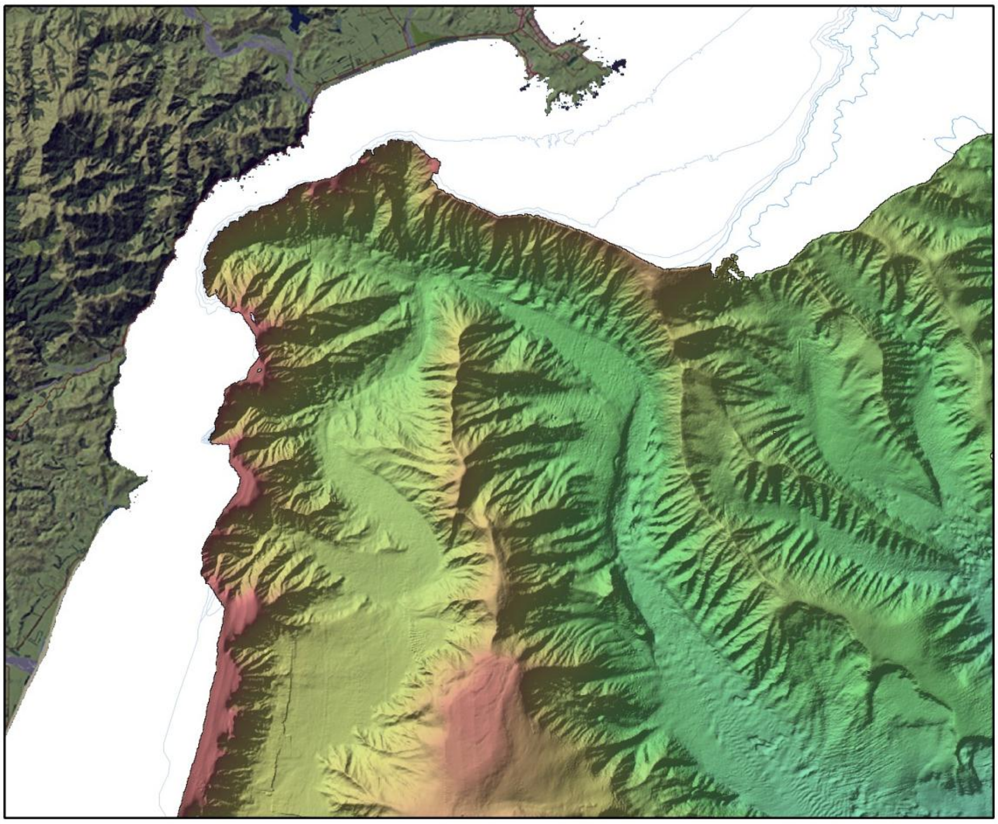
OS20/20 Southern Hikurangi

Voyage Report

Prepared for Land Information NZ

May 2012



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Cover Image: Sun Illuminated digital terrain model of the head of the Kaikoura Canyon

29 May 2012 11.02 a.m.

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Executive summary

The overall purpose of the Southern Hikurangi Mapping cruise was to complete high resolution multi-beam mapping of the Southern Hikurangi Margin to analyse the detailed geomorphic expression of tectonic and sedimentary processes. The survey aims to aid hazard research in terms of earthquake and tsunami source parameters (both landslide and fault sources) and underpin future exploration initiatives.

Funding for the *Tangaroa* sea days for this project were allocated out of the 2011/12 OS20/20 program. The vessel days were divided amongst 3 programs, with the Southern Hikurangi voyage allocation being 23 days. This was extended to 24 days to allow for the additional transits caused by splitting the voyage program into three legs. The additional day was added at NIWA's expense.

The funds for the science personnel, equipment and processing were made available out of NIWA's core science funds.

This survey was undertaken with the intention of collecting data across the southern Hikurangi margin to support tectonic and landslide-tsunami hazard studies, research into submarine canyon processes, and frontier basin petroleum exploration.

At the completion of the survey in excess of 20,000 km^2 of new multi-beam data had been acquired.

The multi-beam data collected reveal a very interesting network of canyon systems, the presence of which has been previously documented, but the detail of which was hitherto unknown. The target area for multi-beam coverage has been a total success in the respect that the canyon, landslide and tectonic features within the data set will be invaluable to support a host of research activities.

The data reveal twelve canyon systems that have never been imaged in high resolution bathymetry before, and completes mapping of the Kaikoura Canyon in its entirety for the first time.

The data reveal widespread gully erosion, contrasting canyon forms, and landslides. Landslides occur in large numbers in the area around the mouth of Pegasus Canyon and scattered across the rest of the dataset.

Numerous active faults occur through the region and have been interpreted previously as earthquake sources. Multi-beam data reveal the surface expression of some active faults and the seafloor deformation associated with folded rock.

1 Background

In November 2004, Cabinet agreed to establish Ocean Survey 20/20 as a 15 year project with the following vision:

> *"Complete by 2020 an ocean survey that will provide New Zealand with the knowledge of its ocean territory to*:
>
> - *demonstrate our stewardship and exercise our sovereign rights;*
> - *conserve, protect, manage and sustainably utilise our ocean resources; and*
> - *facilitate safe navigation and enjoyment of the oceans around New Zealand."*

It was also agreed that the scope of the OS20/20 project would cover:

- *Geographic area: the exclusive economic zone, the continental shelf, the Ross Sea region; and (as a secondary focus) South Pacific islands within the realm of New Zealand;*
- *Physical zones: subsurface, sea-floor, water column and atmosphere; and*
- *Information and Inventory Supporting: minerals exploration, fisheries, maritime safety, oceanographic science (incl geological hazards), protection, conservation, resource management and where appropriate recreation and tourism;*

Projects and objectives were developed with input from multiple agencies, research providers, and other relevant parties under the following themes:

1. sovereignty, stewardship, security and management;
2. maritime safety;
3. natural hazards and risk management;
4. fishing and aquaculture;
5. biodiversity and ecosystems;
6. minerals, hydrocarbons and other physical resources;
7. climate.

Funding for the *Tangaroa* sea days for this project were allocated out of the 2011/12 OS20/20 program. The funds for the science personnel, equipment and processing were made available out of NIWA's core science funds.

2 Voyage Plan

In terms of the original OS20/20 themes this project covers aspects of 3 and 6. The survey aims to aid hazard research in terms of earthquake and tsunami source parameters (both landslide and fault sources). The dataset will cover much of the area of the 2009 Pegasus Multichannel Seismic Reflection Survey, funded by MED (Figure 1), and so will contribute to petroleum exploration and gas hydrate research. Numerous other science disciplines, including continental margin/plate tectonic processes, marine biodiversity and physical oceanography will also benefit from these datasets.

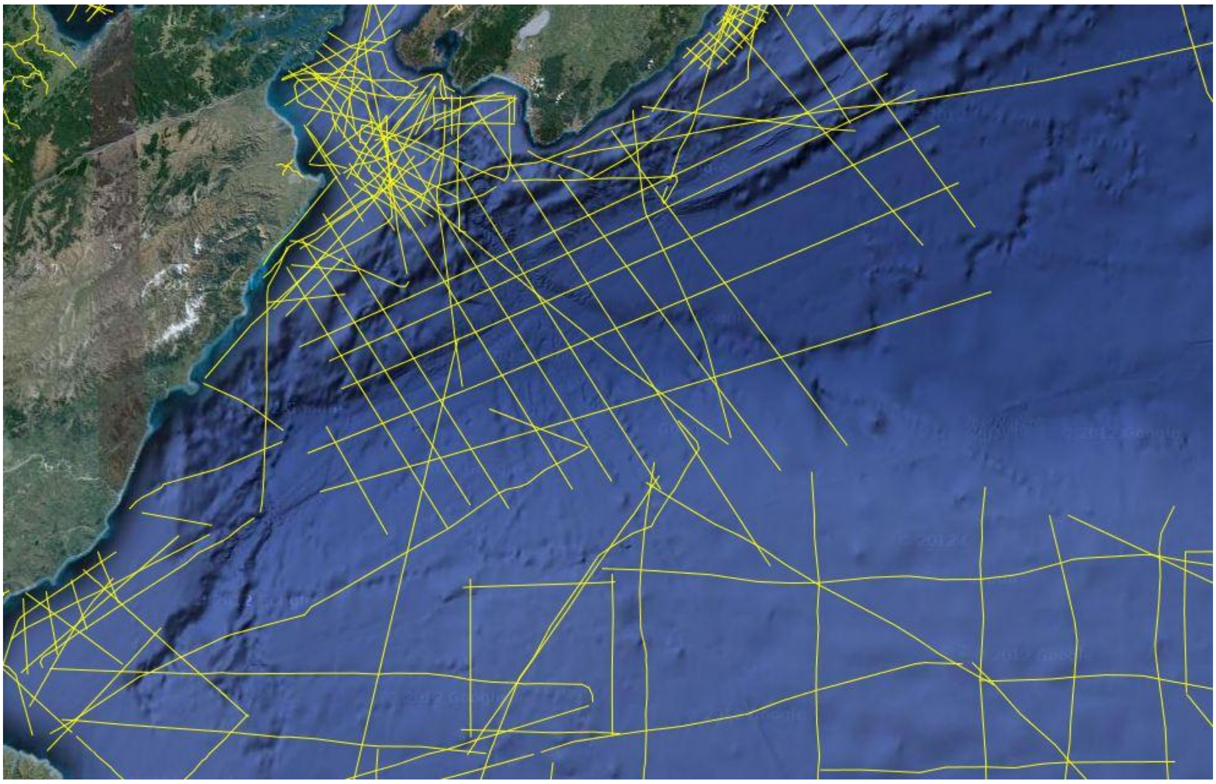

Figure 1: Industry 2D seismic lines in survey area (Image source GNS Petroleum Basin Explorer).

2.1 Objectives

The overall purpose of the Southern Hikurangi Mapping cruise was to complete high resolution multi-beam mapping of the Southern Hikurangi Margin to analyse the detailed geomorphic expression of tectonic and sedimentary processes. This will aid hazards research, and underpin future exploration initiatives.

These objectives include

- obtain a full coverage, high resolution, multibeam bathymetric map of the southern end of the Hikurangi Margin continental slope, Hikurangi Trough and northwestern Chatham Rise.

- Process new multibeam backscatter data and combine it with existing high resolution 30kHz multi-beam data into a single coverage.

- Collect 3.5 kHz seismic reflection data on all ship tracks.

2.2 Voyage Priorities

The original survey priorities for the voyage prior to the commencement of Leg 1 are specified in Figure 2 with details of the priority regions in Table 1. The boundaries of these priority areas were determined by the known bathymetry and location of existing 30kHz multi-beam coverage (Figure 3). As surveying was spread over several legs these priorities were subsequently modified based on coverage obtained. Data was to be collected in order of the priorities dependent on weather and transit distances, i.e. LINZ/NIWA1 first. NIWA6 was an additional area specified to be mapped only should the surveying be completed ahead of schedule. Time estimates for survey areas given in Table 1 were first order estimate only, based on an 8 knot survey speed and were considered conservative.

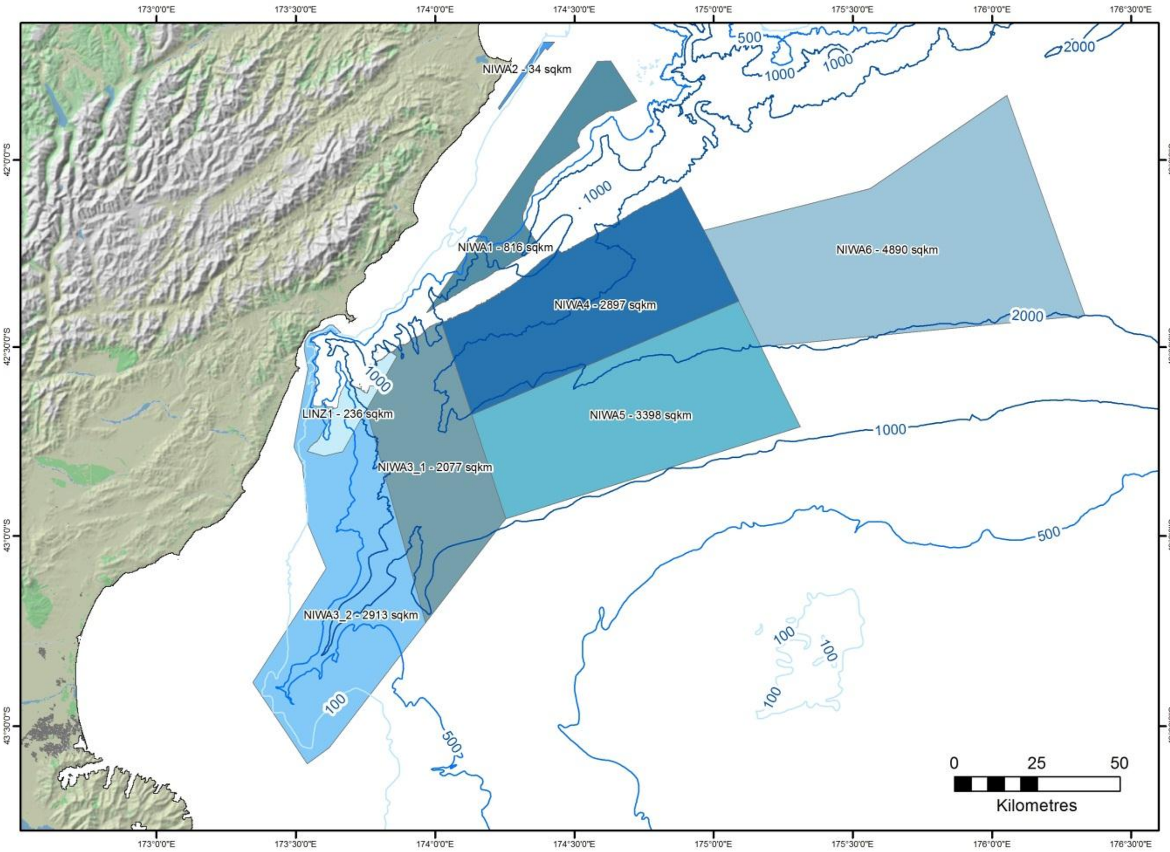

Figure 2: Proposed survey extent and priority areas for OS20/20 Southern Hikurangi Margin Mapping.

Table 1: Priority areas for Southern Hikurangi Mapping voyage.

Priority Area	LINZ	NIWA1_1	NIWA1_2	NIWA2	NIWA3_1
Area (sqkm)	240.0	530.0	300.0	35.0	2080.0
Water Depth (Average) (m)	500.0	200.0	300.0	70.0	1000.0
Width (Average) (km)	9.0	10.0	12.0	3.0	38.0
Width (Average) (nm)	4.9	5.4	6.5	1.6	20.5
Length (Average) (km)	37.0	61.0	25.0	25.0	100.0
Length (Average) (nm)	20.0	32.9	13.5	13.5	54.0
Survey Speed (kn)	8.0	8.0	8.0	8.0	8.0
Survey Speed (km/h)	14.8	14.8	14.8	14.8	14.8
Swath Width (m)	1500.0	400.0	900.0	140.0	3000.0
Coverage (Average) (sqkm/h)	22.2	5.9	13.3	2.1	44.4
Time (h)	10.8	89.4	22.5	16.9	46.8
Time (d)	0.4	3.7	0.9	0.7	1.9
Total Time (incl. SVP) (h)	12.1	100.6	25.3	19.0	52.6
Total Time (incl. SVP) (d)	0.5	4.2	1.1	0.8	2.2

Priority Area	NIWA3_2	NIWA4	NIWA5	NIWA6	Total
Area (sqkm)	2910.0	2900.0	3400.0	4900.0	17295.0
Water Depth (Average) (m)	400.0	2000.0	1000.0	2000.0	
Width (Average) (km)	40.0	35.0	60.0	70.0	
Width (Average) (nm)	21.6	18.9	32.4	37.8	
Length (Average) (km)	85.0	85.0	92.0	105.0	
Length (Average) (nm)	45.9	45.9	49.7	56.7	
Survey Speed (kn)	8.0	8.0	8.0	8.0	
Survey Speed (km/h)	14.8	14.8	14.8	14.8	
Swath Width (m)	1200.0	6000.0	3000.0	6000.0	
Coverage (Average) (sqkm/h)	17.8	88.9	44.4	88.9	
Time (h)	163.7	32.6	76.5	55.1	514.3
Time (d)	6.8	1.4	3.2	2.3	20.7
Total Time (incl. SVP) (h)	184.1	36.7	86.1	62.0	578.6
Total Time (incl. SVP) (d)	7.7	1.5	3.6	2.6	24.1

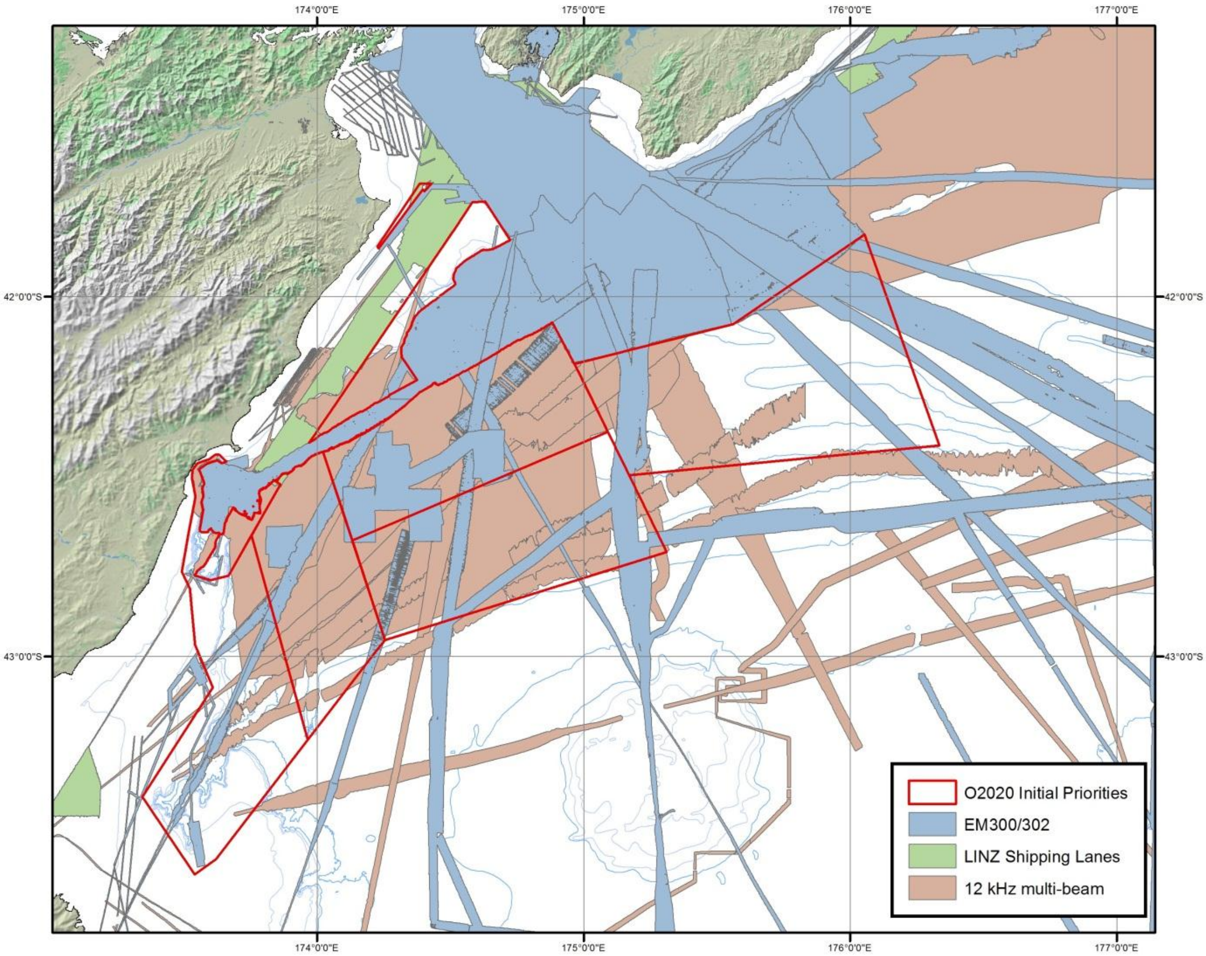

Figure 3: Existing multi-beam coverages prior to the survey showing high resolution 30 kHz (EM300/302), low resolution 12 kHz and LINZ shipping lane swath, overlain by priority areas.

2.3 Voyage Schedule

The OS20/20 vessel days for 2011/12 were divided amongst 3 programs, with the Southern Hikurangi voyage allocation being 23 days. This was extended to 24 days to allow for the additional transits caused by splitting the voyage program into three legs. The additional day was added at NIWA's expense.

2.3.1 Leg 1

Voyage Number	TAN1111	
Vessel	*RV Tangaroa*	
Duration	14 days	
Departure	12 August 2011	1800

Return	16 August 2011	1600	
Crew C/O	17 August 2011		
Departure	18 August 2011	0800	
Arrival	28 August 2011	0800	

Personnel	John Mitchell (Voyage Leader)	NIWA
	Peter Gerring	NIWA
	Dylan Amyes	NIWA
	Kevin McGill	NIWA

2.3.2 Leg 2

Voyage Number TAN1115

Vessel *RV Tangaroa*

Duration 5.5 days

Departure	19^{th} October 2011	1800
Arrival	25^{th} October 2011	0800

Personnel	Arne Pallentin (Voyage Leader)	NIWA
	Peter Gerring	NIWA
	Alan Hart	NIWA

2.3.3 Leg 3

Voyage Number TAN1207

Vessel *RV Tangaroa*

Duration 5 days

Departure	5 May 2012	1800
Arrival	10 May 2012	1900

Personnel	John Mitchell (Voyage Leader)	NIWA
	Kevin Mackay	NIWA
	Peter Gerring	NIWA

2.4 Voyage Narrative

2.4.1 Leg 1

The *Tangaroa* arrived alongside at the Port of Wellington at 1100 on 12th August 2011, after an extended survey period in Papua New Guinea. Once the vessel was cleared by customs and immigration preparations for the OS20/20 survey could commence. As the previous voyage had been a multi-beam survey little preparation was required apart from refuelling and reprovisioning of the vessel.

The vessel departed for the survey area at 1800 12th August arriving at the NIWA1 priority area at 2100. After the completion of an initial sound velocity profile (SVP) surveying commenced. Survey speed was held to 8 knots. Multiple SVPs were collected as required. The data collection in NIWA1 continued in good weather until 1800 14 August when the wind started to gust to 40 knots from the south.

The strong southerly winds and shallow survey area resulted in a significant swell to the point that surveying could only be run with the wind in a northward direction followed by a dead steam to the south to the start of the next line. This single direction surveying continued until 1230 16th August when the ship ceased survey for its return to Wellington.

The ship remained alongside in Wellington 17th August for crew change over. This day was not charged to OS20/20. Planned departure of 1800 17th August had to be abandoned due to the extreme storm conditions of gale force southerlies, 5-10m swells at the entrance and poor visibility due to snow.

The vessel re-departed for the survey area at 0800 18th August even though the gale force southerlies continued. The 30-40 knot winds resulted in a reduced transit speed. Due to the weather conditions the decision was made to transit south out of Cook Strait to calmer weather in the south of the survey area.

Surveying recommenced at 0500 19th August in survey area NIWA3_2. Surveying in this area, NIWA3_1 and the LINZ priority area continued in improving weather until 1200 25th August. This included the nearshore strip adjacent to the head of the Kaikoura Canyon while the weather was calm.

Area NIWA4 followed by NIWA5 was then surveyed until the end of the voyage window. Surveying stopped at 2200 27th August and the vessel proceeded to Wellington, arriving at 0800 on 28th August.

2.4.2 Leg 2

Prior to departure on Leg 2 survey priorities were reset and changes made to ensure the canyon south of area NIWA3_2 was completely surveyed, a missing area in the shipping lane data covered and NIWA1 area completed.

Leg 2 commenced at 1800 on 19th October 2011 with the vessel departing into another gale force southerly. This resulted in the decision to slow-transit to the southern-most area to commence work.

At the completion of an SVP surveying commenced in the south at 1530 20th October and continued until 1500 22nd October in calm conditions. At the completion of this area the ship transited to the north to fill the gap in the shipping lane data. Surveying of this area took from 2200 22nd October until 0900 23rd October.

At the completion of the shipping lane area the survey recommenced in the NIWA1 zone in worsening conditions, with NW winds of 35-40 knots and rough seas. Data was collected from 1200 23rd October until 1500 24th October when the vessel departed for Wellington. Data quality varied depending on line direction.

The *Tangaroa* arrived back alongside at 0800 25th October.

2.4.3 Leg 3

Priorities were reassessed prior to the start of Leg 3 based on the coverage completed on the previous two legs. Priority was given to completion of the NIWA6 area which was realigned and extended to better cover the Hikurangi Trough and its flanks.

The *Tangaroa* departed at 1800 on the 19th May 2012 in relatively calm weather. The transit to the survey area was completed and surveying started at 0100 20th May.

As the weather was good with less than 1m swell and winds generally less than 15 knots the survey speed was increased to 10 knots without any visible degradation in data quality.

Each line was approximately 150km long and several SVPs were required on the first line due to the large scale change in surface water temperatures from 14°C to 17.5°C travelling west to east and the resulting change in sound velocities from 1501 to 1514 m/s (Figure 4). These SVPs were used on subsequent lines until the change in water mass required additional SVPs.

Area NIWA6 was completed at 1200 10th May and the *Tangaroa* returned to Wellington arriving at 2000 on 10th May 2012.

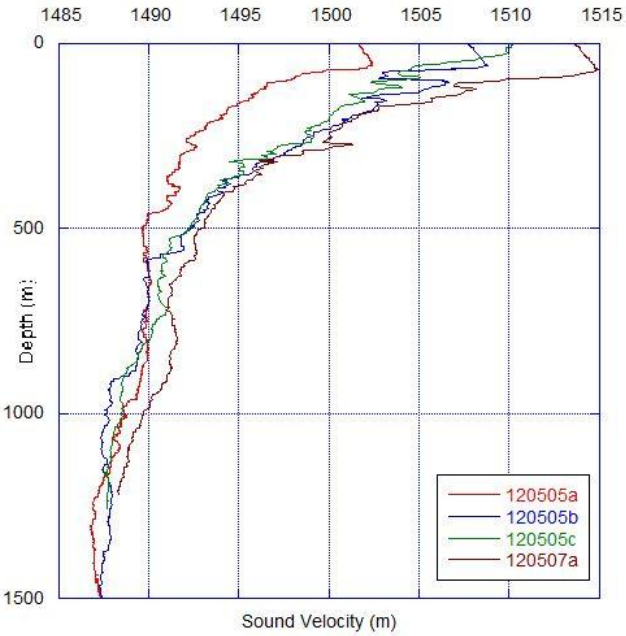

Figure 4: Example Sound Velocity Profiles from Leg 3.

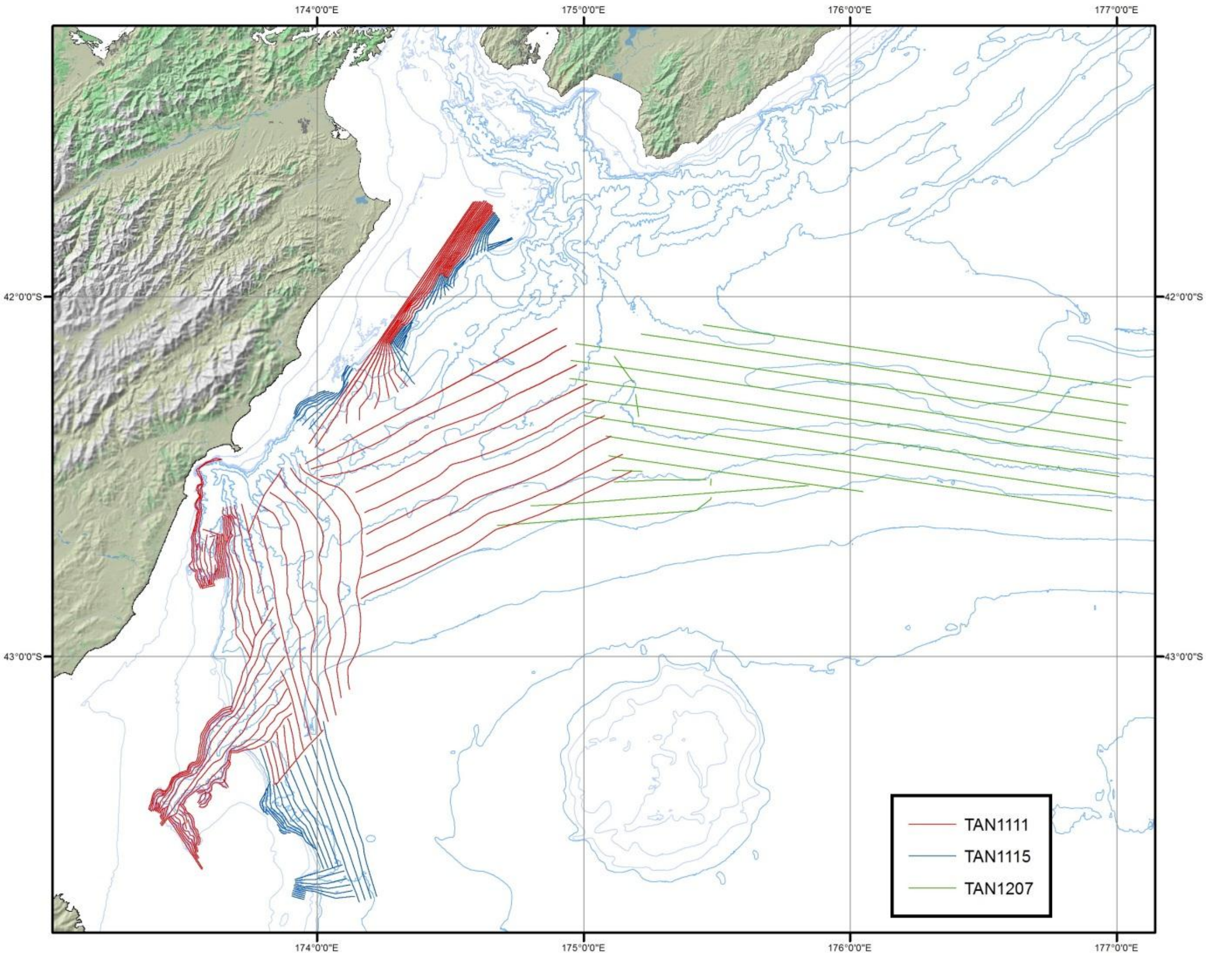

Figure 5: Multi-beam survey lines from the three legs of the Southern Hikurangi project.

3 Equipment

3.1 Navigation

The primary positioning system used was the position derived from the forward Applanix POS/MV GPS Antenna, differentially corrected by the Fugro SeaStar XP Wide Area Differential GPS (WADGPS) service.

The differential corrections consist of pseudo-range corrections generated by the Fugro SeaStar XP WADGPS system. These corrections were uplinked through a Fugro monitoring station and received on board the vessel via the Pacific Ocean Region (POR) satellite.

Analysis of the system accuracies and survey conditions indicate the positioning accuracy of Order 1 horizontal accuracy standards were met or exceeded (Appendix 1).

3.2 Kongsberg EM302 Multi-beam

The Kongsberg EM302 multi-beam echo sounder, centred on 30 kHz was used throughout the survey. The multi-beam was operated to obtain the maximum swath width with a maximum beam angle of 65°/65° apart from a few periods in shallow water where the beam angle was further widened. The Kongsberg EA600 single-beam sounder operating on 12 kHz was run throughout the survey.

The Kongsberg EM302 multi-beam echo sounder and Seafloor Information System (SIS) software were used for data acquisition.

The EM302 multi-beam worked well in all depths experienced during the survey from the shallow part of the survey in 100m to the maximum depth of around 3000m. Swath widths of up to 6.5km were experienced.

Error sources for the multi-beam bathymetry are summarized in Appendix 1. Most errors are predictable and easily accounted for with the exception of sound speed. These predictable errors are normally accounted for by a patch test of the system prior to the start of surveying. The *Tangaroa* was fitted with a new EM302 in August 2010 and a full patch test completed in December 2010. A further patch test was completed on 2nd & 3rd July 2011 prior to the vessel's departure for a Papua New Guinea survey with a partial test in tropical waters 1st August 2011 (Appendix 2).

The unmeasured change in sound speed through the water column is unpredictable and can potentially result in significant depth and positioning errors. This error source is mitigated through continually monitoring the bathymetry data for evidence of sound speed artefacts during sounding operations. The surface sound speed is continuously measured and used to calculate departure angles at the transducer and are also used as an indicator of sound speed changes throughout the water column.

SVP profiles were planned to be collected whenever a change in velocity was observed. The nature of the water masses in the survey area especially around the Cook Strait and Chatham Rise were such that large scale variations were observed and multiple SVP profiles were required to adjust for velocity errors.

Heave and attitude were provided by an Applanix POS/MV 320 motion sensor on *Tangaroa*. The POS/MV generates attitude data in three axes. Measurements of roll, pitch, and heading are accurate to 0.02º or better (manufacturer's specifications) regardless of the vessel's latitude. Heave measurements supplied by POS/MV maintain an accuracy of 5% of the measured vertical displacement or ±5cm (whichever is the larger) for movements that have a period up to 20 seconds (manufacturer's specifications). No significant heave artifacts were observed in the processed data despite the rough weather experienced at times.

Analysis of the system accuracies and survey conditions indicate the multi-beam accuracy of LINZ MB-1 accuracy standards were met with the caveat of the non-application of tidal reductions (Appendix 1).

3.3 3.5 kHz Sub-bottom Profiler

The 3.5 kHz system is a hull-mounted system on the *Tangaroa* controlled by a Knudsen Chirp 3260 sub-bottom profiler. It consists of the Knudsen transceiver and 16 transducers in a 4x4 array, mounted inside a sea-chest, pinging directly through the hull. The plan was to run the 3.5 kHz during the full voyage in conjunction with the swath system. The system was heave-compensated in real-time to improve data quality. All data were recorded to disk in proprietary *.keb format.

It was observed that the 3.5 kHz system running in full chirp mode caused serious interference with the data being collected from the EM302 multi-beam in areas deeper than 2,000m resulting in areas of loss of bottom lock. As a result the system was run in Continuous Wave (CW) mode to reduce this interference and put into standby mode when water depths exceeded 2500m.

This problem will be addressed in future voyages by synchronising the triggering of all devices.

The resulting 3.5 kHz data showed varying degrees of sub-bottom structure up to 50m below the seafloor depending on seabed conditions and slope. The data collected can be viewed using Knudsen PostSurvey software (Figure 6).

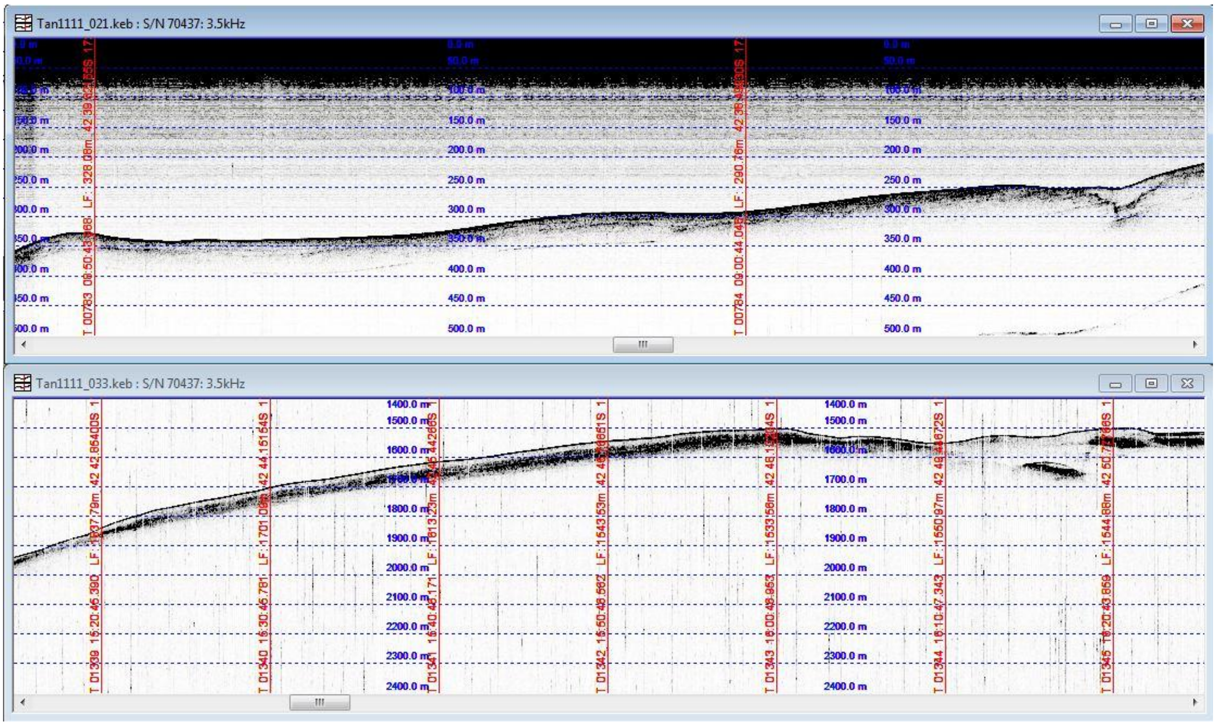

Figure 6: Example 3.5 kHz records from Leg 1.

4 Survey Data

4.1 Data Acquisition & Processing

The Kongsberg EM302 multi-beam echo sounder and SIS software were used for data acquisition. SIS was used to display the previous sounding coverage as well as the current sounding coverage and was used to provide planning and navigation for the data acquisition and bridge personnel. Raw data files were then exported into CARIS for processing and cleaning.

All EM302 bathymetry data collected by the *Tangaroa* were backed up at the end of each line to an external mass storage device. The raw data were then transferred to the processing computer and imported into CARIS HIPS V7.1 software for processing.

Survey datum for the bathymetry data is Mean Sea Level (MSL).

The data were initially cleaned in CARIS HIPS using the swath editor, and then gridded using the CUBE surfacing tool and final cleaning completed using the CARIS subset editor. CUBE was then rerun to produce a digital terrain model of the survey area gridded at 25m (Figure 7). A 5x5 nearest neighbour interpolation was then run to fill in holes in the resulting DTM. A 50m contour coverage was also produced.

The surfaces (in xyz format) were then imported into ESRI ArcMap v10 GIS for plot production. In ArcMap a NIWA tool was run to convert the xyz grid into a sun illuminated tiff (Figure 8). The data were then further processed to produce an overall grid of all high resolution multi-beam data in the region. The data combined for the final coverage were those collected during this survey, previous NIWA EM300 multi-beam surveys and some LINZ Shipping Lane surveys. This grid was then processed to produce an overarching tiff of the area of interest (Figure 9).

These data have been processed following recognised hydrographic methodology to enable the provision of this report.

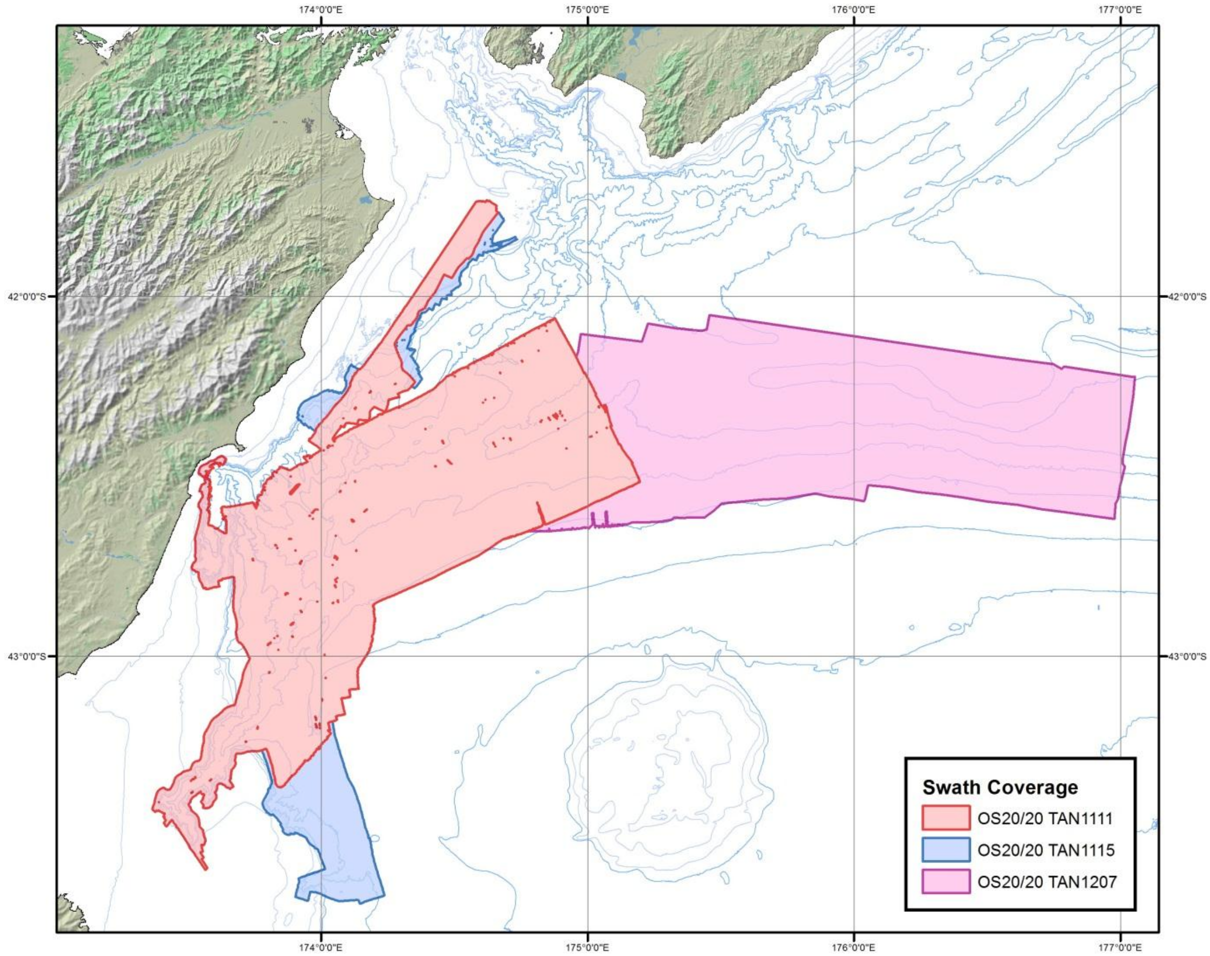

Figure 7: Multi-beam coverage achieved from the three legs of the voyage.

5 Preliminary Results

This survey was undertaken with the intention of collecting data across the southern Hikurangi margin to support tectonic and landslide-tsunami hazard studies, research into submarine canyon processes, and frontier basin petroleum exploration.

The initial plans for the project were to survey approximately 17,000 km^2 of seafloor. At the completion of the survey in excess of 20,000 km^2 of new data had been acquired.

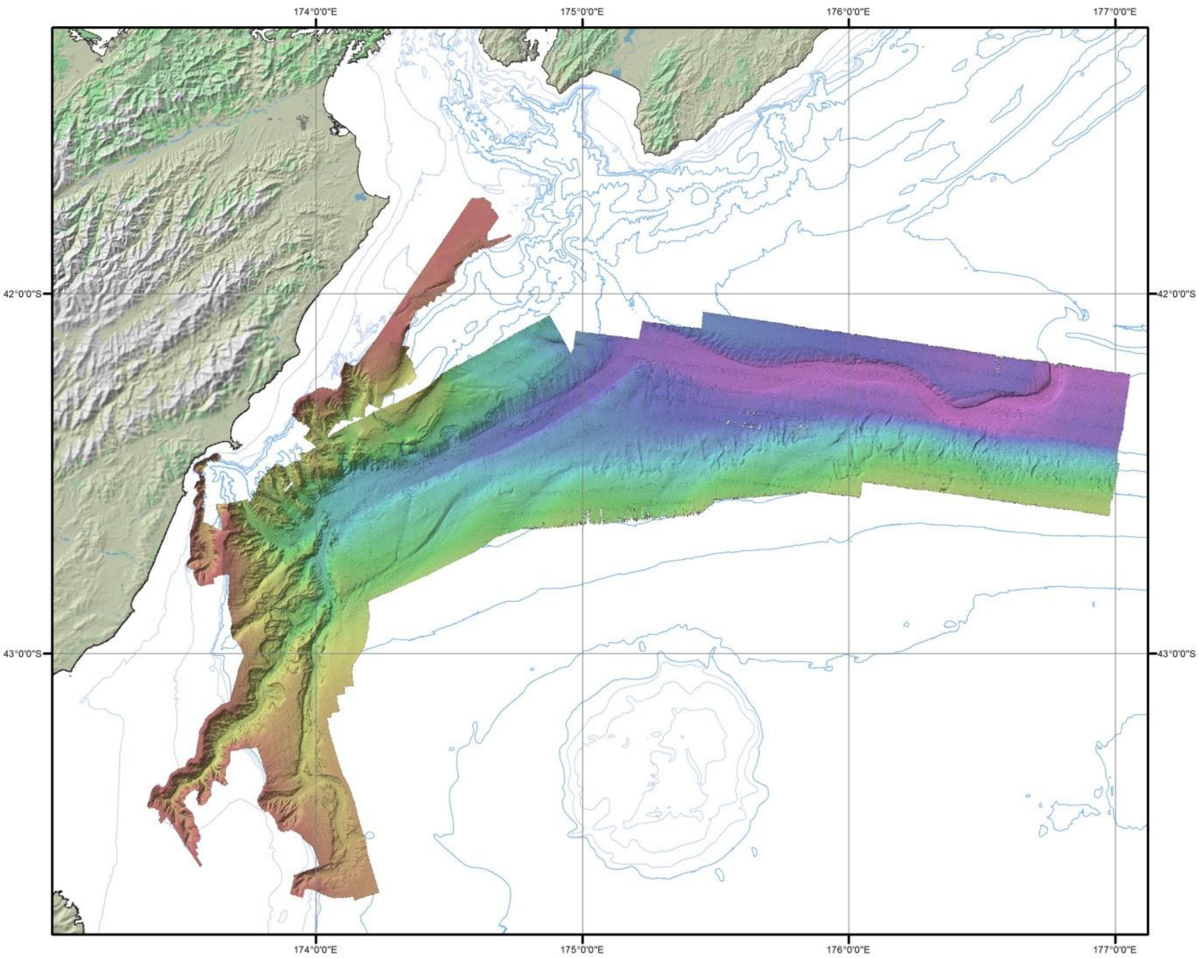

Figure 8: Sun illuminated DTM of the multi-beam data collected during the project.

The multi-beam data collected reveal a very interesting network of canyon systems, the presence of which has been previously documented, but the detail of which was hitherto unknown. The target area for multi-beam coverage has been a total success in the respect that the canyon, landslide and tectonic features within the data set will be invaluable to support a host of research activities. The data cover an area to be offered by the New Zealand government to private companies for the purpose of hydrocarbon exploration.

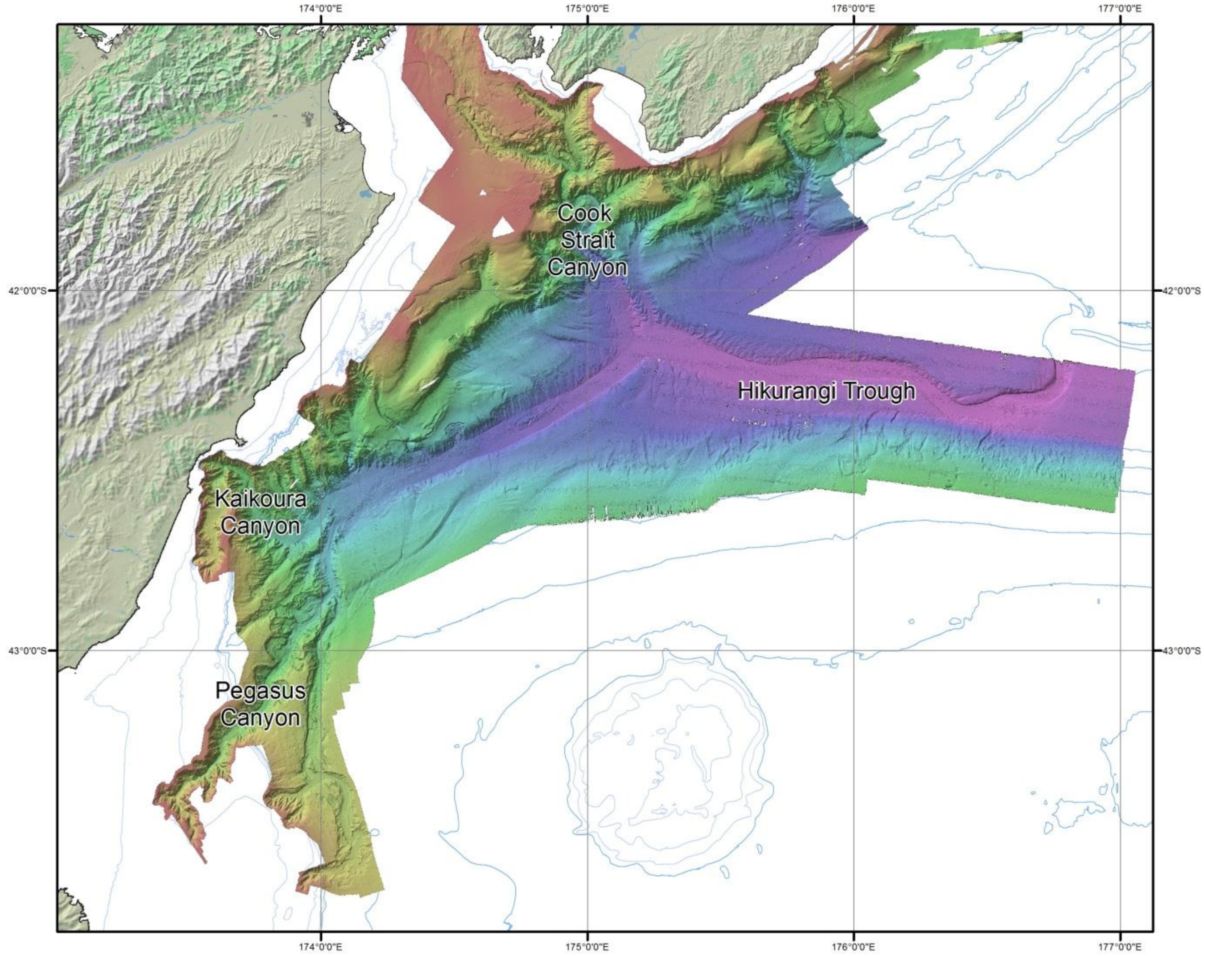

Figure 9: Combined data-set of multi-beam data in the Cook Strait region.

5.1 Submarine canyon systems and Southern Hikurangi Channel

The data reveal twelve canyon systems that have never been imaged in high resolution bathymetry before, and completes mapping of the Kaikoura Canyon in its entirety for the first time. The canyons, from 40 km NE of Banks Peninsula north to Cook Strait, all feed into the Hikurangi Channel, a ~2000 km long channel that carries sediment eroded from the South and North islands to the abyssal floor of the Pacific Basin 350 km east of East Cape.

The morphology of the southern reaches (~300-400 km) of the channel is now imaged with high-quality bathymetry data and connects all the major southern Hikurangi margin canyons together as a sedimentary transport system. The data reveal many detailed submarine canyon features including canyon floor bedforms (dunes) at the mouth of Kaikoura Canyon that are 1000 m long and 200 m wide (Figure 10). Existing cores indicate that these are formed by sand and gravel transport. These sediments are transported in what are referred to as turbidity currents, episodic high density flows that leave distinct sedimentary deposits and erosional features in their wake. Integration of the new multi-beam data with sediment cores and seismic reflection profiles will improve understanding of the surface and subsurface distribution of channel sands in the system. This will be highly relevant to exploration initiatives associated with conventional hydrocarbons and gas hydrates.

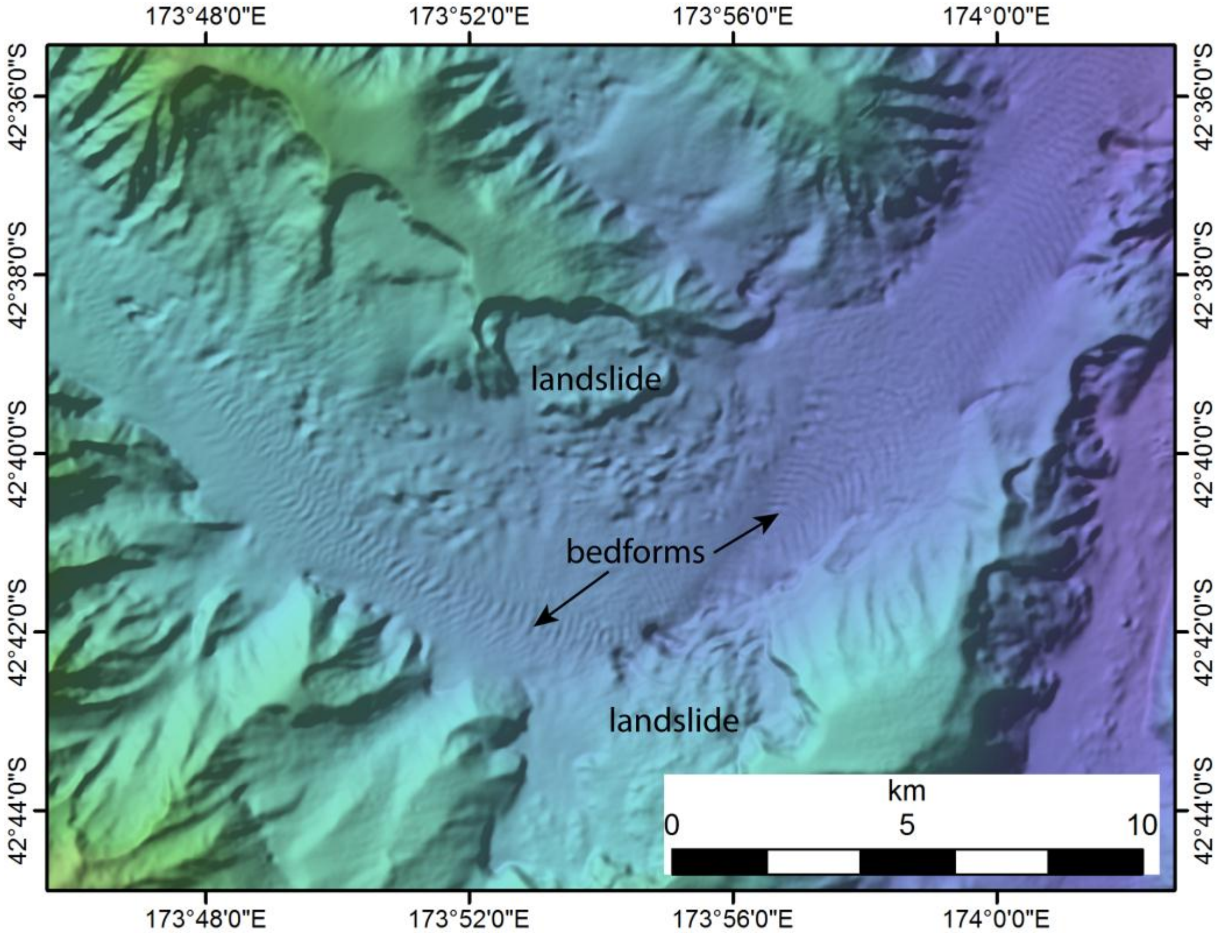

Figure 10: Sediment bedforms on the floor of Kaikoura Canyon where it joins other canyons and exits into the Hikurangi Channel.

5.2 Landslides

The data reveal widespread gully erosion, contrasting canyon forms, and landslides. Landslides occur in large numbers in the area around the mouth of Pegasus Canyon and scattered across the rest of the dataset. Preliminary mapping indicates over 90 individual landslides occur in the region covered by the new data. One landslide has failed across the Hikurangi Channel and, given the debris remains intact on the channel floor, must have occurred recently within the timeframe that reflects the present geomorphology (Figure 11). Many others have left trails of blocky debris, now partially covered to varying degrees by more recent sediments.

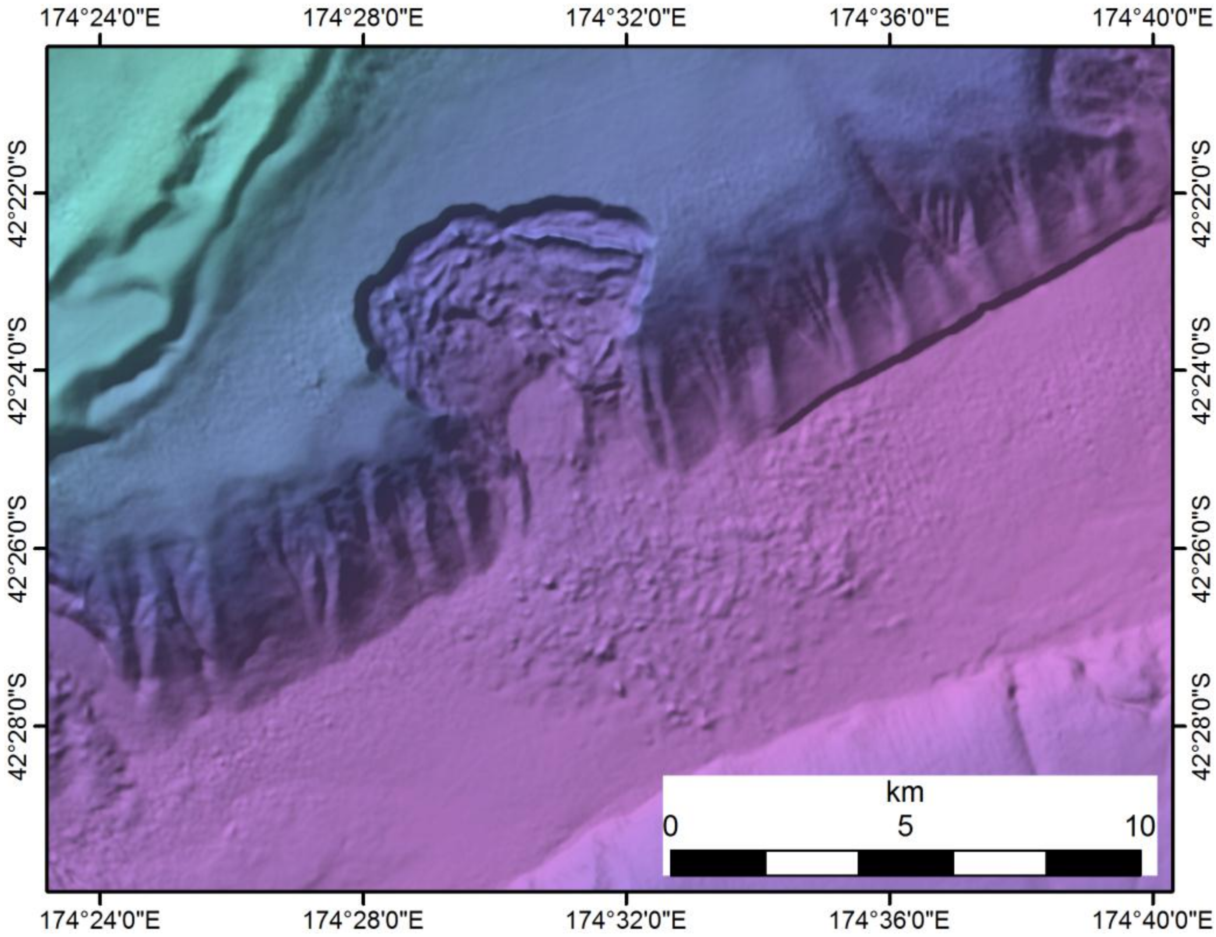

Figure 11: Large landslide source area and deposit on the wall of the Hikurangi Channel.

Pockmarks up to 250 m across occur over large areas of the seafloor around the mouth of Pegasus Canyon, and appear to be coincident with the location of concentrated slope failure (Figure 12). These are likely to be related to fluid expulsion at the seabed, possibly gas or ground water. It is possible that such fluid systems play a critical role in destabilising slopes and causing landslides.

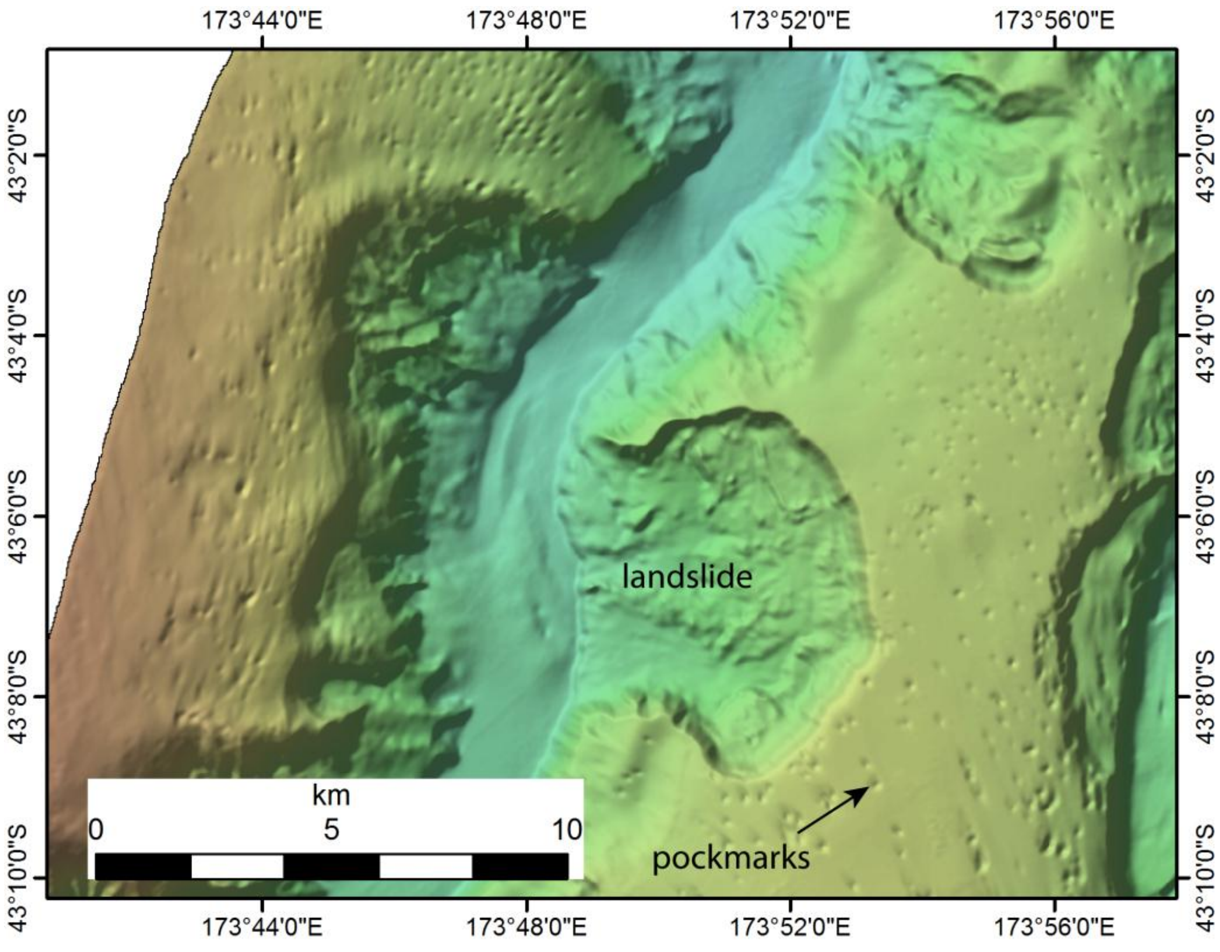

Figure 12: Widespread pockmarks on the slopes adjacent to the lower reach of Pegasus Canyon.

5.3 Tectonic features

The southern Hikurangi margin is at the transition from subduction to continental collision and is therefore subject to widespread tectonic deformation. Numerous active faults occur through the region and have been interpreted previously as earthquake sources. Multi-beam data reveal the surface expression of some active faults (Figure 13) and the seafloor deformation associated with folded rock. These include major *strike-slip* faults of the Marlborough shelf, and large *thrust* faults beneath the Marlborough continental slope.

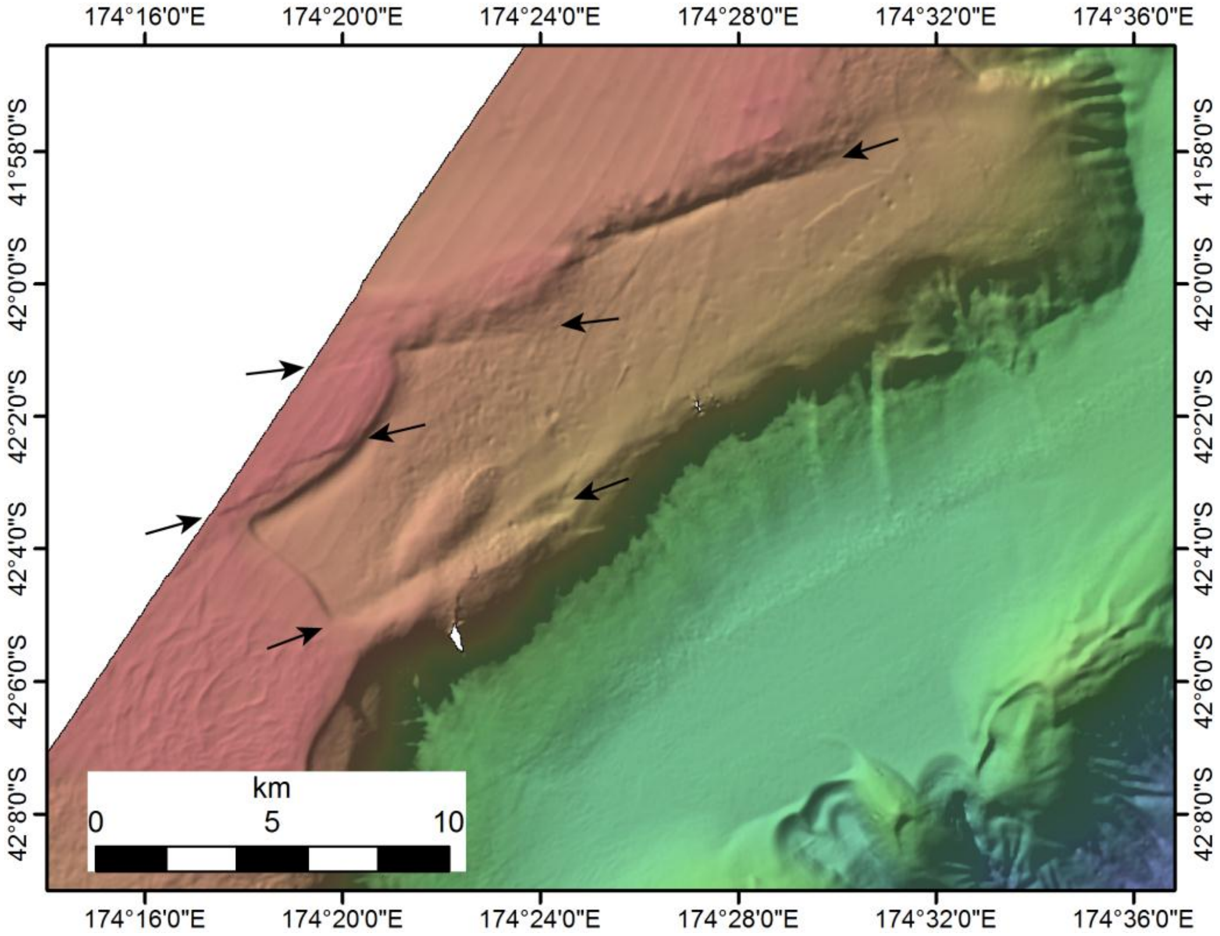

Figure 13: Active traces of the Hope and Te Rapa faults at the seafloor, indicated by arrows.

6 Acknowledgements

All aspects of the survey were very successful thanks to the hard work of everyone involved.

Pre-voyage efforts of all the OS20/20 participating organisations including LINZ, have ensured the success of the project.

The survey could not have been successfully completed without the professional efforts of all involved. We would like to acknowledge the efforts of the master and crew of *Tangaroa* and NIWA Vessels Company. The crew of *Tangaroa* were, as always, helpful and professional and all work was carried out efficiently. The small but dedicated survey party also performed up to high expectations as attested to by the quality of the data obtained.

Appendix 1. Accuracy of Soundings & Positions

Estimate of the sounding error budget for the Kongsberg EM302 multi-beam are listed in Table 1. These values are an estimate based on the survey practices utilized during the sounding survey.

For the EM302 the estimates provided are for soundings gathered at seven depth values and are developed for a swath width of 4 x water depth (WD). The EM302 was operated at port/stbd angles of up to 65°/65° which is equivalent to 4 x WD.

Sounding accuracy has been assessed in accordance with Land Information New Zealand (LINZ) standards for hydrographic surveying.

Table 2: Error Table for Depths collected with EM302.

EM302 *Tangaroa*

	Vertical Accuracy								
	Source of Error		Depth in Metres						
			100	500	1000	2000	3000	4000	5000
		Note							
a.	Draught Setting	1	0.20	0.20	0.20	0.20	0.20	0.20	0.20
b.	Variation in Draught	2	0.15	0.15	0.15	0.15	0.15	0.15	0.15
c.	Velocity of Sound	3	0.29	1.25	2.45	4.85	7.25	9.65	12.05
d.	Spatial Variation in SV	4	0.34	2.44	0.73	0.53	0.00	0.00	0.00
e.	Temporal Variation in SV	5	0.05	0.05	0.05	0.05	0.05	0.05	0.05
f.	Application of Measured SV	6	0.05	0.05	0.05	0.05	0.05	0.05	0.05
g.	Depth Measurement	7	1.00	3.75	7.50	15.00	22.50	30.00	37.50
h.	Heave	8	0.05	0.05	0.05	0.05	0.05	0.05	0.05
i.	Settlement and Squat	9	0.15	0.15	0.15	0.15	0.15	0.15	0.15
j.	Roll, Pitch and Seabed Slope	10	0.10	0.20	0.25	0.30	0.35	0.40	0.45
k.	Co-tidal Readings	11	0.00	0.00	0.00	0.00	0.00	0.00	0.00
l.	Tide Corrections	12	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Total Standard Error: $\sqrt{(a^2 + b^2 + \ldots)}$			**1.14**	**4.66**	**7.93**	**15.78**	**23.64**	**31.52**	**39.39**
Required accuracy:									
IAW TH Standard 31 for MB-1			1.19	5.64	11.26	22.50	33.75	45.00	56.25
IAW TH Standard 31 for MB-2			1.58	7.52	15.01	30.00	45.00	60.00	75.00
IAW TH Standard 31 for MB-3			1.98	9.40	18.76	37.51	56.25	75.00	93.75

Notes

1	Based primarily on ships' drawings and draught readings at W/L
2	Very little change throughout survey
3	Based on SV Plus accuracy. acc+0.0024WD where acc=0.05m/s
4/5	Spatial Variation could be significant
6	Used during data acquisition
7	Estimates from MBES trials and rated accuracy of system. If WD <150m then 1m. If WD >150m then 0.75% WD
8	POS/MV manufacturers specifications apply
9	Based on squat trials
10	Errors minimised through patch testing
11	Not Applied.
12	Not Applied.

Table 3: Horizontal position accuracies for beams 45° from nadir for EM302.

	Horizontal Accuracy								
	Source of Error		Depth in Metres						
			100	500	1000	2000	3000	4000	5000
		Note	Metres						
a.	DGPS Position at Transducer	1	3.00	3.00	3.00	3.00	3.00	3.00	3.00
b.	MBES/Positioning latency (100ms)	2	0.40	0.40	0.40	0.40	0.40	0.40	0.40
c.	Range measurement accuracy	3	0.14	0.14	0.14	0.14	0.14	0.14	0.14
d.	Gyro Error 0.05° (Uncoupled to roll, pitch)	4	0.09	0.44	0.87	1.75	2.62	3.49	4.36
e.	Roll Error 0.05° (Uncoupled to gyro, pitch	5	0.12	0.62	1.24	2.47	3.71	4.94	6.18
f.	Pitch Error 0.05° (Uncoupled to gyro, roll)	6	0.09	0.44	0.87	1.75	2.62	3.49	4.36
g.	Gyro, Roll and Pitch errors coupled in 3D	7	0.20	0.98	N/A	N/A	N/A	N/A	N/A
Approximate (errors treated as linear)									
Total Standard Error:√ (a2 + b2 + c2 + d2 + e2 + f2)			**3.03**	**3.15**	**3.50**	**4.62**	**6.05**	**7.61**	**9.24**
Accurate (errors coupled in 3D)									
Total Standard Error: √ (a2 + b2 + c2 + g2)			**3.04**	**3.18**	N/A	N/A	N/A	N/A	N/A
Required accuracy:									
IAW TH Standard 31 for Order-1			10.0	30.0	55.0	105.0	155.0	205.0	255.0
IAW TH Standard 31 for Order-2			15.0	35.0	60.0	110.0	160.0	210.0	260.0

Notes

1	As realised during survey
2	Latency test cannot detect timing biases less than 100 milliseconds.
3	Maximum value taken from MBES operators' manual
4/5/6	Accuracy of POS/MV motion sensor. Errors treated as if in a linear system. Roll, pitch and gyro errors are coupled to each other and can act synergistically in 3D space.
7	The three motion errors are coupled to one another and computed using a Tate-Bryant rotation sequence.
	Although the two methods of computing the TSE yield very similar values, this similarity may not be valid for larger angular errors and beam angles.
	It would require a rigorous and complex model to give mathematically accurate horizontal accuracies across the full swath width and such an undertaking is beyond the scope of this ROS.

Estimates from the above tables indicate that MB-1 standards have been achieved by the EM302 for all depths. This may not be the case for all depths if tidal corrections are applied. For the majority of work conducted during this survey lines were run such that the vessel ran in the outer beams of the preceding line; therefore these would have not complied with the target detection criteria for MB-1.

Appendix 2. EM302 Calibration Report

TAN1110

RV Tangaroa
EM302 Multibeam Calibration Report

July, 3. 2011

TAN1110

RV Tangaroa
EM302 Multibeam Calibration Report

Anne-Laure Verdier
John Mitchell

Prepared for

NIWA

July, 3. 2011

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Contents

Introduction

Calibration of the Kongsberg EM302 multibeam echo-sounder installed on *R. V. Tangaroa* was undertaken in Cook Strait on Saturday 2nd of July 2011. The system was calibrated after modifying the lever arm values of the GPS antennas. Weather conditions during the calibration were favourable with 10 knots of wind and less than 1m swell. Calibration tests were conducted by Anne-Laure Verdier and John Mitchell.

Offset measurements

All offsets are in terms of the "NIWA frame" defined and measured at installation of the EM302 multibeam. The origin of the NIWA frame or "reference point" is the centre of the face of the EA600 12 kHz transducer, located 0.20m forward of frame 63, 1.1 metres to starboard of the centre line and 0.23 metres below the baseline. The X, Y plane of the NIWA frame is parallel to the design baseline of the vessel. The NIWA frame is square with but offset from the builders design frame. The builders design frame has its origin at the intersection of the rudder shaft and the baseline. .

Offsets between the *Tx* and *Rx* transducer arrays of the EM302 multibeam and the reference point are applied in the SIS acquisition software (figure 1 "Sensor setup").

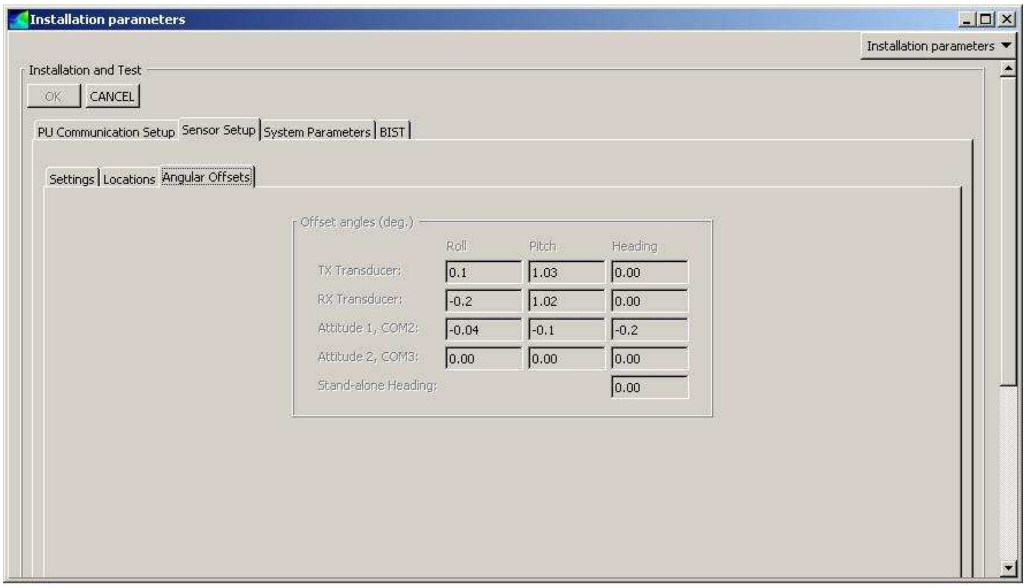

Figure 1: Sensor setup of the EM302 multibeam echo-sounder from the Installation menu in SIS prior to Patch Test calibration.

The offsets between the positioning antenna and the reference point are applied in the POS-MV. The POS-MV outputs position and attitude at the reference.

Sound Velocity measurement

Sound Velocity for the EM302 transducer face is measured using an Applied Microsystems Smart SV&P probe housed in a water tank in the bow thruster room. Additionally, Applied Microsystems a SVPlus probe are used to collect sound velocity profiles of the water column.

Patch Test

Calibration was carried out over a significant features in Cook Strait: Holmes Rock (41° 27.48'S - 174° 51.622'E), Canyon slope (41° 48.50'S - 175° 07.00'E), Hikurangi Trough (41° 53.25'S - 175° 15.25'E). This was the second calibration of the EM302 multibeam since its installation on board *R. V. Tangaroa*.

Diary of events

All dates and times are in UTC.

02/07/11	0615	SVP Measurement
	0721	Begin Latency calibration.
	0757	End Latency calibration.
	1252	SVP Measurement
	1526	Begin Pitch calibration.
	1555	End Pitch calibration
	1642	Begin Roll calibration.
	1759	End Roll Calibration
	1814	Begin Heading Calibration
	2015	End Heading Calibration

Latency

Two survey lines were run over Holmes Rock. Lines in same direction at different speeds (9.5 knots and 4.5 knots) were used to confirm there was no latency offset in the EM302 using the SIS calibration tools (Figure 3).

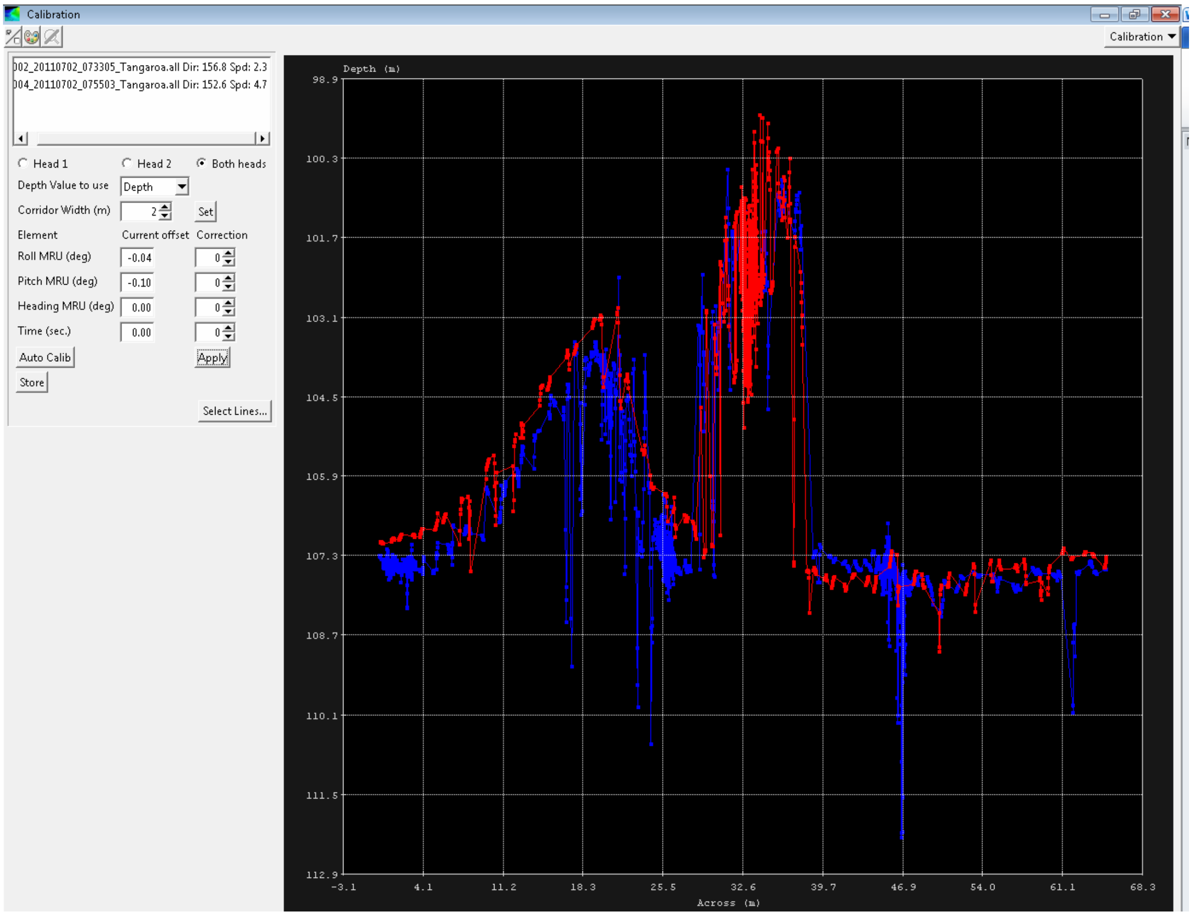

Figure 3. Latency test showing time delay of 0 sec.

Pitch

Pitch tests were undertaken over a canyon slope. Two reciprocal collinear lines were surveyed over the edges of the feature. The lines were analysed in the SIS calibration module. There was no pitch offset in the EM302 (Fig. 4).

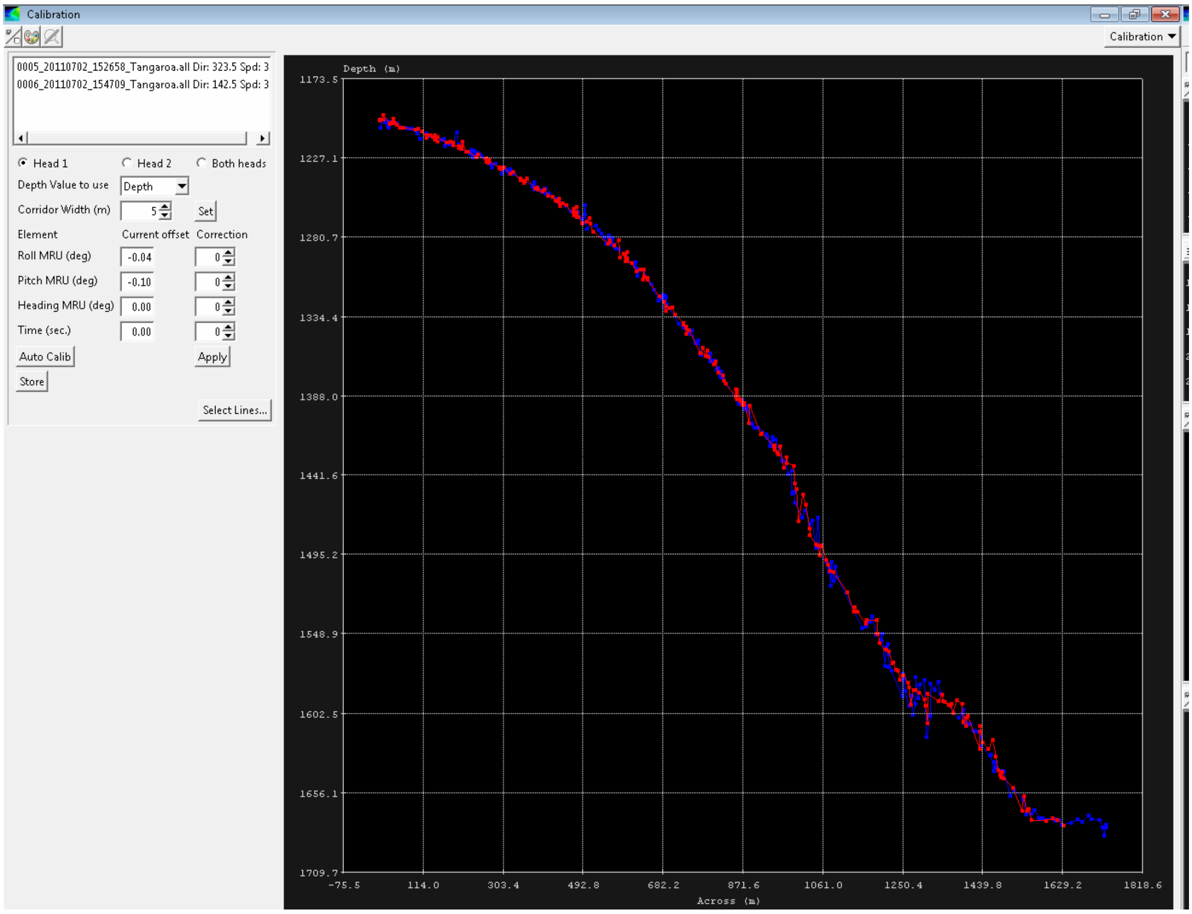

Figure 4. Pitch test showing no offset.

Roll

Roll tests were undertaken over a flat area. Two collinear lines were run over a flat seabed. The lines were analysed in the SIS calibration module and an offset of 0.1° was found and applied to the system (Figs. 5a, 5b and 5c).

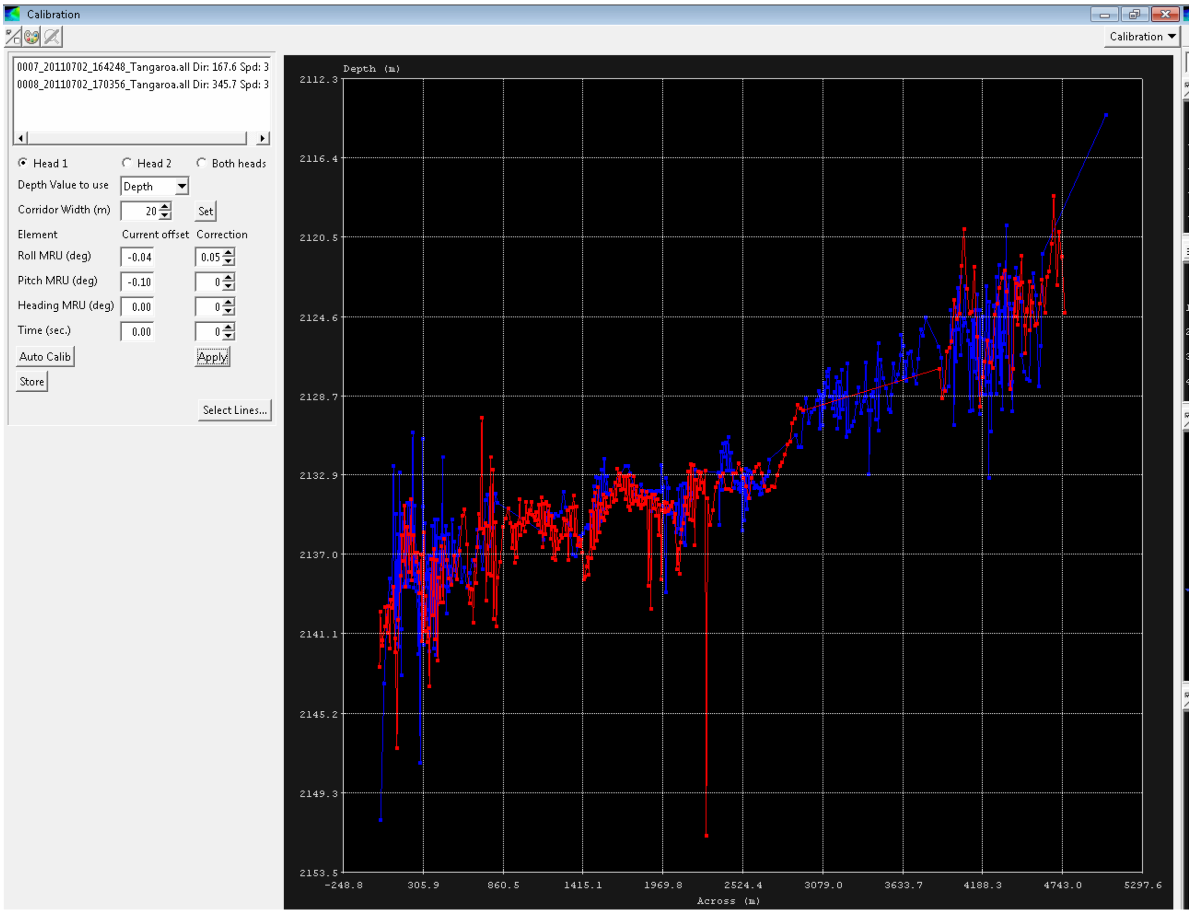

Figure 5a. Roll test showing an error of 0.05°.

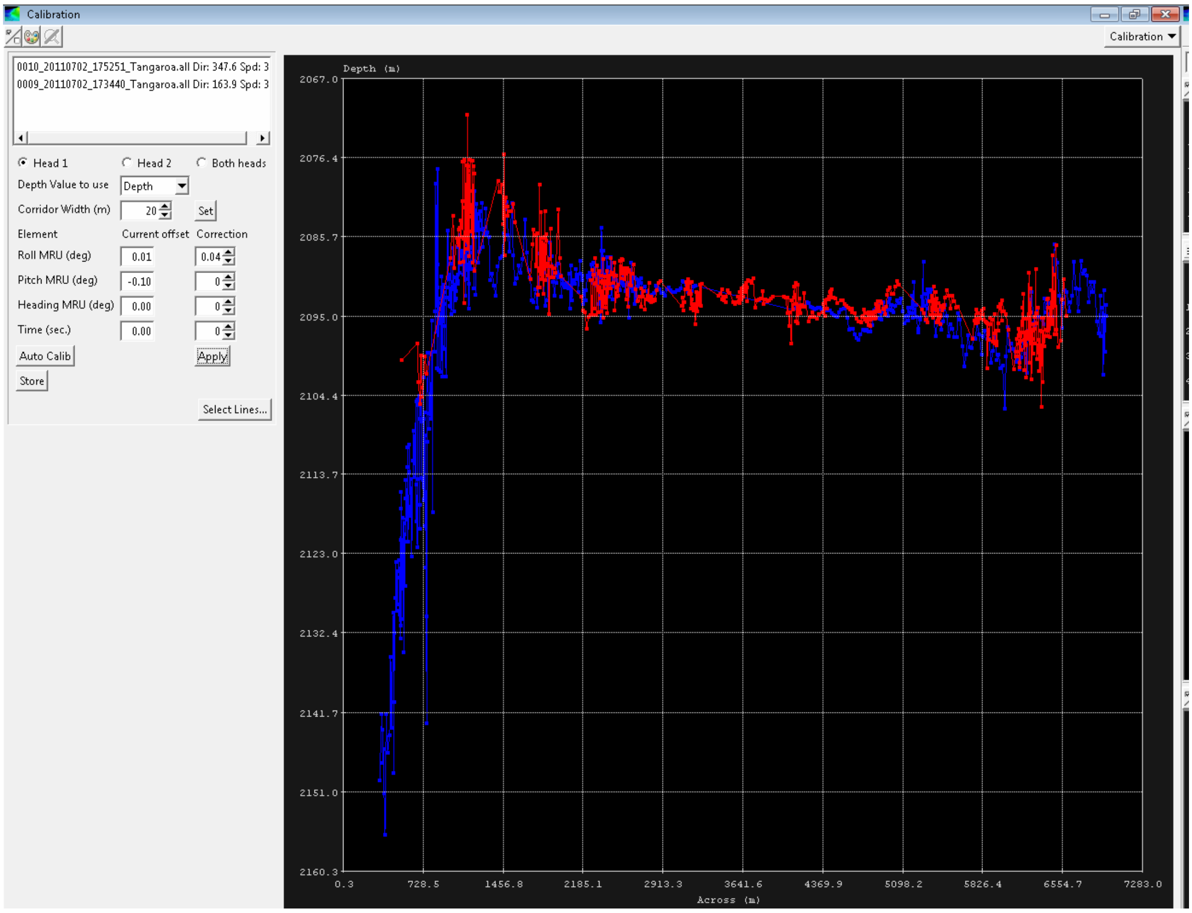

Figure 5b. Roll test after correction showing an error of 0.05°.

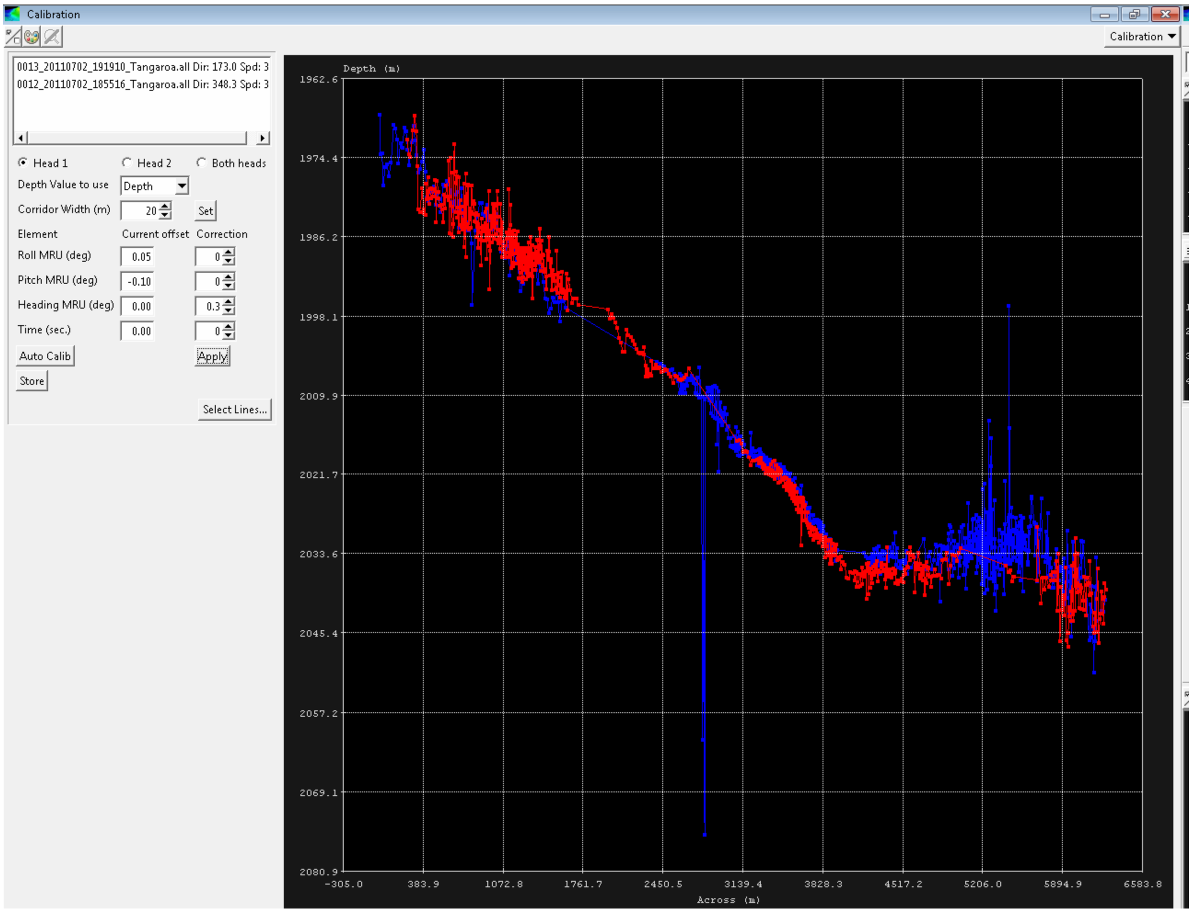

Figure 5c. Roll test after correction showing no more error.

Heading

Heading tests were conducted over a canyon slope. Two parallel lines were surveyed in same direction. The target was analysed in the region of overlap between the two lines using the SIS calibration module and an offset of 0.3° was found and applied to the system (Figs. 6a and 6b).

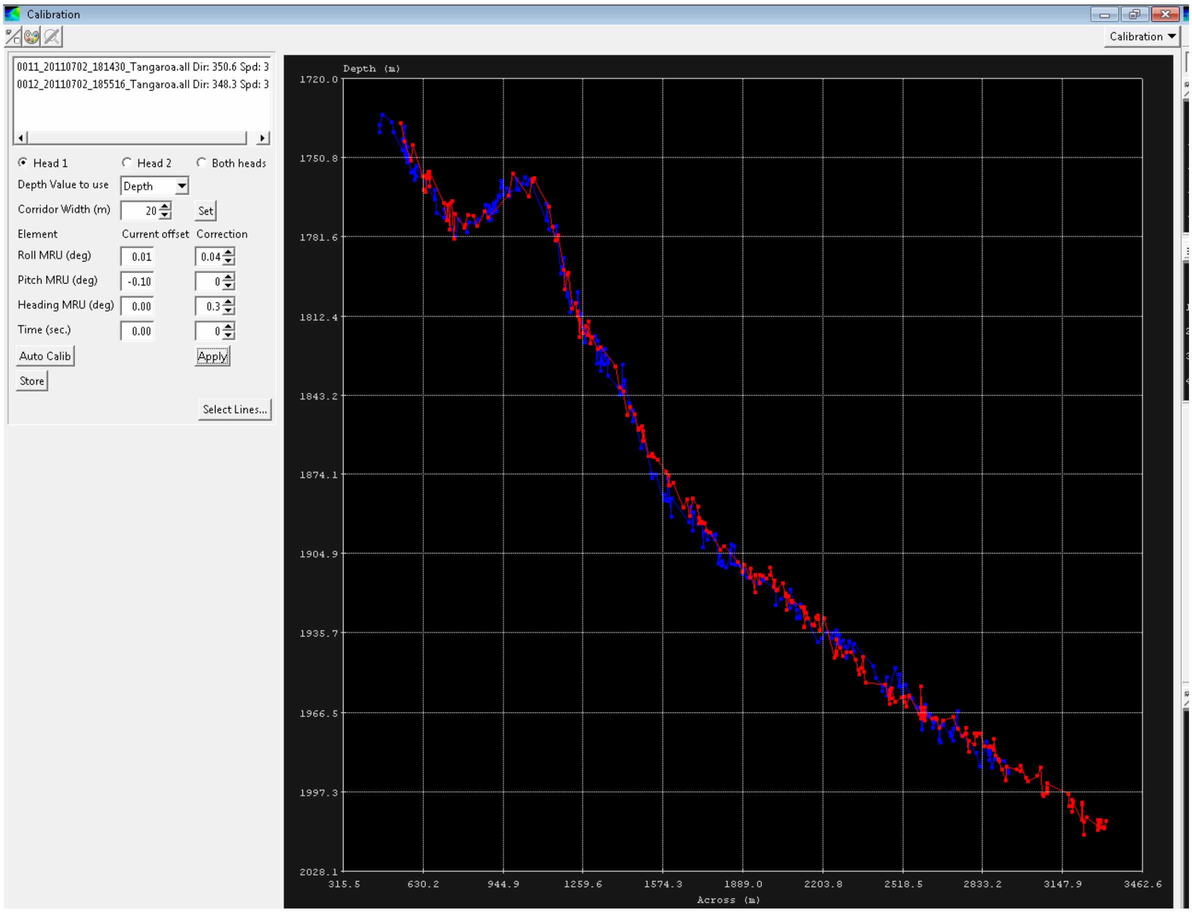

Figure 6a. Heading test showing an error of 0.3°.

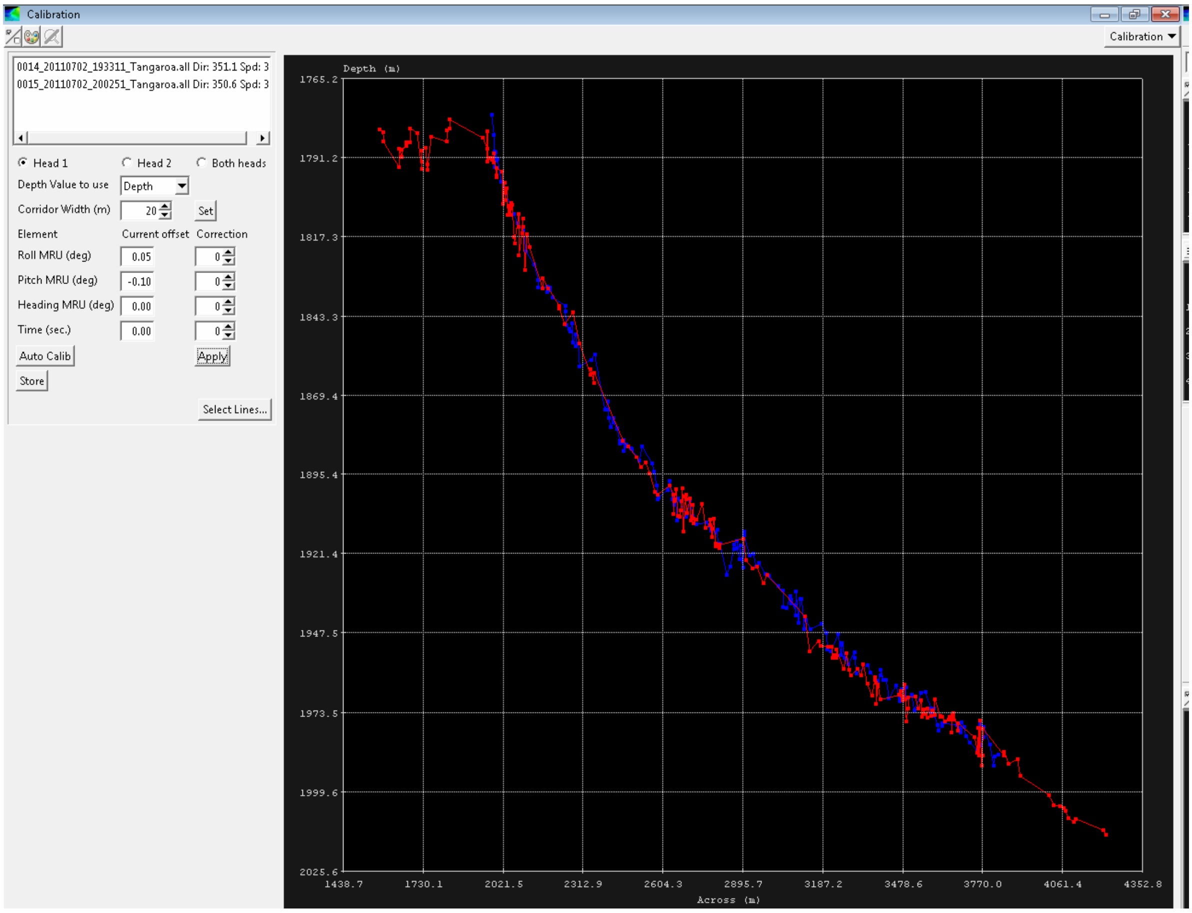

Figure 6b. Heading test after correction showing no more error.

Calibration results

On completion of the calibration some adjustments were required for the EM302 (Figure 7).

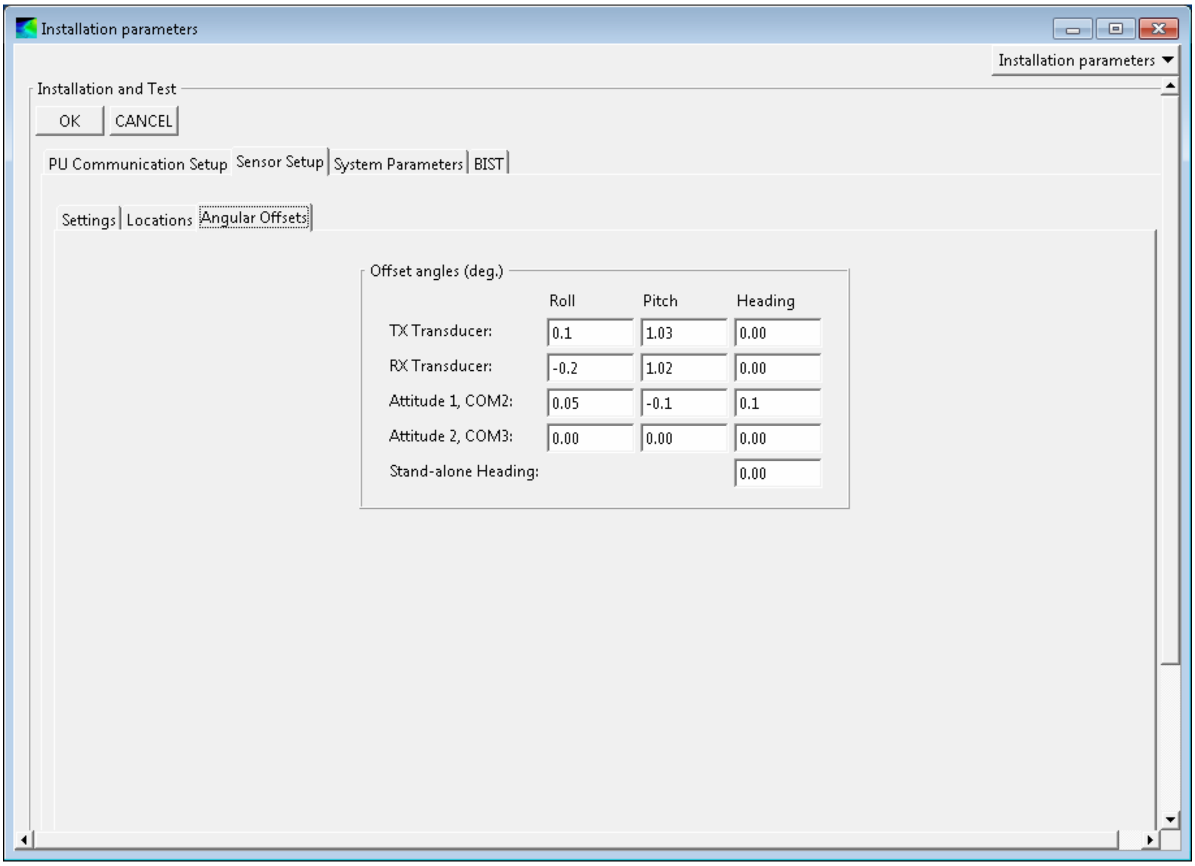

Figure 7. Final settings on Installation menu of EM302 multibeam following calibration.

Appendix A: EM302 Multibeam maintenance history.

Date	Description
August-November 2010	Installation of Multibeam in Drydock, Singapore. Installed under supervision of Kongsberg.
November 2010	Harbour Acceptance Trials. RX32 board 2 was changed to spare board.

TAN1110

RV Tangaroa
EM302 Multibeam Calibration Report Addendum

August, 1. 2011

TAN1012

RV Tangaroa
EM302 Multibeam Calibration Report Addendum

Anne-Laure Verdier
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Prepared for

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August, 1. 2011

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Contents

Introduction

Full calibration of the Kongsberg EM302 multi-beam echosounder installed on *R. V. Tangaroa* was undertaken in Cook Strait on Saturday 2nd July 2011. As a check of the system's calibration in tropical waters a partial calibration was conducted during the transit between Madang, PNG and the survey site off Wuvulu Island. Calibration tests were conducted by Anne-Laure Verdier and John Mitchell.

Sound Velocity measurement

Sound Velocity for the EM302 transducer face is measured using an Applied Microsystems Smart SV&P probe housed in a water tank in the bow thruster room. Additionally, Applied Microsystems a SVPlus probe are used to collect sound velocity profiles of the water column.

Calibration Checks

Calibration checks were carried out over suitable features between Madang and Wuvulu Island.

Diary of events

All dates and times are in UTC.

20/07/11	0729	SVP Measurement (05° 10.29'S - 145° 52.05'E)
	0825	Begin Pitch calibration.
	0857	End Pitch calibration
21/07/11	0602	SVP Measurement (02° 45.24'S - 143° 52.01'E)
	0941	Begin Roll calibration.
	1045	End Roll Calibration

Pitch

Pitch tests were undertaken over a sloping seafloor. Two reciprocal collinear lines were surveyed over the feature. The lines were analysed in the SIS calibration module and no offset was found in the data (Figure 1).

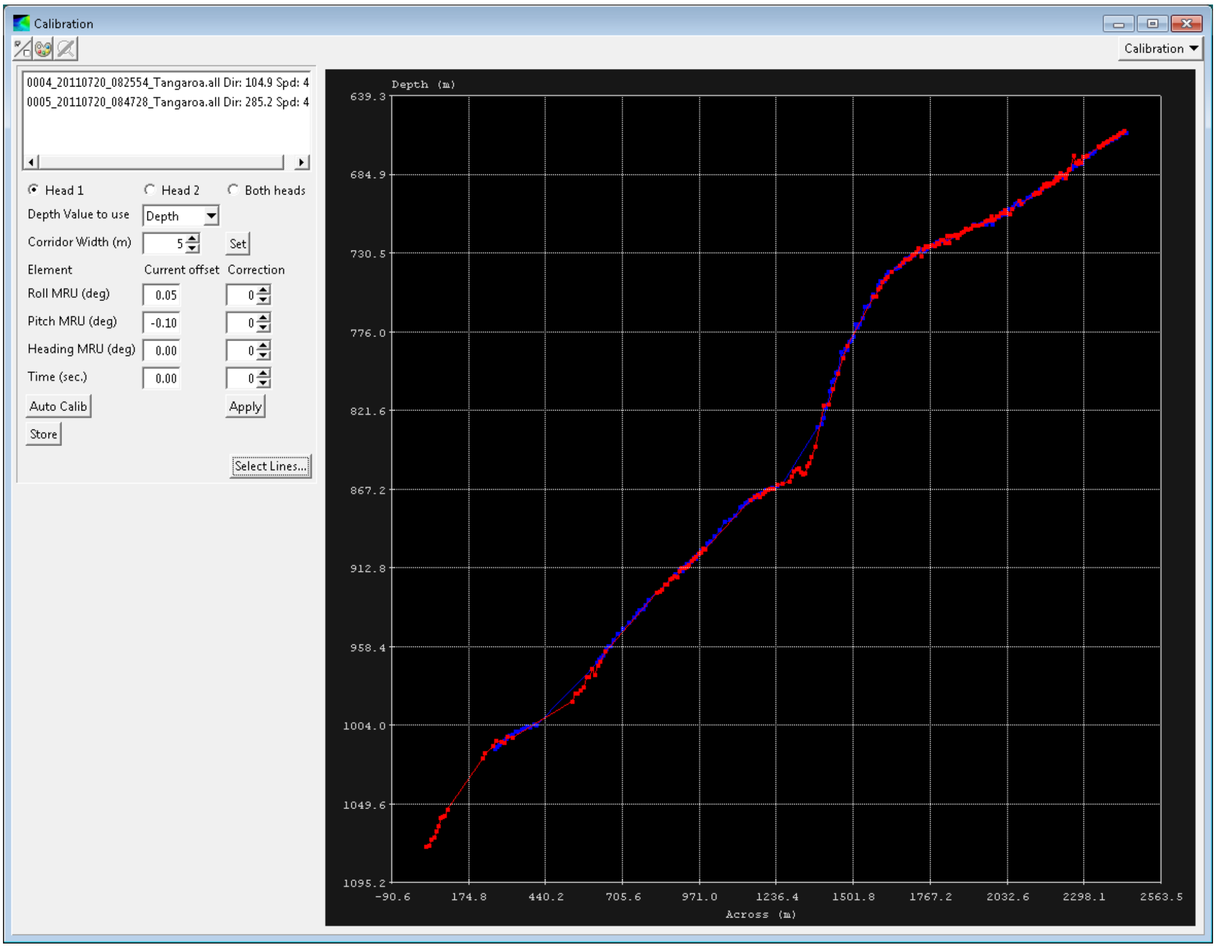

Figure 1. Pitch test showing no error.

Roll

Roll tests were undertaken over a relatively flat seabed. Two collinear lines were run over the seabed. The lines were analysed in the SIS calibration module and no offset was found (Figure 2).

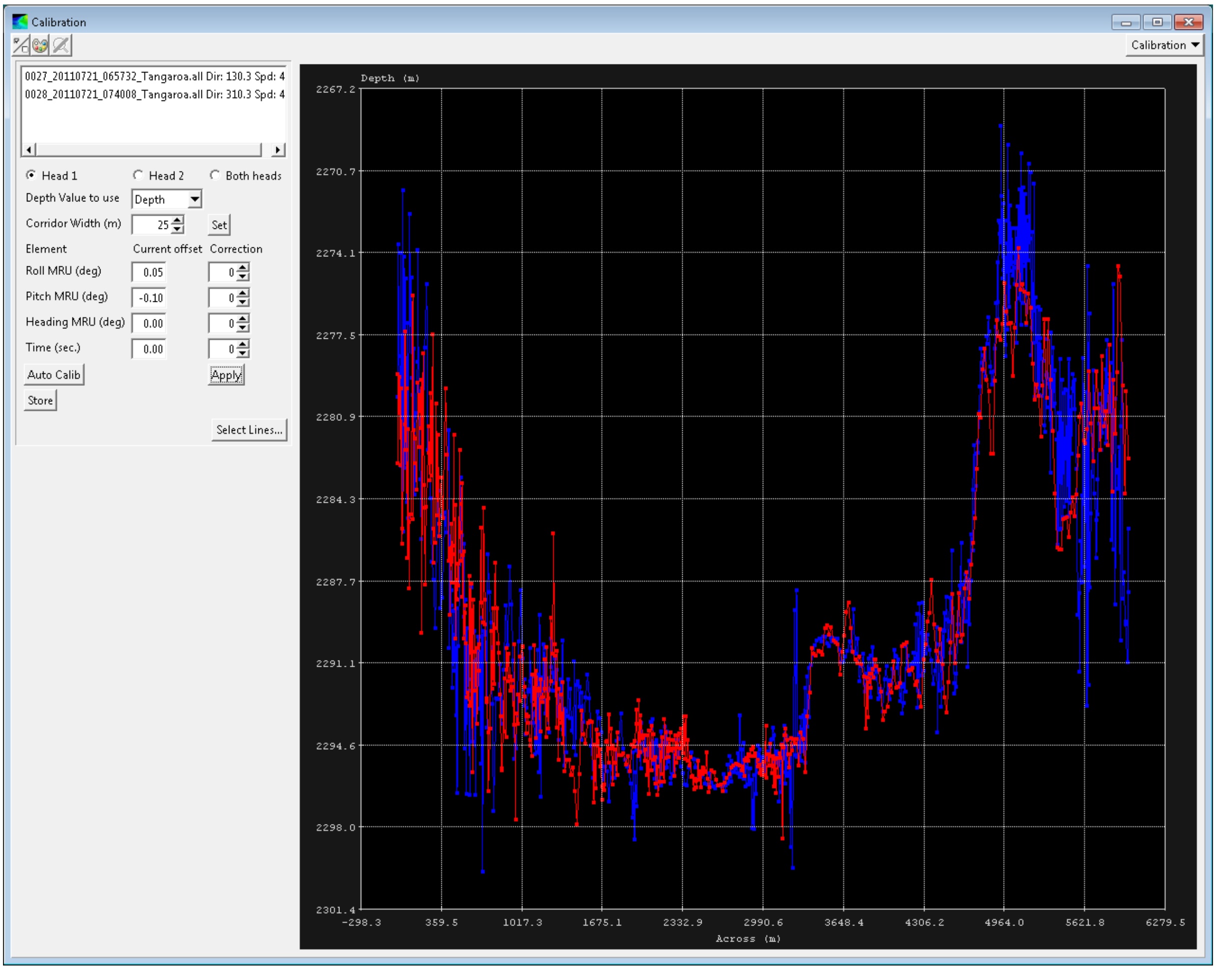

Figure 2. Roll test showing no error (large vertical exaggeration).

Calibration results

On completion of the calibration checks no adjustments were required to the installation angles. This shows that the patch test completed in Cook Strait, Wellington, was still relevant for data to be collected in the tropical waters north of Papua New Guinea.