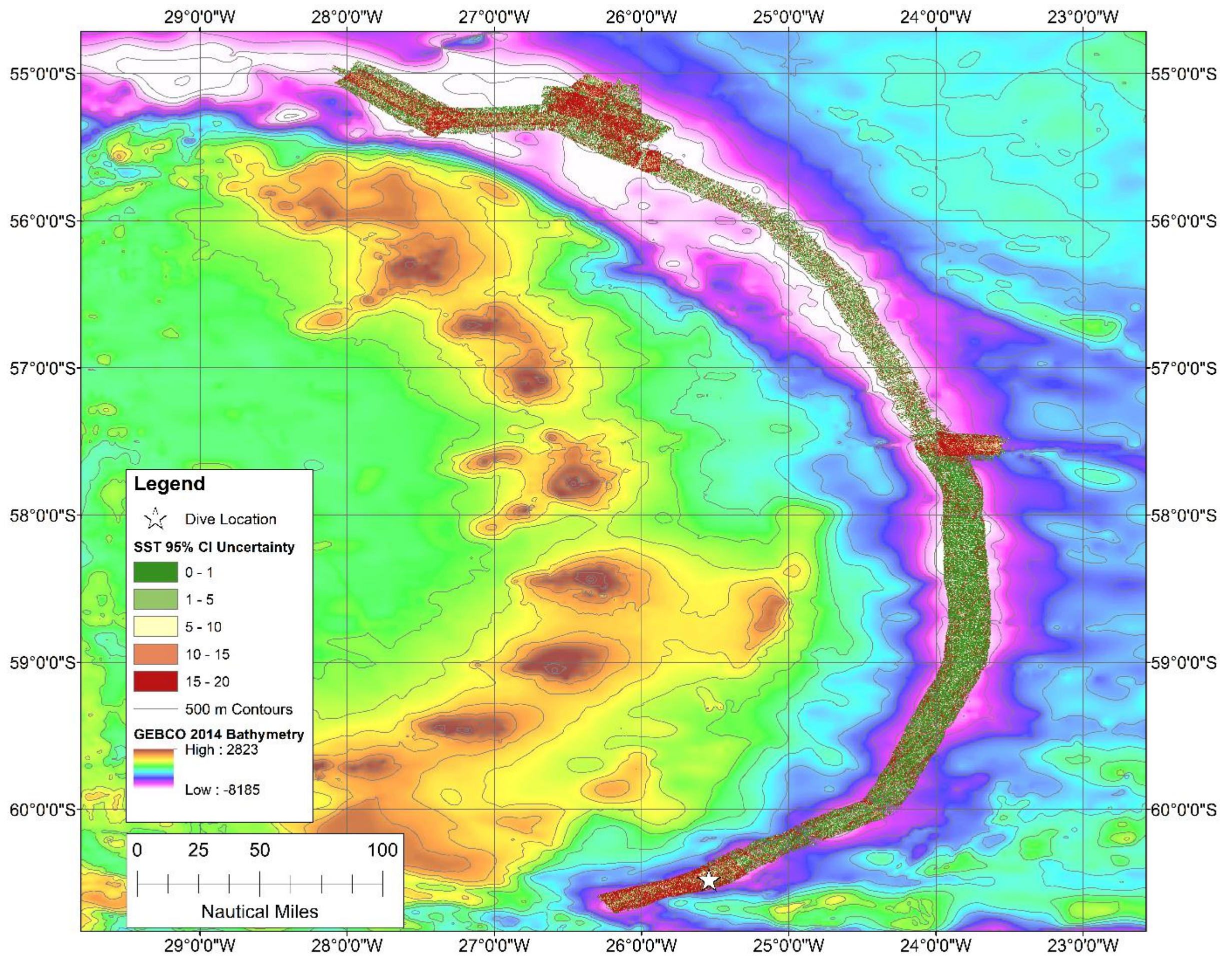

Figure 8: SST uncertainty at 95% confidence - red indicating areas of higher uncertainty.

The average estimated uncertainty of the SST survey area is 13 m. This falls well below the acceptable value for this survey based on the TPU estimates for the depth range. Figure 8 shows that uncertainty surface mapped to a color range with a minimum of 0.

1.3.2 Agulhas Fracture Zone

For Special Order surveys, the maximum allowable horizontal uncertainty is 2 m at 95% confidence while the maximum allowable vertical uncertainty is $\pm\sqrt{(0.25)^2 + (0.0075 \times d)^2}$ of a given depth (d) at 95% confidence. The AFZ survey area has a depth range between 1,681-5,548 m. With these values, the range of allowable TPU is ± 12.6-41.6 m at 95% confidence.

TPU statistics were generated for the Qimera CUBE uncertainty surface in the ESRI ArcGIS.

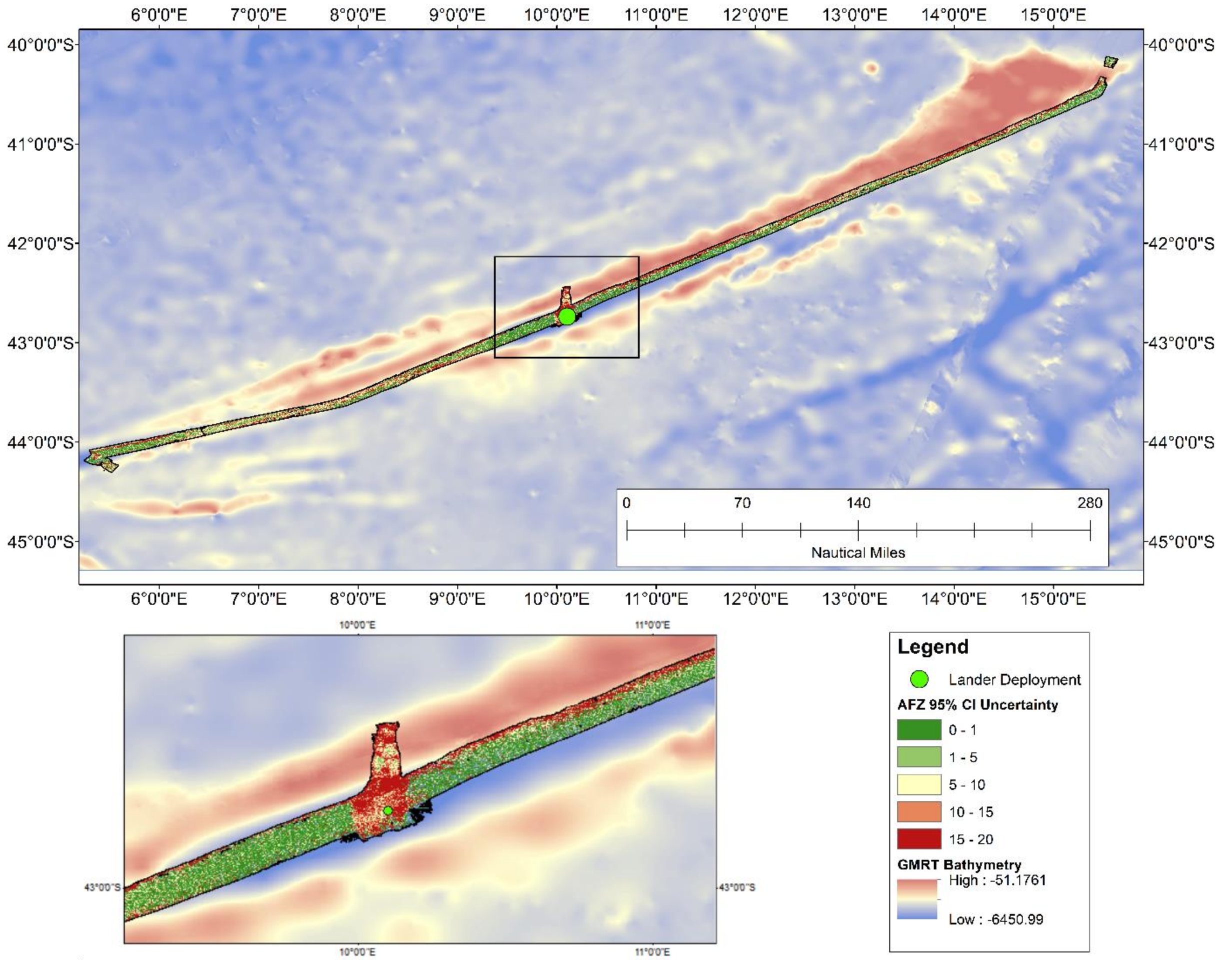

Figure 9: AFZ CUBE uncertainty at a 95% confidence interval. Red indicating areas of higher uncertainty and green of lower.

The average estimated uncertainty of the AFZ survey area is 8.76 m. This falls well below the acceptable value for this survey based on the TPU estimates for the depth range. Figure 9 shows that uncertainty surface mapped to a color range with a minimum of 0.

1.4 Junctioning Surveys

1.4.1 SST and GEBCO 2014 Comparison

General Bathymetric Chart of the Ocean (GEBCO) is an international effort funded by the Nippon Foundation that focuses on maps of the ocean. The GEBCO 2014 world ocean grid is the widely used standard of known bathymetric information and vertically referenced to mean sea level (MSL). The portion of the data covering the SST survey area was extracted from the GEBCO website (https://www.gebco.net/data_and_products/gridded_bathymetry_data/) and used as a base-layer map to help with line-planning and deep dive location identification. This surface was differenced with the EM 124 SST survey data in ESRI ArcGIS.

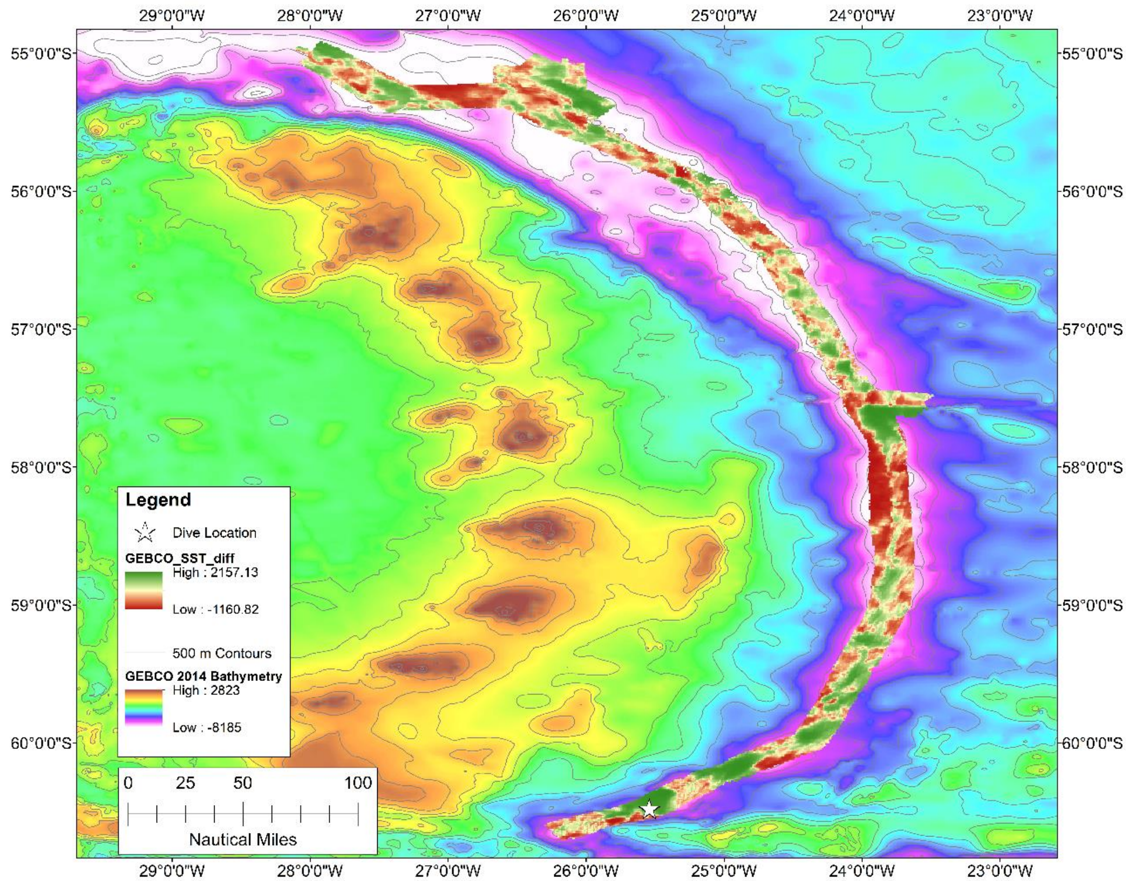

Figure 10: GEBCO 2014 bathymetric grid differenced with the SST data. Red indicated areas where SST is shoaler than GEBCO estimates.

There is an average difference of 116.7 m, with the SST survey (on average) being deeper. The largest differences are observed within the deep basins and the western trench wall near 58ºS (Figure 10). The GEBCO 2014 grid has a resolution of ~900 m which is of lower quality in comparison to the 75 m SST survey. This resolution discrepancy likely contributes to some of the large difference values.

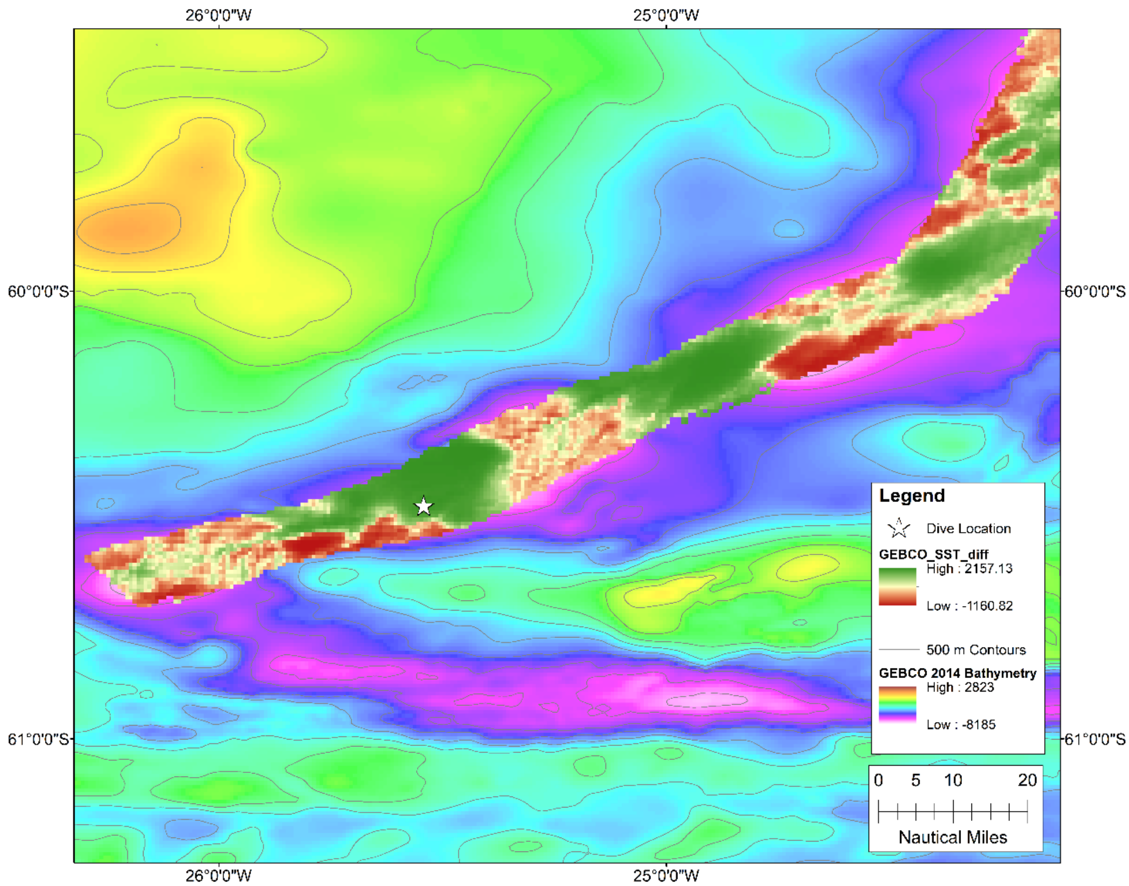

Figure 11: SST and GEBCO 2014 difference over the deepest area. Reds identify where SST data are deeper than GEBCO 2014 estimates.

Focusing exclusively on the dive location for the Southern Ocean, the average difference between the GEBCO 2014 and SST grids is -92.6 m where the SST is on average deeper than the GEBCO grid. At the exact dive location, the SST is ~1100 m deeper than GEBCO reports (Figure 11).

1.4.2 AFZ and GRMT Comparison

Global Multi-Resolution Topography Synthesis (GMRT) of the Lamont-Doherty Earth Observatory (LDEO) is a multi-resolution topographic and bathymetric synthesis created from existing datasets and is processed by hand. Outputs will be anywhere from 10-2,000m in resolution. The portion of the data overlapping the Agulhas Fracture Zone (AFZ) were obtained online (https://www.gmrt.org/) and used as a base-layer map to help with line-planning and deep dive location identification. This surface was differenced with the EM 124 AFZ survey data in ESRI ArcGIS (Figure 12).

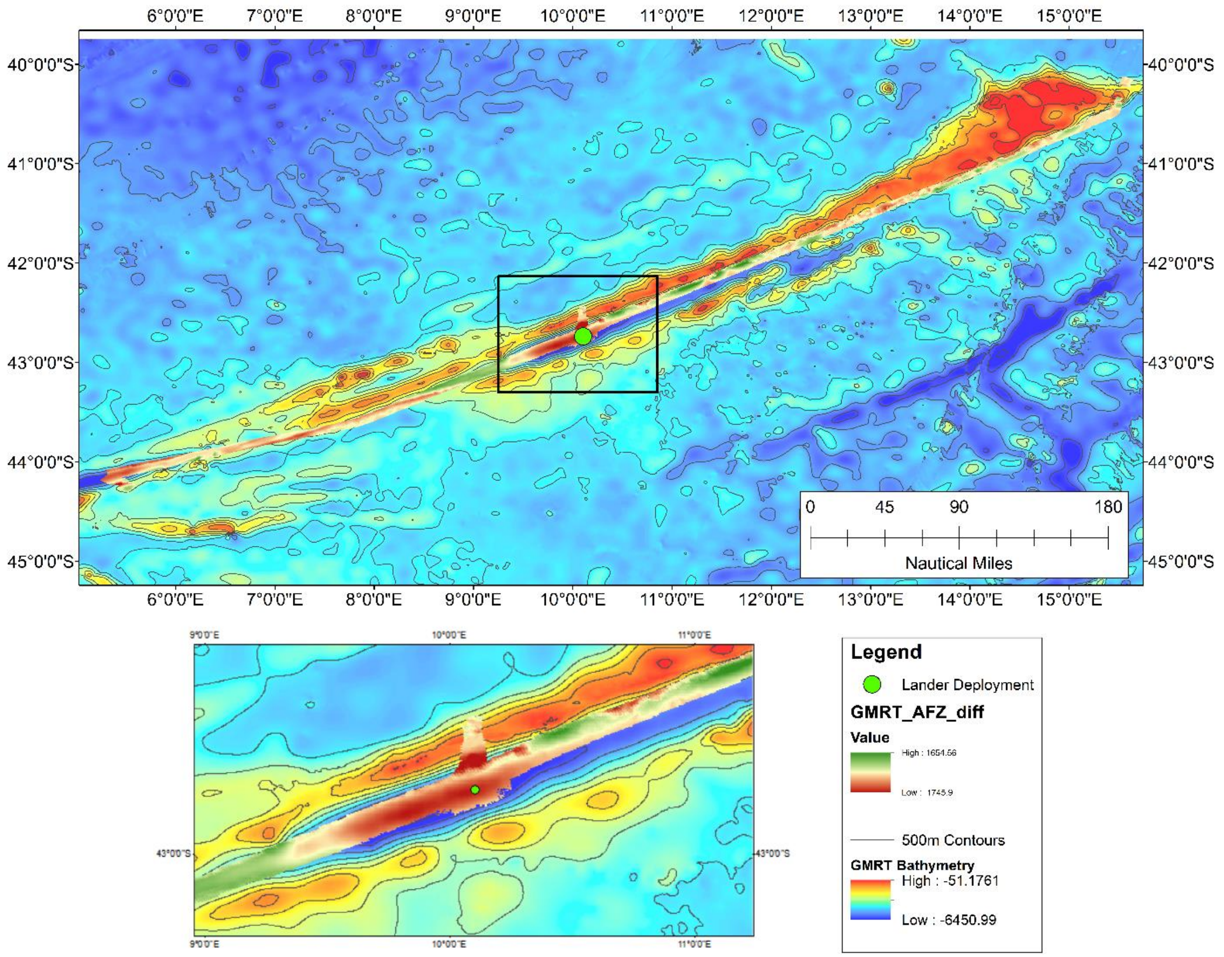

Figure 12: Agulhas Fracture Zone comparison with GMRT grid. Reds indicate areas where the EM 124 data is shallower than GMRT predicts, green is deeper.

There is an average difference of 37.1 m, with the AFZ survey (on average) being deeper. However, the majority of the deepest parts of the fracture zone were on average 1000m shallower than the GMRT predicted. The lander deployment site had a point difference of 980m with GMRT being deeper than EM 124 observations.

As such, the largest differences are observed within these deep basins. The GMRT grid has a resolution of ~450 m which is of lower quality in comparison to the 75 m AFZ survey. This resolution discrepancy likely contributes to some of the large difference values, but certainly not all of them.

1.4.3 Summary

Only small amounts of bathymetric data have ever been collected in the SST and AFZ areas where we surveyed (Figure 13). For South Sandwich specifically, ~91% of the area was interpolated from satellite estimates, meaning 91% of the area has never been mapped before. Only 5% of the area was mapped with a previous multibeam system, and about 3% was mapped with single beam surveys. As such, this mapping effort collected over 13,500 km^2 of new data.

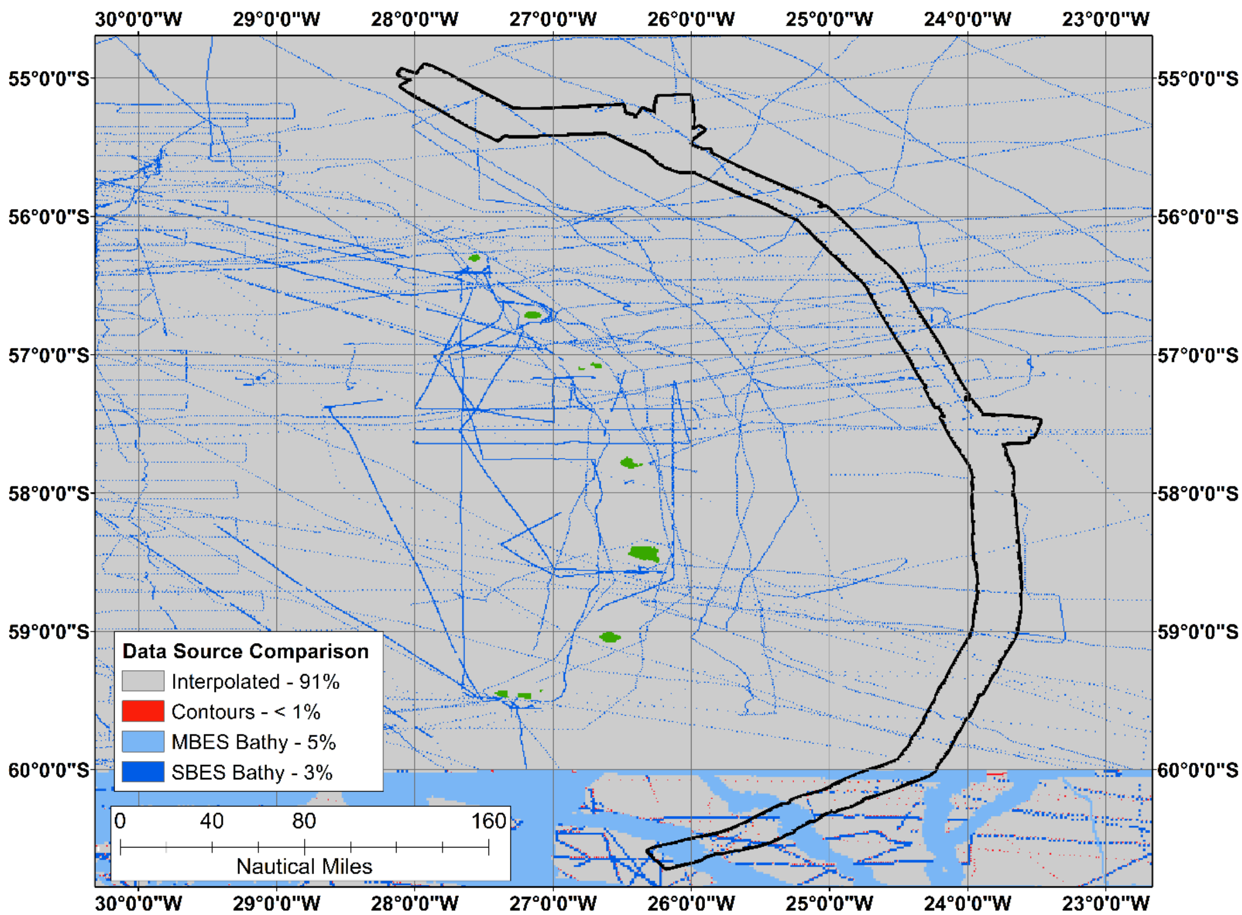

Figure 13: GEBCO data sources. Grey represents areas that were interpolated, pink is multibeam data from GMRT, and blue is single beam bathymetry data. The black outline is the area in the SST where EM 124 data were collected.

Similarly, only fractions of the AFZ were previously mapped. About 96% of the area of the AFZ we mapped is estimated from interpolation, so ours is the first data collected (Figure 14). Only about 4% of the area was collected from modern echosounders – single and multibeam systems. Thus, we collected over 17,000 km^2 of new data.

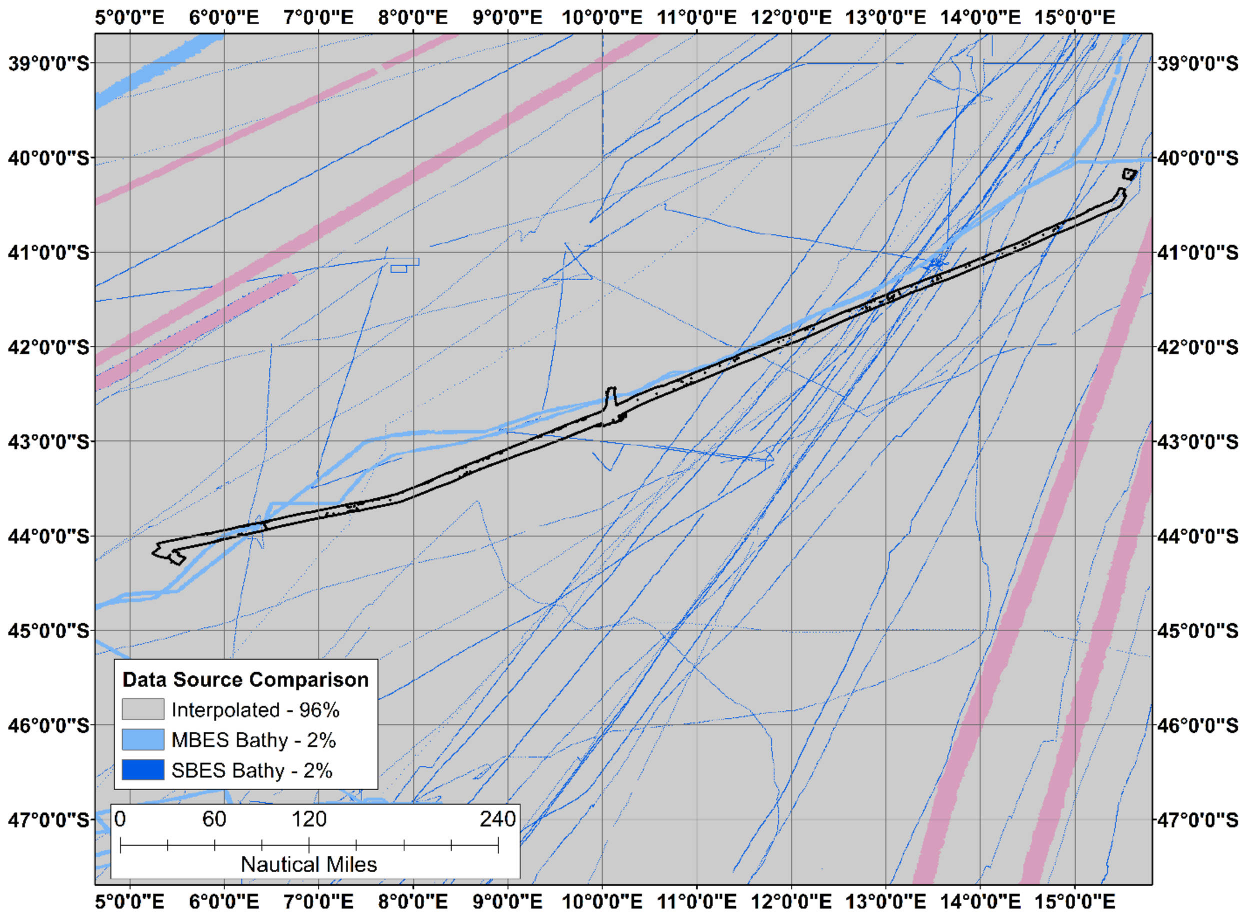

Figure 14: GEBCO data sources. Grey represents areas that were interpolated, pink is multibeam data from GMRT, and blue is single beam bathymetry data. The black outline is the area in the AFZ where EM 124 data were collected.

This was the first time the South Sandwich Trench and Agulhas Fracture Zone have ever been mapped completely. It is anticipated that these data will be a fundamental contribution to the scientific community. We also now can confirm the location and depth of the Meteor Deep within the South Sandwich Trench (Figure 15) and can correct the depths associated with the Agulhas Fracture Zone.

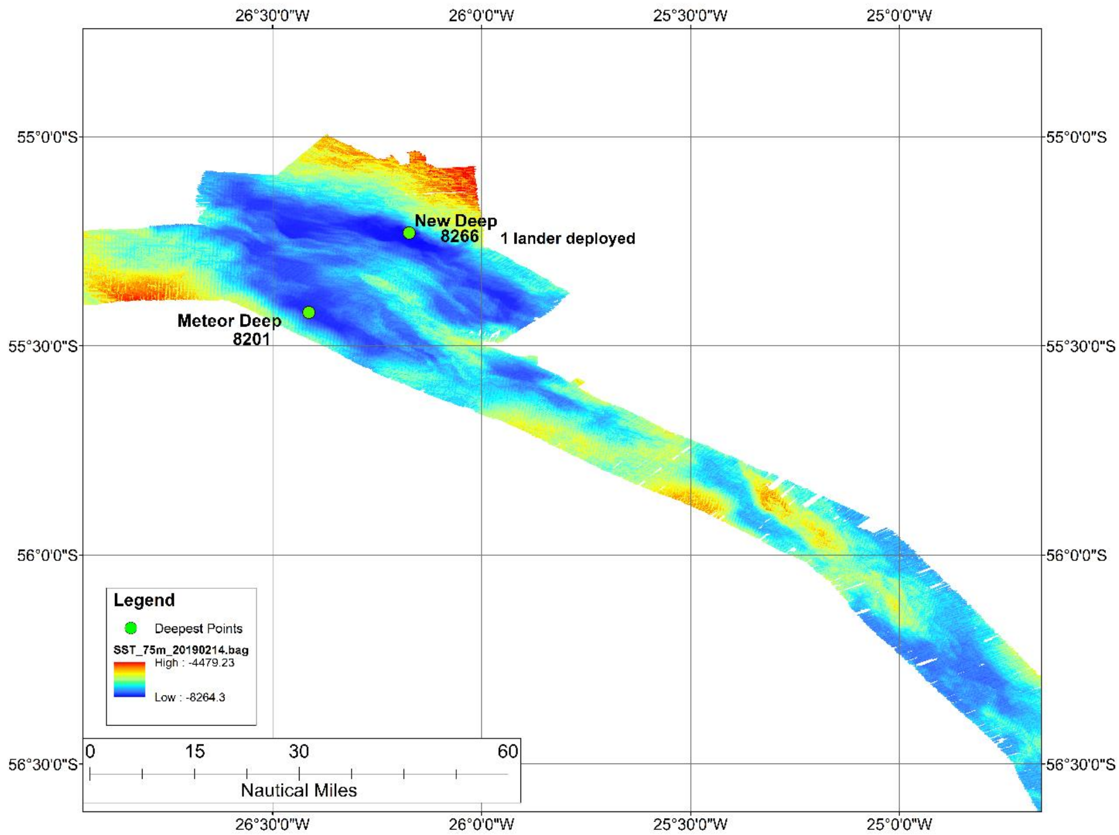

Figure 15: Thought to be location of historic Meteor Deep is the western green dot, while the true location is the eastern green dot. Modern depths from EM 124 are labeled. 1 lander was deployed at the location of the new meteor deep.

1.5 Sound Speed

Synthetic profiles were generated as needed during the survey operations using Sound Speed Manager. A true full-ocean depth sound speed profile was collected during the dive and later applied to the data from the entire survey area during post-processing. The sub CTD data were sampled at 1 Hz (1 per second) for the entire round-trip voyage, totaling over 56,000 data points. To make this a more manageable dataset for SIS and Qimera, these data were brought into MATLAB 2018a (*personal license*). Code was written to average the sound speed values at each depth in 1 m depth increments (Figure 16)

```
%% Minimizing the CTD data from the Sub
x=0;

for i=1:(max(SubCTD(:,3))+1)

    %pull out the pressure
    c=SubCTD(:,3);

    %Identify which points fall between a certaint interval
    n=find(c>=x & c<x+1);
    %take the maximum pressure value from the interval
    %(i.e. between 1-2,take 2)
    m=max(c(n));
    %take the average of those points and add to a new matrix
    l(x+1,1:1:4)=[mean(SubCTD(n,1)) mean(SubCTD(n,2)) m mean(SubCTD(n,4))];

    %add one more to the interval
    x=x+1;

end
```

Figure 16: MATLAB (personal license) *code created to average the sound speed values at each depth.*

Additionally, a code was obtained to translate pressure (dbar) into depth (m) (Figure 17). These depths were used for a final sound velocity profile.

```
function DEPTHM = sw_dpth(P,LAT)

% DEPTHM = depth in meters
% P = pressure in decibars
% LAT = latitude in decimal degrees north

DEG2RAD = pi/180;
c1 = +9.72659;
c2 = -2.2512E-5;
c3 = +2.279E-10;
c4 = -1.82E-15;
gam_dash = 2.184e-6;

LAT = abs(LAT);
X   = sin(LAT*DEG2RAD);  % convert to radians
X   = X.*X;
bot_line = 9.780318*(1.0+(5.2788E-3+2.36E-5*X).*X) + gam_dash*0.5*P;
top_line = (((c4*P+c3).*P+c2).*P+c1).*P;
DEPTHM   = top_line./bot_line;
end
```

Figure 17: MATLAB (personal license) *code used to translate pressure in dbar to depth in meters.*

1.5.1 South Sandwich Trench

As the data were collected over the course of only one day, the sub CTD data were applied to all below 60ºS SST data. The application of this profile reduced the agreement between the depth recorded from the EM 124 and the depth from the CTD.

Figure 18 shows most of the difference between the synthetic profile (World Ocean Atlas 2009 – red) and the CTD profile from the SST sub dive (blue) occurs in the upper 600 m of the water column. This is not unexpected as mixing from wind, waves, and biological material as well as the temperature effects from the sun are known contributors to these dynamic upper layers and the primary reason for sound speed errors.

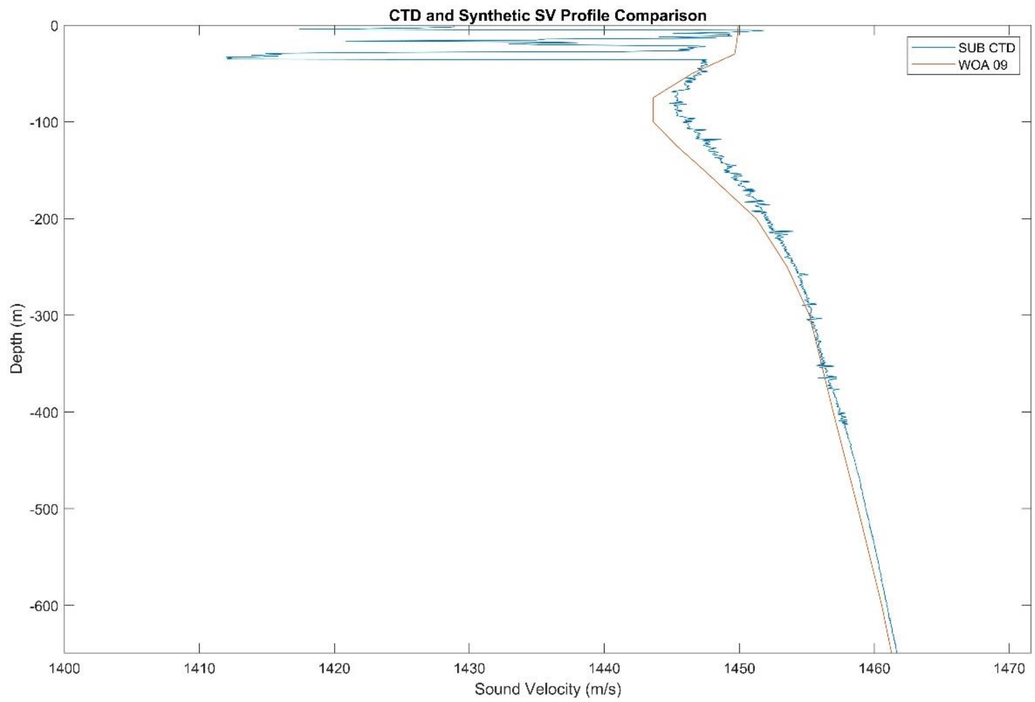

Figure 18: Sound Speed Manager comparison of synthetic sound speed profiles (red) and the CTD data (blue).

1.5.2 Agulhas Fracture Zone

No full-depth CTD profiles were collected during lander deployment in the AFZ. Only synthetic and XBT data were used.

1.6 Data Corrections

No further data corrections were applied.

1.7 Calibrations

1.7.1 Sonar Acceptance Test (SAT)

A Sonar acceptance test was performed on the new Kongsberg EM 124 by Cassie Bongiovanni and four Kongsberg technicians/engineers beginning December 13, 2018. More information on the survey plan is outlined in the SAT Plan report and the DSSVPD PRT DAPR.

1.8 Backscatter

1.8.1 South Sandwich Trench

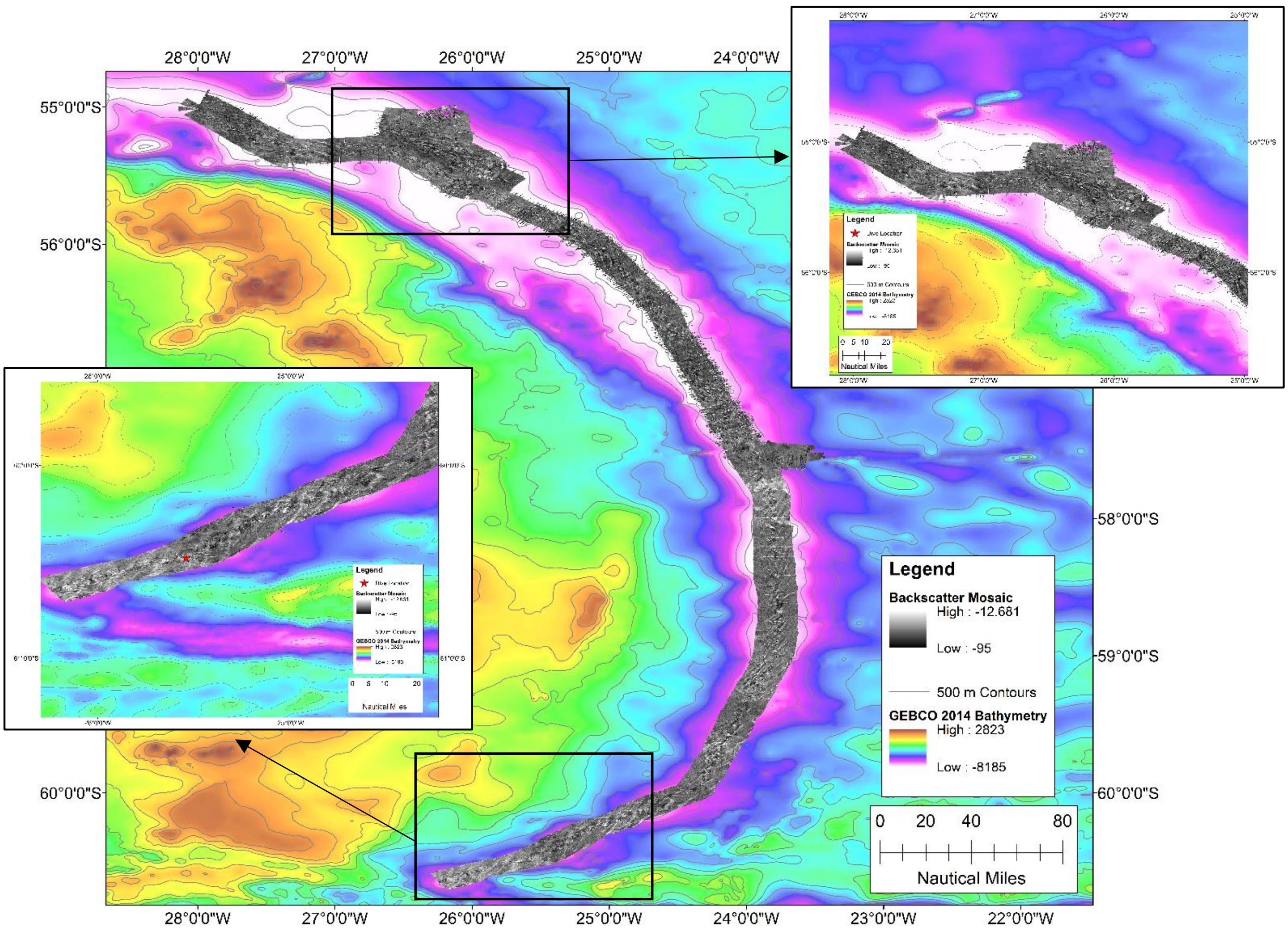

Figure 19: South Sandwich Trench backscatter mosaic – zoom -ins on the Southern Ocean dive location and the new Meteor Deep location. Mosaic created in QPS FMGT.

Backscatter data were collected from the EM 124 during bathymetric data collection. Data were processed in QPS FMGT and a 75m mosaic was created (Figure 19). No sediment samples were taken for verification.

1.8.2 Agulhas Fracture Zone

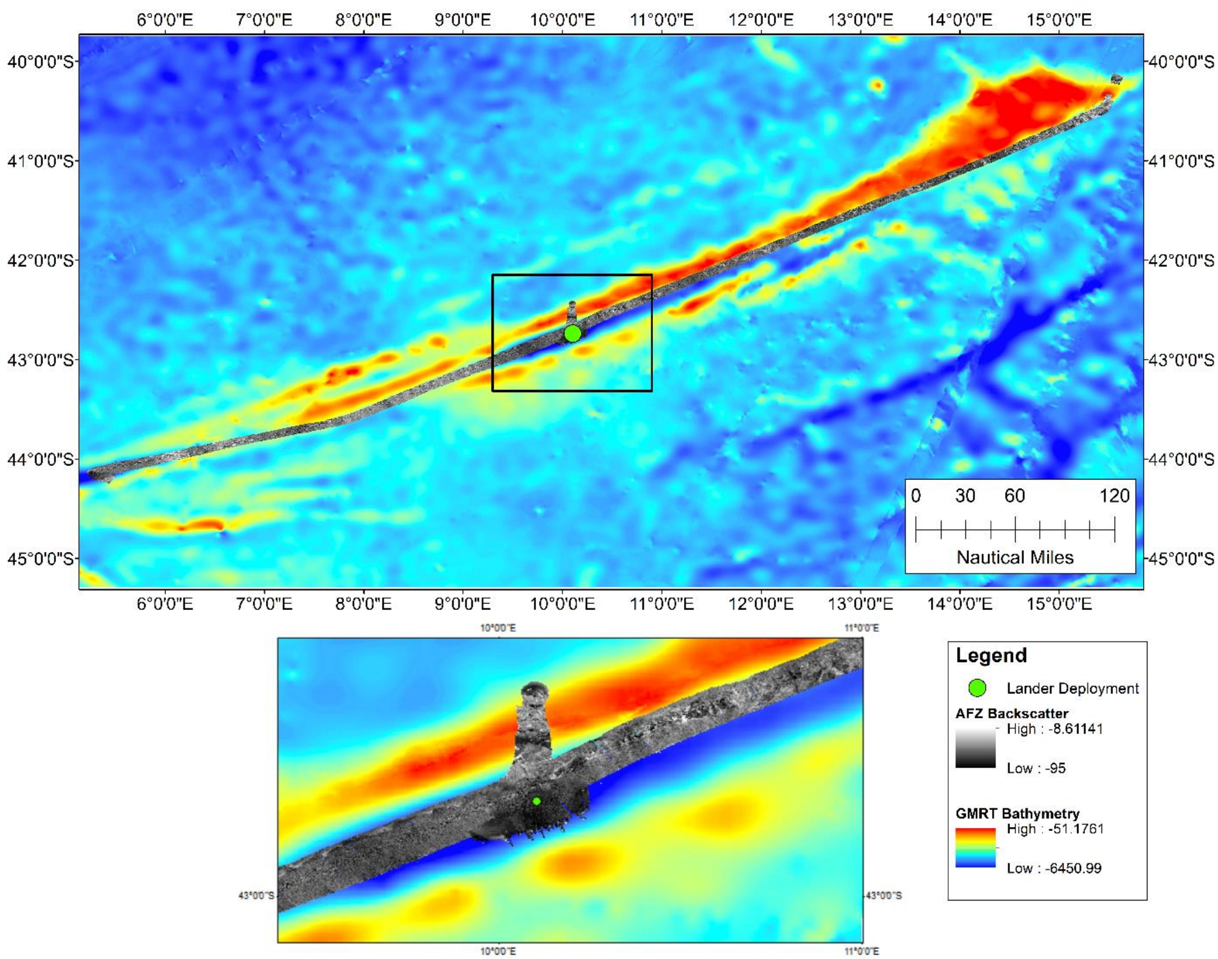

Figure 20: Agulhas Fracture Zone backscatter 75m backscatter mosaic. Zoom in of the lander deployment location in the deepest point of the fracture zone.

Backscatter data were collected from the EM 124 during bathymetric data collection. Data were processed in QPS FMGT and a 75m mosaic was created (Figure 20). No sediment samples were taken for verification.

1.9 Processing Software

Name	Manufacturer	Version	Installation Date

Qimera	QPS	1.7.5	12/04/2018
Hydro Office Sound Speed Manager	UNH CCOM/ Hydro Office	2018.1.50	12/06/2018
Matlab*	Matlab	R2018a	09/18/2018
Fledermaus & FMGT	QPS	7.8	12/04/2018
ArcMap/ArcGIS*	ESRI	10.6.1	09/18/2018

*Table 10: Processing software. *personal license*

More detailed information on processing software is outlined in the DSSVPD SST DAPR.

1.10 Surfaces

The following surfaces and/or BAGs are submitted with these reports:

Surface Name	Surface Type	Resolution	Depth Range
SST_CUBE_75m.xyz	CUBE	75 m	-4479.2m to -8264.3m
SST_95Uncertainty.tiff	Uncertainty	75 m	N/A
SST_Surface_75m.bag	Surface	75m	-4479.2m to -8264.3m
SST_backscatter.tiff	Mosaic	75 m	N/A
AFZ_CUBE_75m.xyz	CUBE	75 m	-1681.2m to -5548.05m
AFZ_95Uncertainty.tiff	Uncertainty	75 m	N/A
AFZ_Surface_75m.bag	Surface	75m	-1681.2m to -5548.05m
AFZ_backscatter.tiff	Mosaic	75 m	N/A

Table 11: Final mission surfaces

1.11 Patch Test

As the system was calibrated only days before, a patch test was not needed.

2. Vertical and Horizontal Control

2.1 Vertical Control

All data are referenced to the geoid (MSL). No further vertical corrections were applied.

2.2 Horizontal Control

No horizontal corrections were applied.