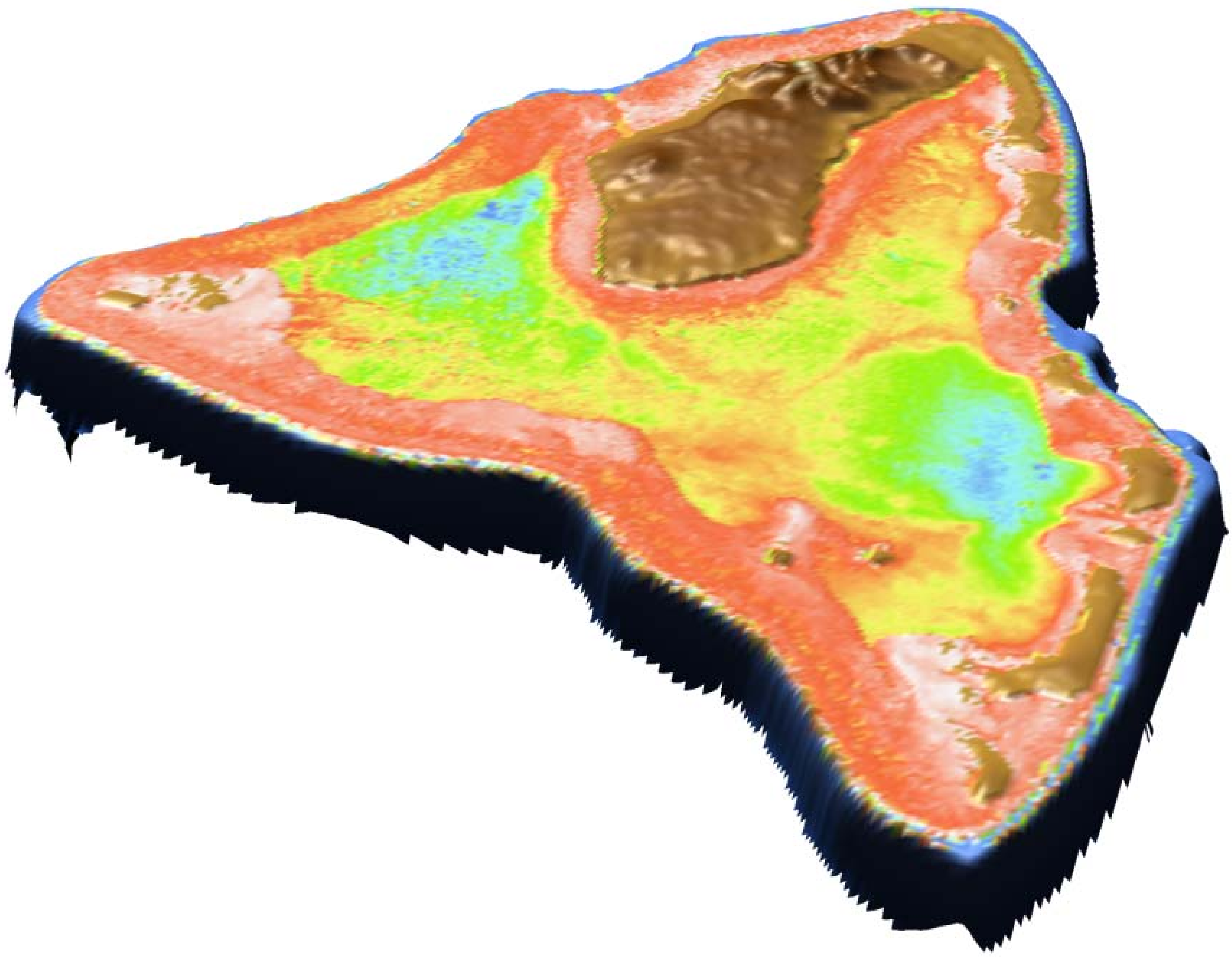
EU EDF 9 – SOPAC Project Report 121
Reducing Vulnerability of Pacific ACP States

COOK ISLANDS TECHNICAL REPORT

High-Resolution Bathymetric Survey of Aitutaki

Fieldwork undertaken from 9 April to 16 May 2008

October 2008



Three-dimensional perspective image of Aitutaki, Cook Islands

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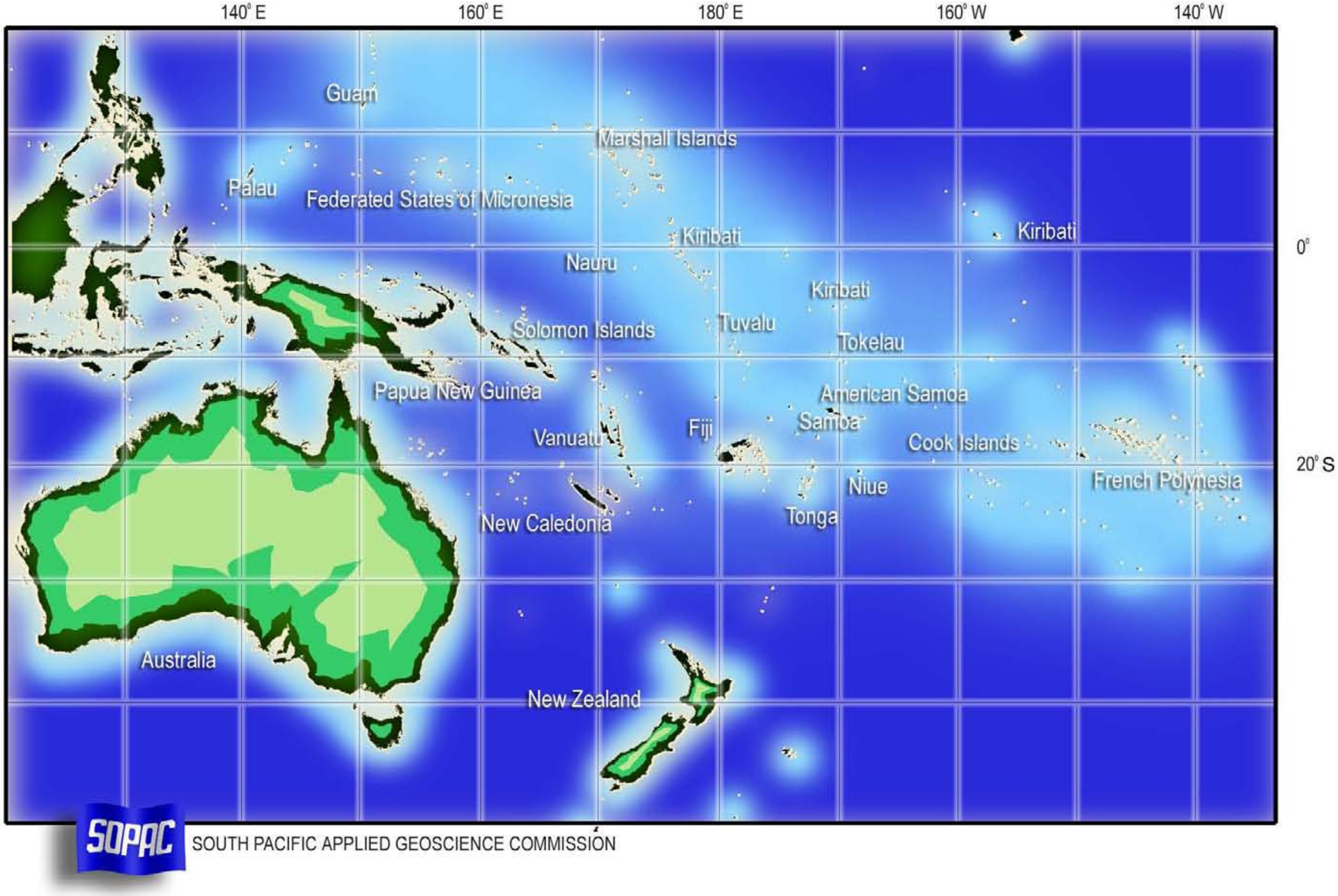


Figure 1. Location map of Pacific Island countries and territories constituting SOPAC.

Acronyms and their meaning	
ACP	African, Caribbean, and Pacific
ADV	Acoustic Doppler velocimeter
ARGO	Array for real-time geostrophic oceanography
ASCII	American standard code for information interchange
CD	Chart datum
CTD	conductivity – temperature – depth
DTM	Digital terrain model
EEZ	Exclusive economic zone
EU	European Union
GDEM	Generalised digital environmental model
GEBCO	General bathymetry chart of the oceans
GPS	Global positioning system
LAT	Lowest astronomical tide
MBES	Multibeam echosounder
MMR	Ministry of Marine Resources
MRU	Motion reference unit
MSL	Mean sea level
NOAA	National Oceanic and Atmospheric Administration
PI-GOOS	Pacific Islands global ocean observing system
RTK	Real-time kinematic
S2004	Global bathymetry grid merging GEBCO and predicted depths from satellite altimeter measurements
SBES	Singlebeam echosounder
SOPAC	Pacific Islands Applied Geoscience Commission
SV	Sound velocity
TAO	Tropical atmosphere ocean array
UTC	Universal time co-ordinated (Greenwich meridian time, GMT)
UTM	Universal transverse Mercator
WGS	World geodetic system

EXECUTIVE SUMMARY

Krüger, J., Sharma, A. and Kumar, S. 2008. High-Resolution Bathymetric Survey of Aitutaki, Cook Islands. *EU EDF9 - SOPAC Project Report 122*. Pacific Islands Applied Geoscience Commission: Suva, Fiji, vi + 41 p. + 1 chart.

This report describes a high-resolution bathymetric mapping survey of the seabed surrounding the island of Aitutaki in the Cook Islands. This work was initiated by the SOPAC/EU project 'Reducing Vulnerability of Pacific ACP States'. It called for an investigation of the nearshore seabed around the island of Aitutaki using a shallow water multibeam echosounder (MBES) and a single beam echosounder (SBES). The survey was carried out over a period of six weeks in April and May 2008. The SBES survey achieved coverage within the lagoon while the MBES surveyed the seafloor from the outer reef area, starting from a minimum depth of 10 m, to an average offshore distance of 0.5 km, and reaching water depths of some 300 m.

A review of external sources of available bathymetry was also undertaken, and the survey data was supplemented with publicly available sources. The resultant data compilation was used to produce a bathymetric chart of Aitutaki at a scale of 1 : 25 000. These new bathymetric maps give a descriptive picture of the ocean bottom terrain, vividly revealing the size, shape and distribution of underwater features. It can serve as the basic tool for scientific, engineering, marine geophysical and environmental studies, as well as marine and coastal resource management.

1. INTRODUCTION

1.1 Background

This report describes a high-resolution bathymetric mapping survey of the seabed surrounding the island of Aitutaki in the Cook Islands (Figure 2). The survey was conducted using a shallow water multibeam echosounder and a singlebeam echosounder, and was carried out over a period of 30 days in April and May 2008. This work was initiated by the Pacific Islands Applied Geoscience Commission (SOPAC) and European Union (EU) Reducing Vulnerability of Pacific ACP States Project.

It is envisaged that data from the survey will be used to support activities in fisheries, mineral exploration, coastal management, and geo-hazard studies. The tidal, wave and current regime at Aitutaki was also investigated through eh deployment of acoustic Doppler current profilers, as well as tide and wave gauges. The oceanographic data was collected in order to calibrate a water circulation and wave model of Aitutaki using MIKE21 hydrodynamic modelling software. The present report presents the results of the MBES and SBES survey, and the oceanographic data and modelling results for Aitutaki are covered elsewhere.

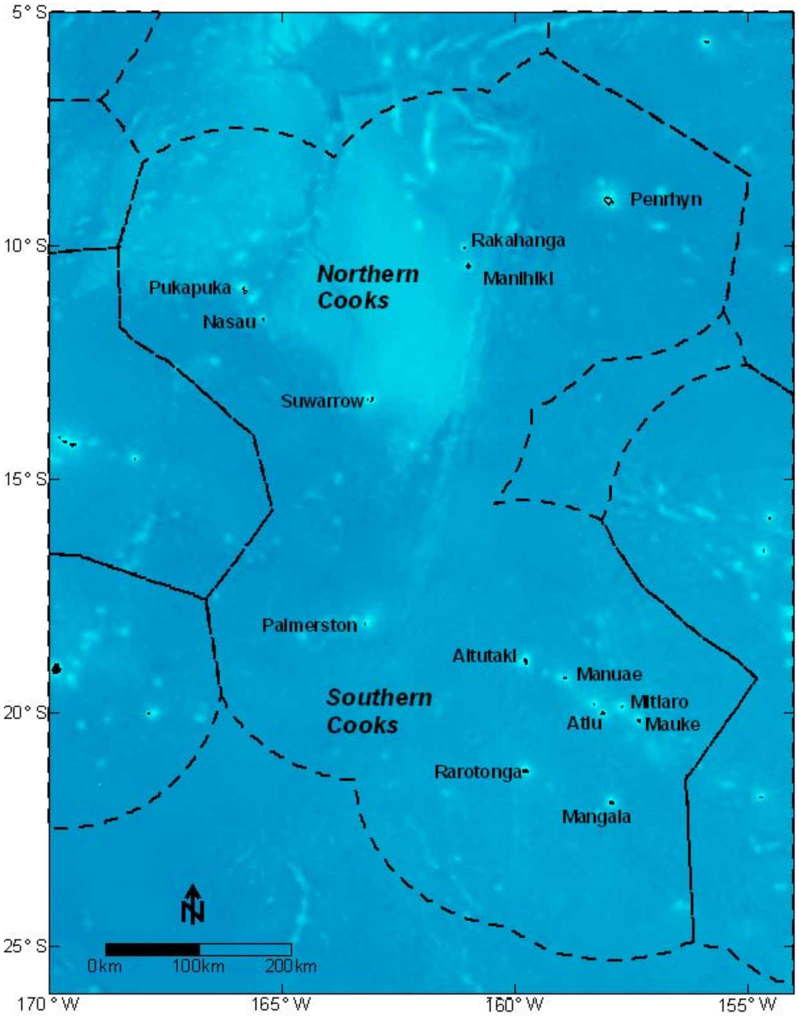


Figure 2. Bathymetric map of the Cook Islands, showing the islands and approximate position of the exclusive economic zone, EEZ (black dashed line). Major islands and important geological features are named. The 200 nautical mile boundary (dashed line) is indicative only. Bathymetric data are General Bathymetry Chart of the Oceans (GEBCO) and Smith and Sandwell (1997) predicted water depths, with shallow to deep shown as light to darker blue (S2004 1-minute grid as described in Marks and Smith 2006).

1.2 Geographic Situation

The Cook Islands comprises 15 islands with a total land area of 237 square kilometres and a maximum height above sea-level of 652 m (Figure 3). The islands are scattered over an Exclusive Economic Zone (EEZ) of 1.8 million square kilometres; one of the largest EEZs in the South Pacific.

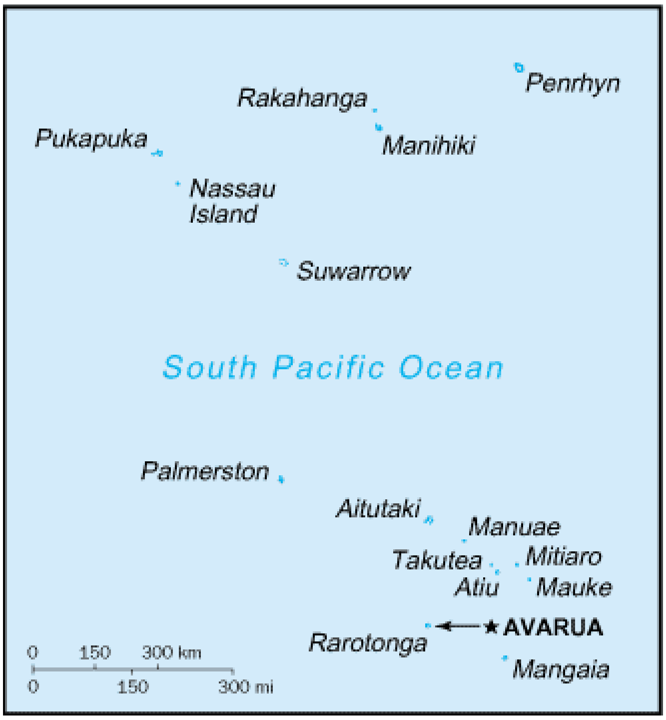


Figure 3. The Cook Islands group.

The islands are formed geographically into a Northern Group of low coral atolls (Manihiki, Nassau, Penrhyn, Pukapuka, Rakahanga and Suwarrow) and a Southern Group of volcanic, hilly islands (Rarotonga, Aitutaki, Atiu, Mangaia, Manuae, Mauke, Mitiaro, Palmerston and Takutea). Rarotonga, situated in the Southern Group, is the largest island (67 km^2) followed by Mangaia (51 km^2).

Aitutaki lies 225 km north of Rarotonga in the southern Cook Islands (Figure 3). It is a triangular “almost-atoll” consisting of a low, hilly, volcanic island from which fringing reefs extend south-east and south-west as a barrier reef, eventually curving sharply toward each other to enclose a lagoon of approximately 50 square kilometres (Figure 4). Twelve coral islets are situated along the eastern reef and another one at the southwest corner, varying in length from 150 to 2250 metres with a combined area of 2.4 square kilometres. The total land area of Aitutaki is 18.5 square kilometres and the reef circumference is 43 km. The main island, at the northern end of the lagoon, is about 16 square kilometres but it is not the only emergent part of the largely submerged Aitutaki volcano: two other small volcanic islets, Rapota and Moturakau, are located in the south-eastern corner of the lagoon (Figure 4) (He 1999).

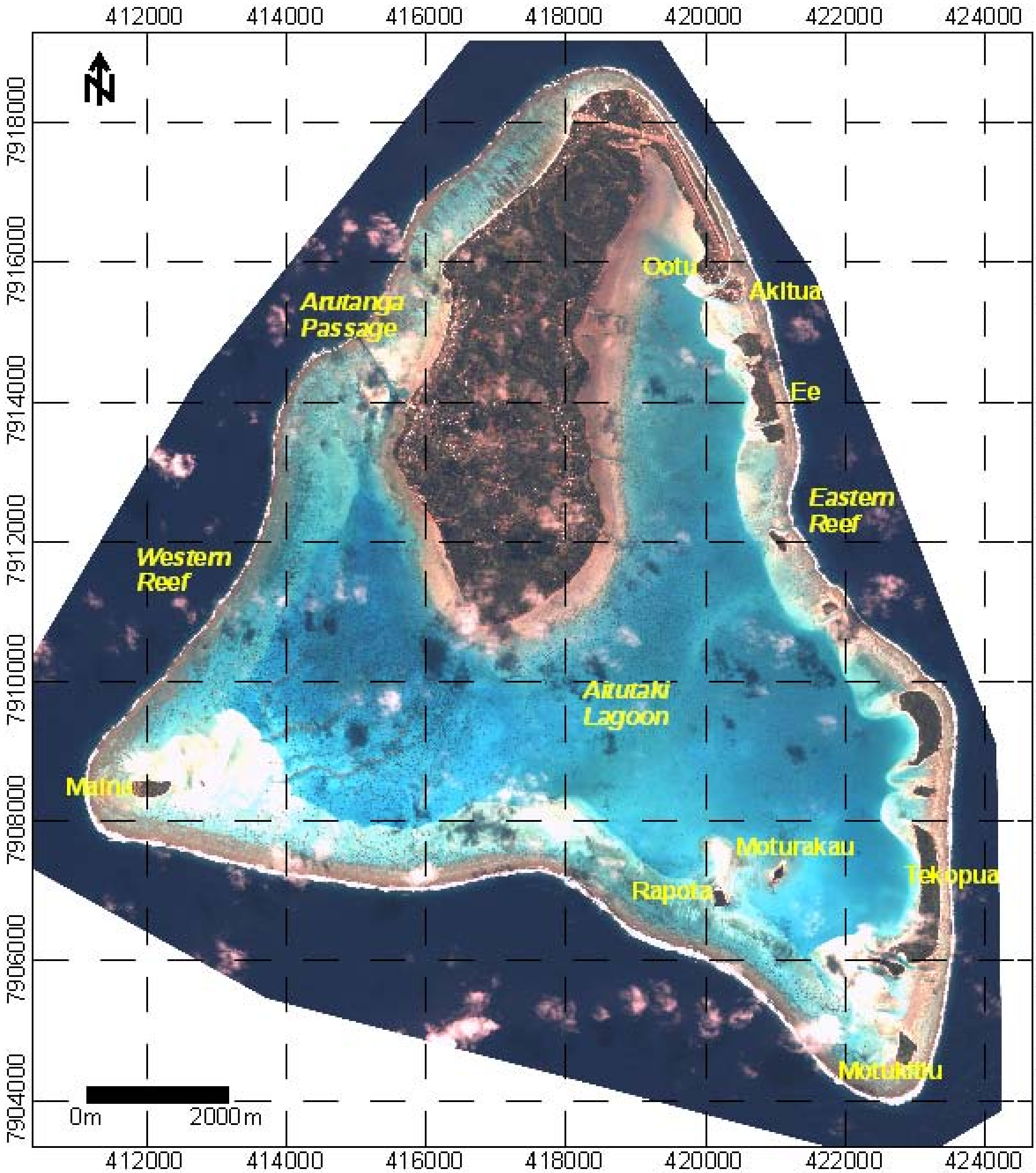


Figure 4. Satellite image of Aitutaki Lagoon. Satellite image is a Quickbird image with a 2.4 m resolution taken in July 2007.

Selected geographic facts about the Aitutaki are listed in the table below.

Geography of the Aitutaki	
Location	Aitutaki is an “almost atoll”, located at 18° 50’ S and 159° 45’ W
Population	2000 (2001)
Land area	Total is 18.05 km^2, of which the main island occupies 16.8 km^2. It has a maximum elevation of approximately 123 meters with the hill known as Maungapu close to its northernmost point.
Coastline	Coastal areas comprise features such as barrier reefs, lagoons, and natural beaches. The barrier reef that forms the basis of Aitutaki is roughly the shape of an equilateral triangle with sides 12 km in length. The southern edge of the triangle is almost totally below the surface of the ocean, and the eastern side is composed of a string of small islands. The western side of the atoll contains many of Aitutaki’s important features including a boat passage through the barrier reef allowing for anchorage close to shore at Arutanga.
Tides	Semi-diurnal, varying from 0.49 m at springs to 0.12 m at neaps at Aitutaki.
Climate	Mainly tropical and moderated by the trade winds. The mean annual precipitation varies is around 2040 mm per annum. The mean temperature is 24ºC. The mean sea surface temperature ranges from 25.5°C in June to 27.3°C in January. Natural hazards include cyclones, storm surges, coastal flooding, river flooding, drought, earthquakes, landslides, and tsunamis.
EEZ	Approximately 1.8 million km^2.

1.3 Geological Setting

The Cooks Islands lie south of the equator, just east of the International Date Line. The 15 islands are divided into a northern and a southern group, separated by 1000 km of empty sea. The northern island group are older, low-lying coral atolls and have no significance regarding karstification or caves. Nassau is a sand cay on a coral reef foundation. These islands are widely scattered and their surrounding bathymetry shows that some are parts of submarine ranges of volcanic mountains, and others are summits of single volcanic cones rising some 15 000 to 22 000 feet [4.6 to 6.7 kilometres] above the ocean bed (Wood and Hay 1970).

With the exception of Penrhyn Atoll, which is an isolated edifice built up from the abyssal seafloor, the northern Cook Islands are located at the margin of Manihiki Plateau. The Manihiki Plateau is a 5 x 105 km^2 area of anomalously shallow water and thick crust. The plateau formed at about 110 million years (Ma), probably from an immense outpouring of lava at a triple junction between the Pacific, Antartic, and Farallon Plates. The most likely tectonic setting was a hotspot situated at or near a slow-spreading ridge (Mahoney 1987).

During the Cretaceous, the summit of the plateau was near sea level and subsequently subsided about 3 km to its present position (Winterer et al. 1974). Atolls of the northern Cook Islands formed during this period of subsistence; from seismic reflection studies, the carbonate caps are estimated to be at least 500 m thick as measured on Manihiki Atoll (Hochstein 1967). None of the volcanic edifices of the northern Cook Islands have been age-dated but the islands are likely to be about the same age as Manihiki Plateau upon which they rest. Manihiki Plateau basement basalt has a minimum age of 106 ± 3.5 Ma (Lanphere and Dalrymple 1976), and the plateau basement is probably as old as 112–110 Ma (Jackson and Schlanger 1976).

The southern islands are generally larger, constituting about 90% of the total area and differ widely in form, structure and relief, which makes it difficult to deduce a generalised geological history that is consistent for the whole group (Wood and Hay 1970). However, the group include a high mountainous island of Rarotonga, four raised coral islands with volcanic cores (Mangaia, Mauke, Mitiaro and Atiu), one atoll (Manuae), one near atoll with a volcanic core (Aitutaki), and a sand-cay on a coral foundation (Takutea). Several of the islands are isolated submarine mountains, but those between Aitutaki and Mauke form a distinct chain that trends northwest parallel such as the Austral Group to the southeast (Wood and Hay 1970).

The southern islands form two linear northwest-southeast chains that apparently converge to the southeast on the volcanically active Macdonald Seamount, which has been proposed to be a hotspot volcano. The eastern chain included the islands of Aitutaki, Manuae, Takutea, Atiu, Mitiaro, and Mauke, which together form a ridge defined by the 4500 m isobath. The western chain includes three isolated edifices, Palmerston, Rarotonga, and Mangaia, and numerous recently discovered seamounts to the southeast (Diament and Baudry 1987).

The ages of the dated southern Cook Islands, with the exception of Mangaia, do not fit within a single hotspot framework (Dalrymple et al. 1975). According to Turner and Jarrard (1982), a hot-line hypothesis places fewer constraints on age predictions than does the hotspot model. Renewed volcanism on Aitutaki during the Pleistocene after about 6 Ma of quiescence may have originated from the same hotspot that formed Rarotonga, because the two islands are within the 300 km diameter of volcanism that defines known hotspots.

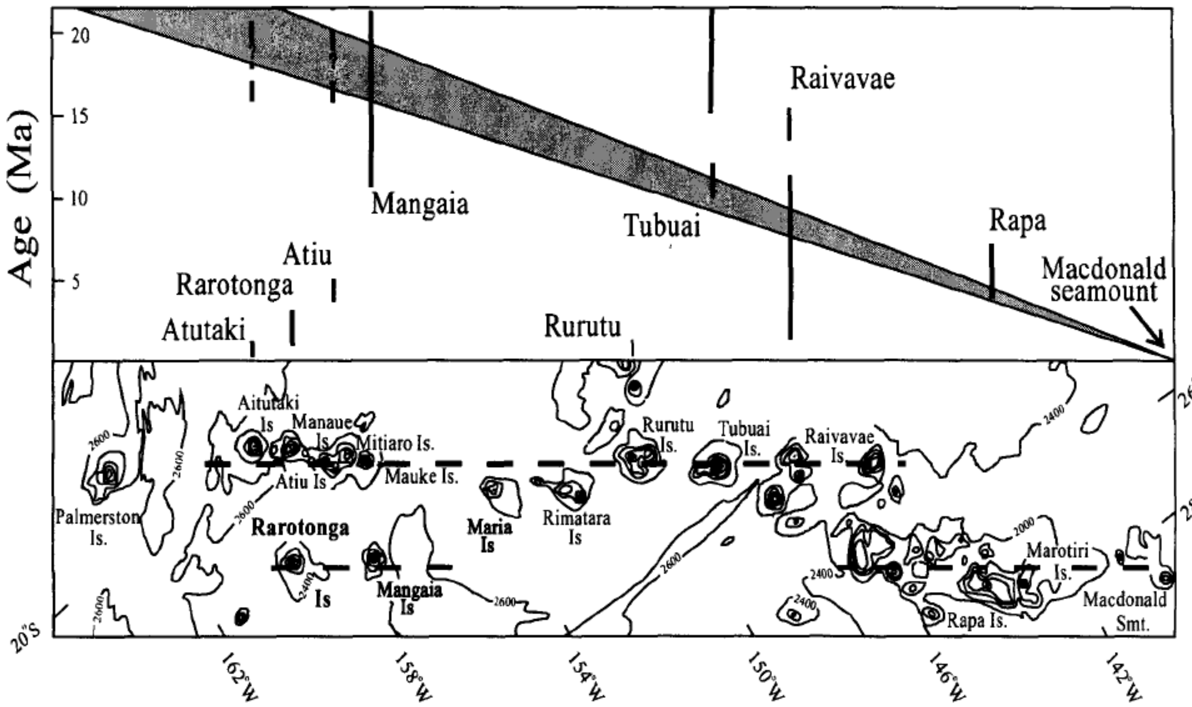


Figure 5. Map of the Cook-Austral island chain in the South Pacific, showing the ages of volcanic edifices on the chain and their age-distance relationship with respect to the active volcanism now manifested at MacDonald Seamount. The ages of the islands are all based on radiometric dating, except for the two dashed lines for Atiu and Aitutaki that show the possible age of the shield-building stage of these volcanoes based on geomorphic criteria. The shaded region is the predicted age for the volcanic edifices if volcanism was due to the Pacific plate moving over a stationary mantle plume located beneath the MacDonald Seamount (after Dalrymple et al. 1975).

Four of the Southern Group of islands, the so called “"raised islands” of Atiu, Mauke, Mitiaro and Mangaia have a remarkable topography showing signs of karstification and cave development. The islands were formed about 10 million years ago as volcanic islands and gradually became encircled by coral reefs. Over time the volcanic cones sank and the Pacific plate moved on. Two million years ago more volcanic activity occurred. This time the main island, Rarotonga, appeared. The same activity caused a buckling of the sea floor in the area nearby, causing the four islands to be raised above sea level. This exposed the coral reefs, which became fossilized coral limestone, forming the rugged coastline and the low-lying plateaus. In the last 100 000 years a narrow belt of young coral reefs developed around most of the islands.

In the central part of the islands are depressions in the middle of the limestone plateaus; the remains of the volcanic rocks are found here, covered by fertile soil. Between the depressions and the limestone plateaus, swampy rims were formed. The islands can be described as being like a very low-brimmed hat with a flat outer rim. The fossilised coral limestone has undergone intense karstification. As a result of the tropical limestone solution and the characteristics of the coral limestone, very rugged surfaces have developed. This is the so called “makatea”. The makatea covering the plateau surfaces hides a razor-sharp 1–3 m high, mass of limestone rocks. Between these are deep, vegetation-covered fissures. The limestone plateaus resemble a sponge as a consequence of the combined solutional effects of the infiltrating rain water and the tropical vegetation. This is the basis for cave development. In the islands several hundred minor caves and cavities exist. In some favourable cases, extensive caves with large chambers have formed. Due to the frequent changes to the sea level in the last 15 000 years, some of the caves are now beneath the water table.

1.4 Previous Bathymetry Surveys

Bathymetric maps are topographic maps of the sea floor, giving a descriptive picture of the ocean bottom terrain. With a shallow and easily accessible lagoon, Aitutaki lagoon has been the subject of a number of bathymetric surveys. Most bathymetric data originates from sparse singlebeam soundings, but also from remote sensing models. Some notable surveys are listed below.

Bathymetry surveys of Aitutaki	
1892	Arutanga Passage and Te Avu Tapu (southern boat passage) mapped during a British survey, and reproduced on chart 83425 of US Defense Mapping Agency, 1980 (Forbes 1995).
1961	HMNZS Lachland surveys the anchorage at Aitutaki. Results from this survey are published on chart: Cook Islands, Southern Sheet, NZ 955.
1965	Survey collected visual observations, sediment samples and depth soundings. Depths were measured by 48 wire-line soundings fixed by prismatic compass (Summerhayes 1971).
1969	Bathymetric survey using an echosounder and line-soundings. Positions were fixed by horizontal sextant angles (Stoddart 1975).
1986	Sounding data were collected using an echosounder, and positioning was accomplished by range fixes using a radio navigation trisponder system (Richmond 1986).
1986	A hydrographic survey was carried out in the waters around Aitutaki and Arutanga channel and anchorage by the HMNZS Monowai in 1986. Results from this survey are published on chart: Cook Islands, Southern Sheet, NZ 955.

Bathymetry surveys of Aitutaki	
1991	Bathymetry model derived SPOT satellite image using a numerical model (Loubersac et al. 1991), as shown in Figure 7. Depths were computed by applying a mixed approach of radiometric and empirical algorithms, with errors reported to be as high as 22%, especially in shallow (0–2 m) areas.
2005	Bathymetry was collected using an echosounder and a stand-alone GPS positioning system in the Ootu area, northeast lagoon (Figure 9), and Arutanga (Figure 10). This data was collected by SOPAC as part of a project to develop a proposed resort in the Ootu area (R. Smith pers. comm.).
2007	Approximately 170 sounding were taken along transects using a handheld sonar depth sounder and stand-alone GPS (G. Rankey pers. comm.)
2008	Bathymetry model derived from an atmospherically corrected and rectified July 2007 multispectral Quickbird image and groundtruthing data from this report. A feed forward fully connected neural network approach was used with a reported average error of 0.4 m (F. Magron pers. comm.)

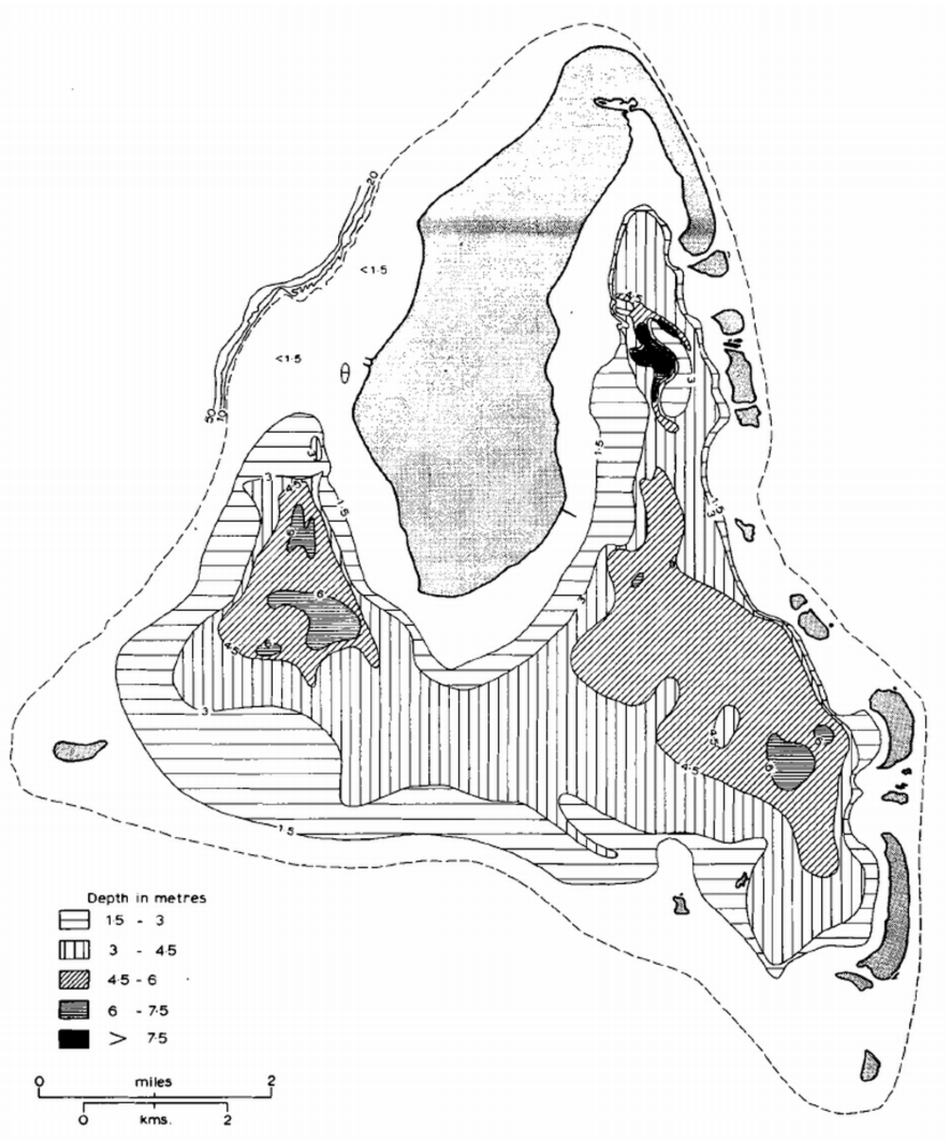


Figure 6. First bathymetric map of Aitutaki lagoon using an echosounder (Stoddart 1975).

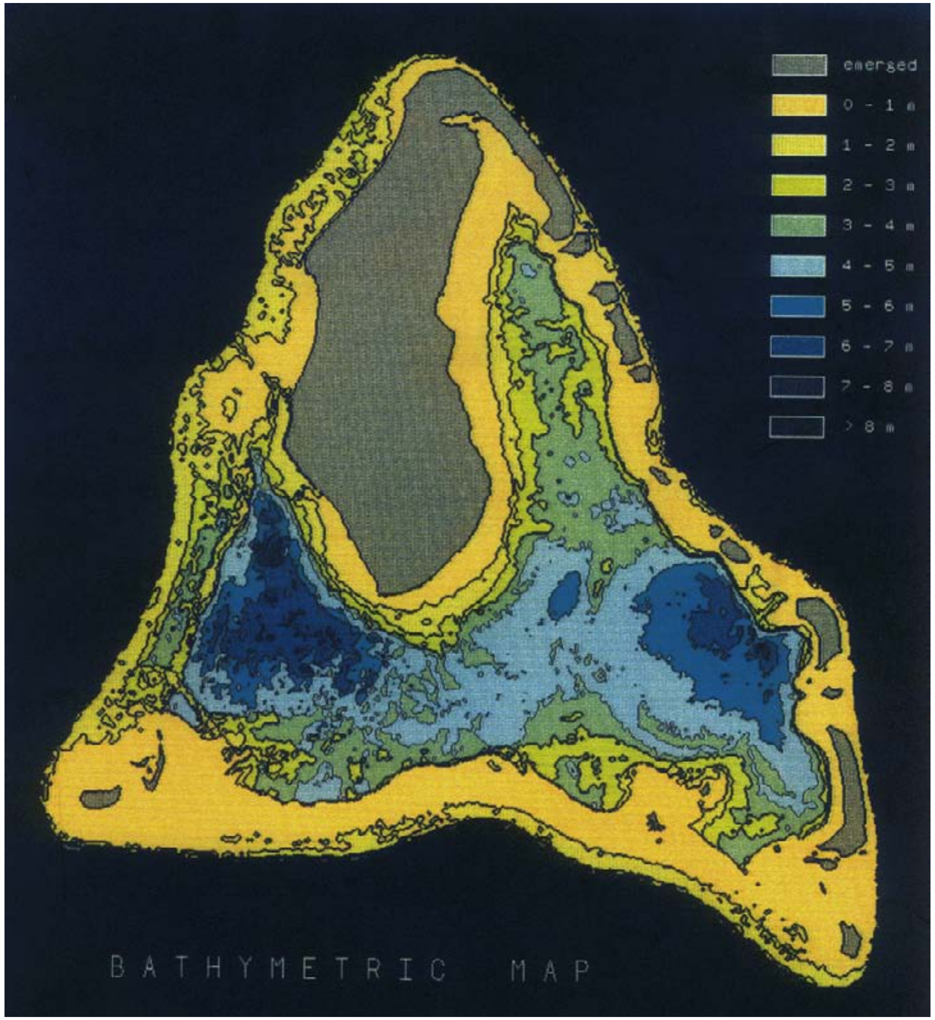


Figure 7. Bathymetry of Aitutaki lagoon derived from a June 1986 SPOT satellite image (Loubersac et al. 1991). SPOT imagery does not have a blue channel, thereby limiting detected depths to approximately 5 m.

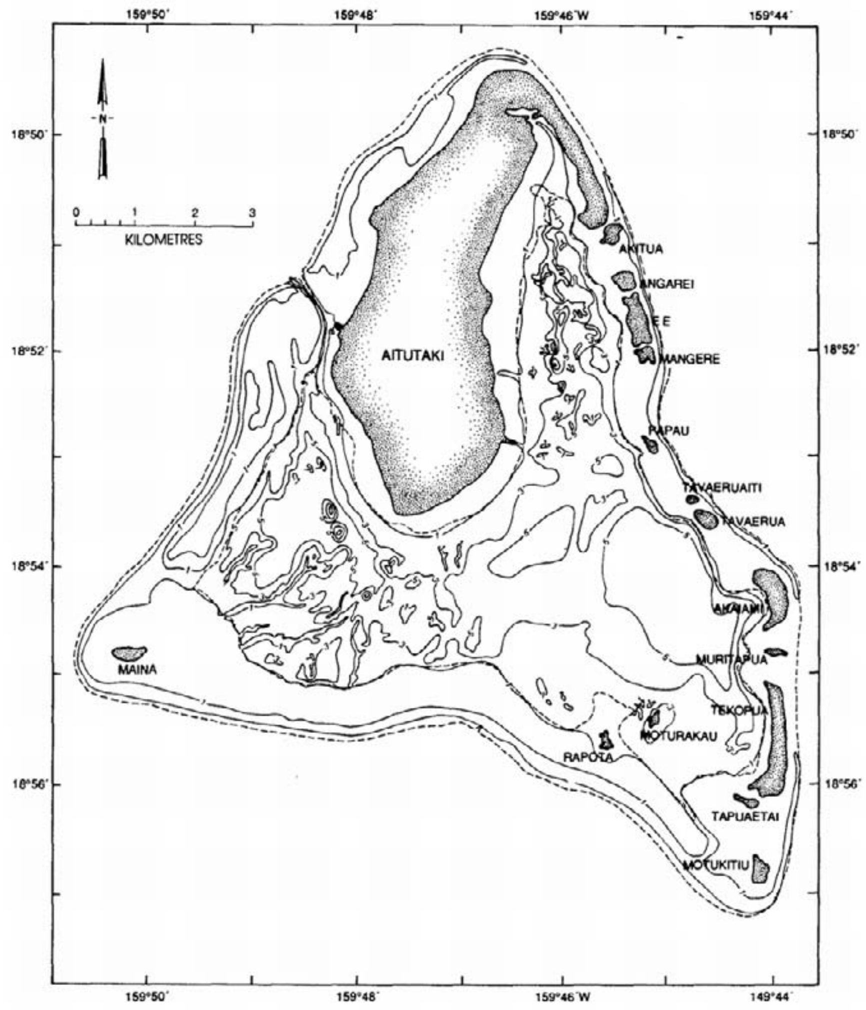


Figure 8. Bathymetry of Aitutaki lagoon (Richmond 1992).

Figure 9. Single beam soundings for the Ootu area (R. Smith pers. comm.). Spot depths are shown relative to LAT. Background image is a rectified July 2007 Quickbird image.

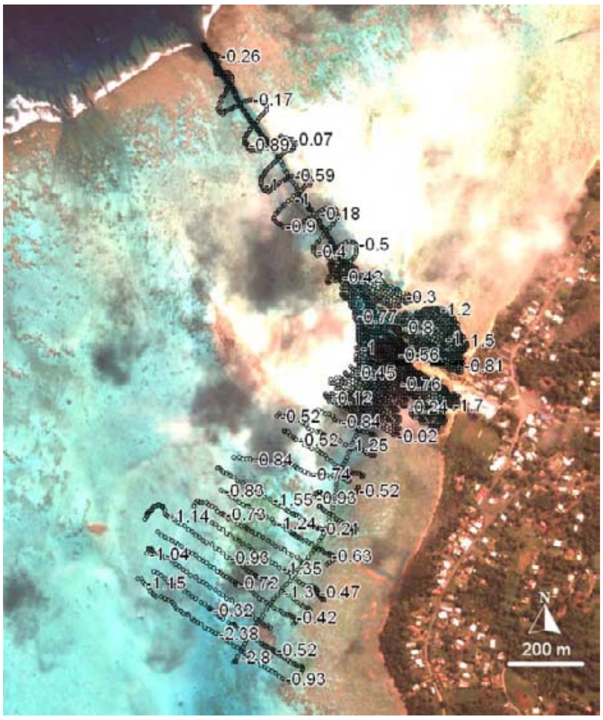


Figure 10. Single beam soundings for the Arutanga area (R. Smith pers. comm.). Spot depths show raw depth measurements. Background image is a rectified July 2007 Quickbird image.

2. RESULTS

2.1 Bathymetry and Derivatives

The area of seabed covered by multibeam echosounder during this survey is shown in Figure A2.1. Bathymetric data provide information on the depth and morphology of the seafloor, as well as the shape and size of submarine features. Three bathymetry derivatives namely, slope angle maps, shaded relief maps, and three-dimensional rendered surfaces, were used in addition to the high-resolution bathymetry to aid visual interpretation of the seabed morphology. These results are shown in the Figures below.

Bathymetric Derivatives	
Slope angle	Slope is a measure of steepness between locations on the seabed, and is reported in degrees from zero (horizontal). Slope values are computed as a mean value for one grid cell from the slope gradient between it and the eight neighbouring grid cells.
Shaded relief	Shaded relief maps use shades of grey to indicate the local orientation of the seafloor relative to a user-defined light source direction. The light source can be thought of as the sun shining on a topographic surface, much like artificial hillshading that illuminates bathymetric roughness. Portions of the surface that face away from the light source reflect less light toward the viewer, and thus appear darker.
Three-dimensional surface	For three-dimensional surfaces the height of the surface corresponds to the depth of the seafloor.

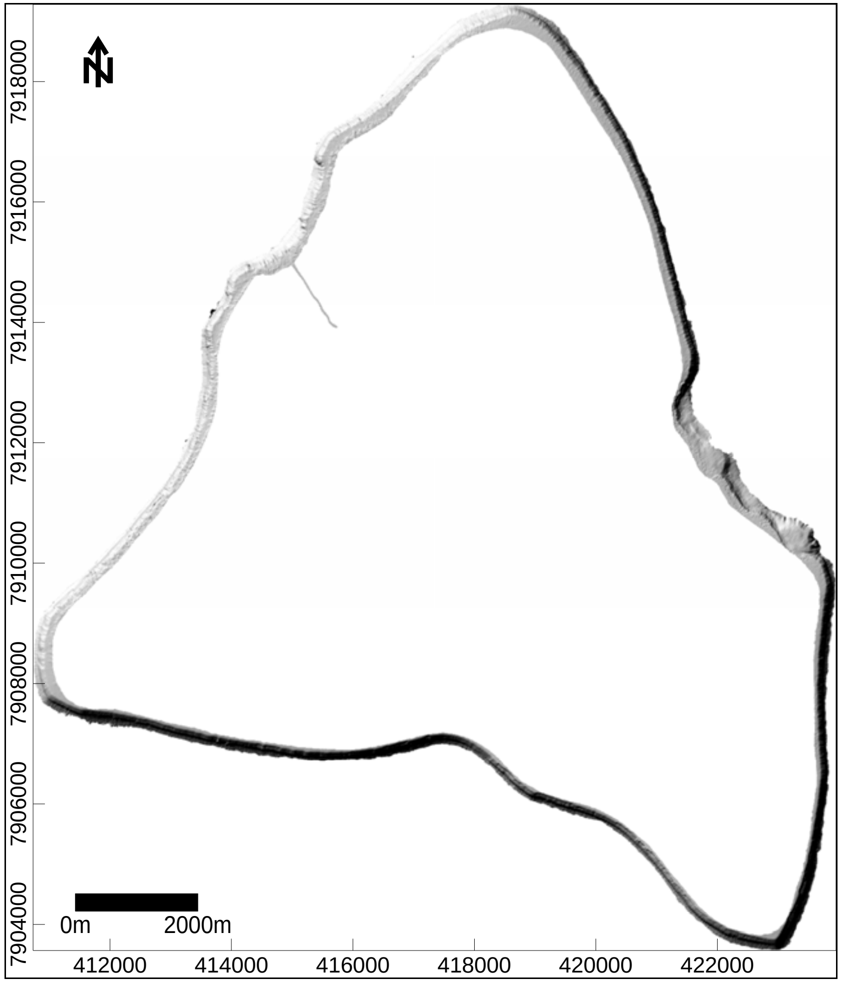


Figure 11. Shaded relief map of Aitutaki. Illumination is from the northwest

Figure 12. Three-dimensional bathymetry map of Aitutaki looking north. Shallow to deep from red to blue.

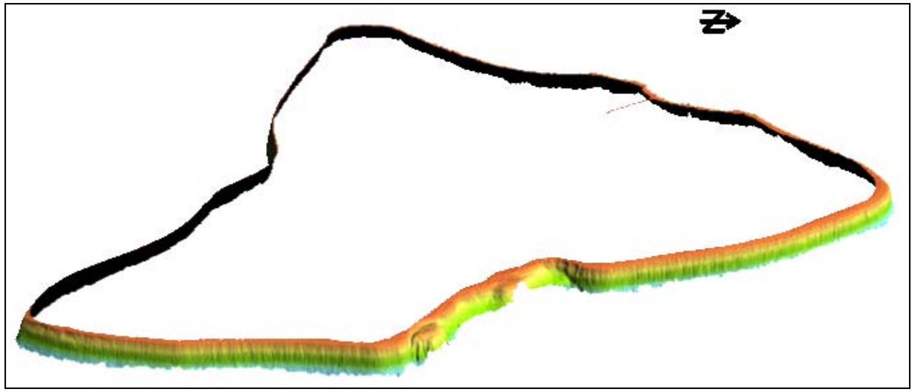


Figure 13. Three-dimensional bathymetry map of Aitutaki looking west. Shallow to deep from red to blue.

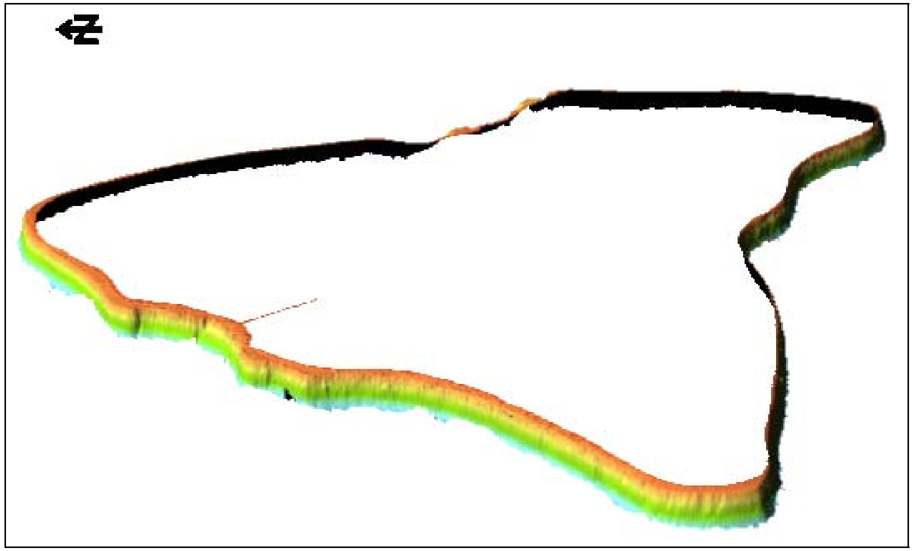


Figure 15. Three-dimensional bathymetry map of Aitutaki looking east. Shallow to deep from red to blue.

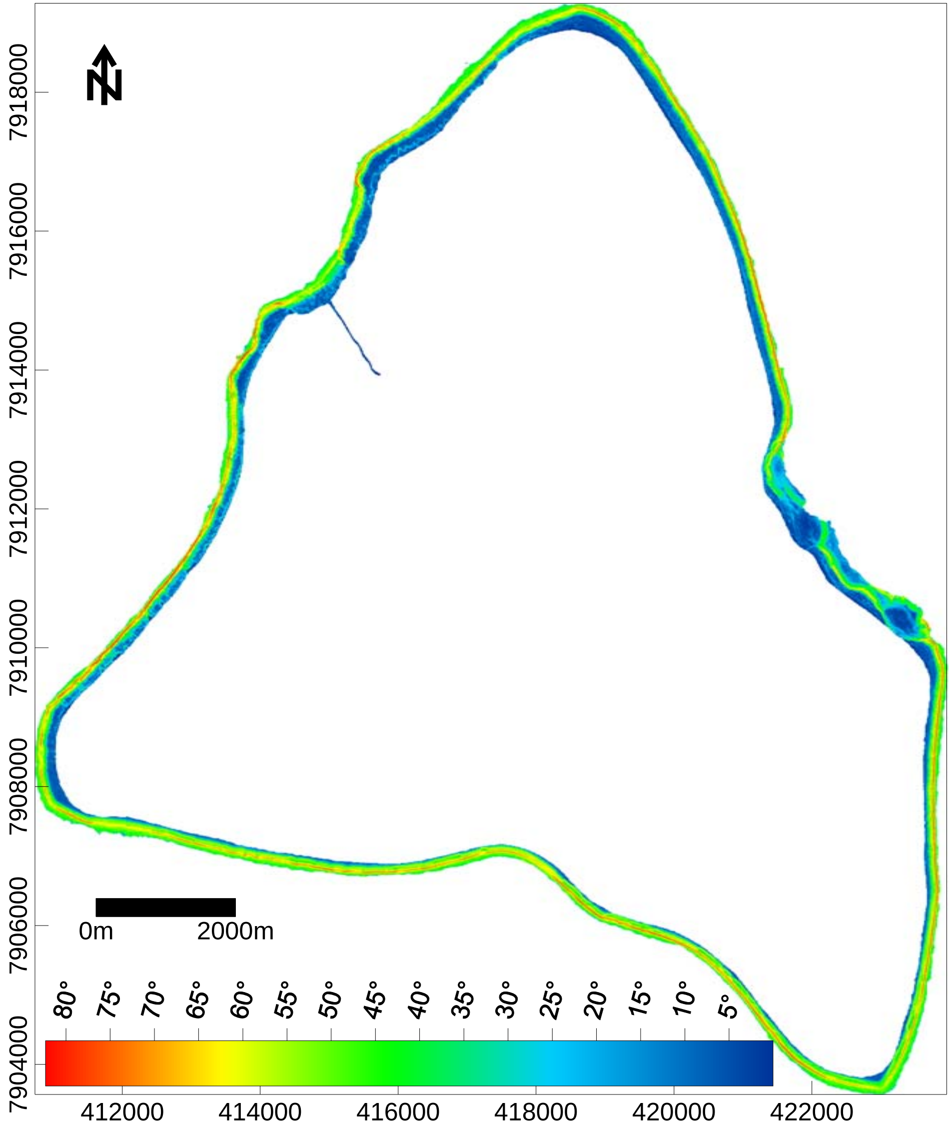


Figure 14. Slope angle map of Aitutaki.

A composite digital terrain model (DTM) was created for Aitutaki, using the following data sources as shown in Figure 16:

(1) the land topography was taken from the Shuttle radar topography mission (srtm.usgs.gov);

(2) the lagoon bathymetry was derived from the August 2007 ALOS AVNIR-2 data using the Stumpf method (Stumpf et al. 2003), calibrated with the SBES sounding from this study;

(3) the forereef was mapped using MBES from this study.

A modified version of this DTM will be used in a numerical model to assess the hydro-environmental impact of the proposed capital dredging of the Arutanga entrance channel. This hydrodynamic numerical model is currently under development and will be described elsewhere.

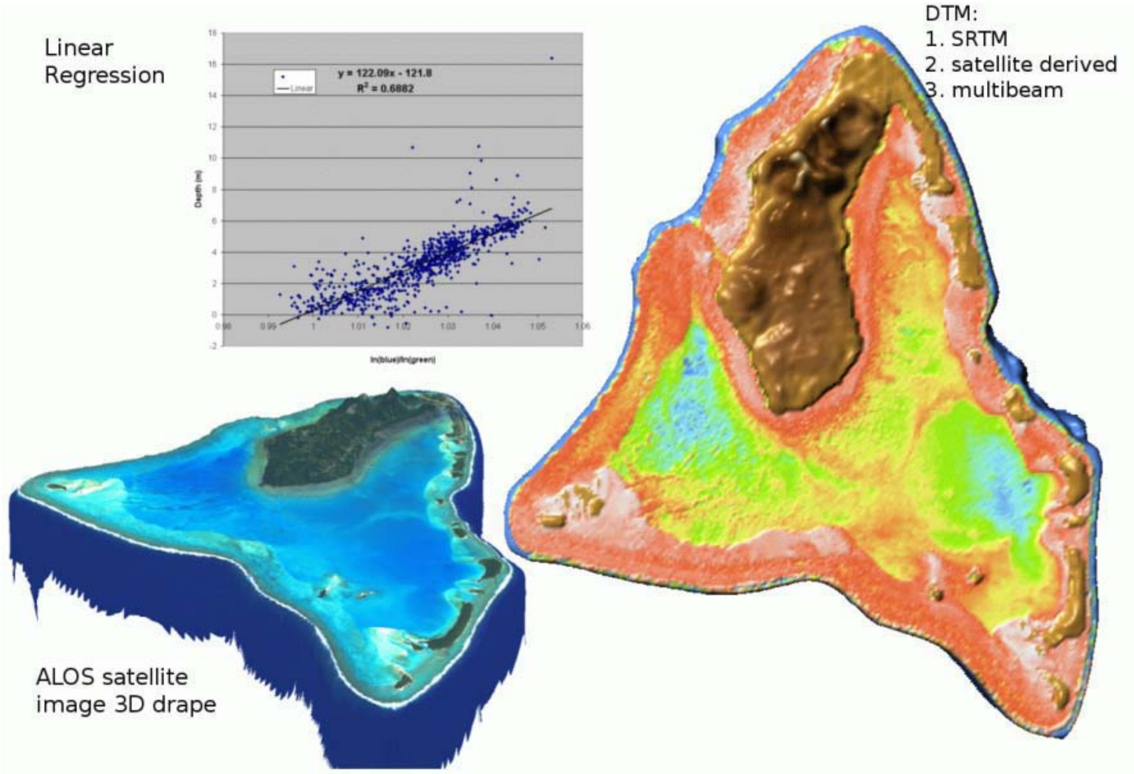


Figure 16. Three-dimensional surface of Aiutaki island. The digital terrain model (DTM) is gridded at 50 m spacing and illumination is from the northwest. The depths of the shallow lagoon area are shown in the following colours: red is –2 m, yellow is –4 m, green is –5 m, light blue is –7 m, and dark blue in the lagoon represents depths greater than –8 m. The bathymetric model has a goodness of fit of 0.69 as shown in the inset. See text for further detail.

2.2 Morphological Features

Due to a very limited coverage of the offshore area around Aitutaki, little morphological interpretation was possible. A brief summary is detailed in the table below:

Summary of offshore seabed morphology	
~0 m	Modern fringing reef and rock platform, up to 50 m wide.
~50 m	Submarine terrace, 200 – 300 m wide
60–400 m	Seaward sloping seabed, slope angles 30–40°

No additional information such as backscatter or seismic profiles for the area was available. For the lagoon area, however, ground-truth data (e.g. near-bottom visual observations, photos and direct sampling) was used in addition to the high-resolution bathymetry to create a benthic habitat map and describe the submarine morphology of Aitutaki Lagoon in more detail. The interpretations are presented in a separate report, and may be refined as additional data become available in the future.

Several geomorphological maps of Aitutaki have been published (e.g. Gray and Colgan 1989; Richmond 1992), with the most recent one derived from Landsat image by the Millennium Coral Reef Mapping Project (Figure 17).

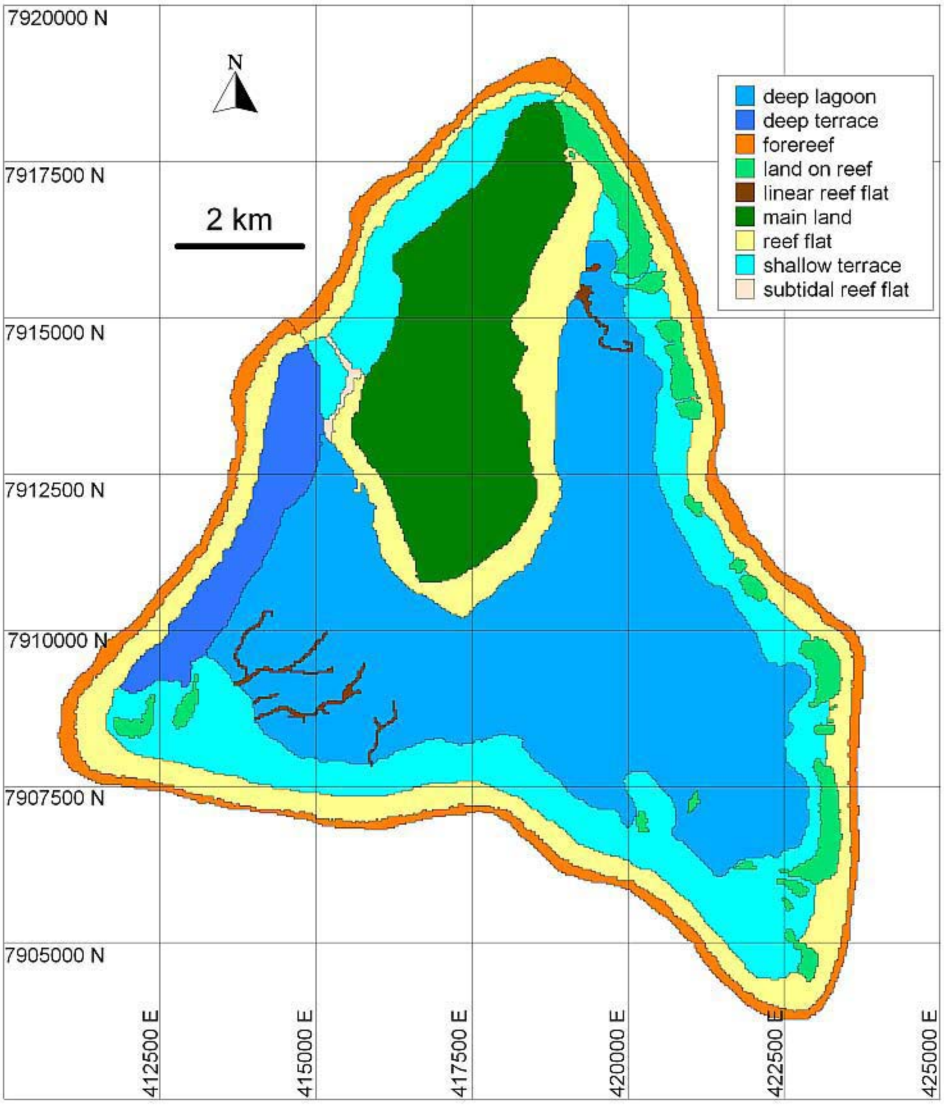


Figure 17. Landsat derived morphology map of Aitutaki lagoon (Andréfouët et al. 2005). This dataset is available on the Reefbase website (www.reefbase.org).

3. DATA ACQUISITION AND PROCESSING

3.1 Fieldwork Summary

Survey Particulars	
Survey vessel	*Orongo* MMR yellow banana boat
Fieldwork date	MBES: 17/04/2008 to 22/04/2008 SBES: 01/05/2008 to 06/05/2008
Equipment used	Reson 8101 MBES Echotroac CVM SBES

All dates and times in this report are given in the local Cook Island time zone.

3.2 Field Personnel

SOPAC	
Jens Krüger	Physical Oceanographer
Salesh Kumar	Technical Officer
Ashishika Sharma	Technical Officer
Peni Musunamasi	Electronics Engineer
Maleli Turagabeci	Assistant Electronics Engineer
Donato Roqica	Assistant Geology Technician

Vessel	
Mike Henry	Master (Orongo)
Ngere George	Captain (MMR boat)
Richard Story	Captain (MMR boat)

3.3 Geodetic Reference System

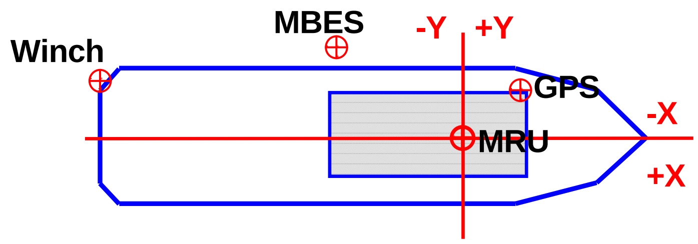
The survey results were mapped in terms of the following geodetic reference system:

Geodetic datum	WGS84	
Ellipsoid	WGS84	
	Semi-major axis (a)	6378137.000
	Semi-major axis (b)	6356752.314
	Inverse flattening (1/f)	298.257223563
	Eccentricity sq. (e2)	0.0066943800
Projection	UTM zone 4 south	
	Projection type	Transverse Mercator
	Origin latitude	00° 00' 00.000" North
	Origin longitude	159° 00' 00.000" West
	Origin false easting	500000.0000
	Origin false northing	1000000.0000
	Scale factor	0.9996000000
	Grid unit	metres
Geodetic transformation	From WGS84 (GPS satellite datum) to UTM 4 South	
	Source coordinate system	WGS84
	Target coordinate system	UTM 4 South
	Transformation parameters	
	dX	0.00
	dY	0.00
	dZ	0.00
	rX	0.00000
	rY	0.00000
	rZ	0.00000
	Scale	0.00000

3.4 MBES Vessel Description and Static Offsets

Sensor	X (m)	Y (m)	Z (m)
Reference point at water level	0.00	0.00	0.00
Motion Reference Unit (MRU)	0.00	0.00	–0.29
Positioning Antenna (GPS)	–0.64	1.56	–5.49
Multibeam Echo Sounder (MBES)	–1.97	–1.42	1.61

Vessel	
Name	*Orongo*
Length overall	12 m
Breadth (mid)	4 m
Draft (mid)	1.34 m
Displacement	10 t
Port of registry	Aitutaki



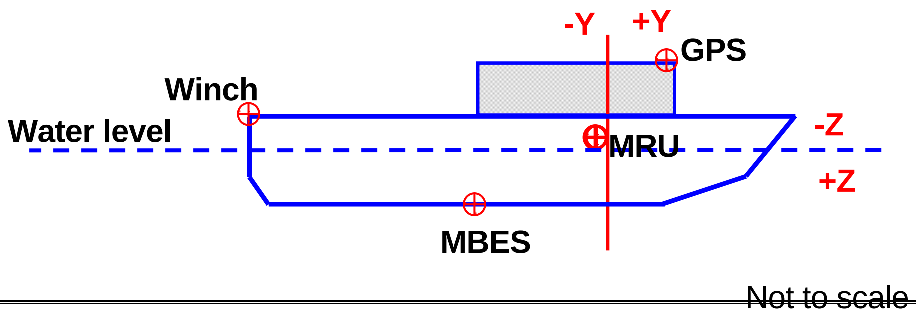


Figure 18. The chartered survey vessel, Orongo. Note the over-the-side pole-mount of the MBES amidship .

3.5 Positioning Control

The vessel's reference point (X=0, Y=0, Z=0) was the motion reference unit (MRU) position at the waterline. Positioning during the MBES survey phase was by RTK GPS, using an Ashtech Aquarius dual-frequency P-code receiver. Positioning during the SBES survey phase was by RTK GPS, using a Trimble R8 system. The pre-survey patch test was conducted in Aitutaki, Cook Islands (see details below). The GPS base station was set up on Maungapu using a survey block near the telecom repeater station consisting of a steel pin set in a concrete block marked with the number 41204. The position of the pin was determined by a Trimble R8 system as shown in Figure 19, for the periods shown in the table below.

Figure 19. Photograph showing the base station tripod on the Maugapu 41204 benchmark. The Trimble R8 system can be seen in the yellow case in the foreground. Also shown is one of the 12V batteries used to power the system.

Maungapu benchmark (41204) position summary					
Start	Duration	Epochs	Northing	Easting	Height (EGM96)
14/04/2008	09:22:20	16871.00	7916856.622	417792.326	133.795
13/04/2008	14:17:18	25720.00	7916857.679	417792.498	132.348
13/04/2008	16:20:16	29409.00	7916857.112	417792.324	134.053

Using the long-term averages given in the table above, a final position for the steel pin was calculated as 7916857.138N, 417792.383E, or S18°50'18.73372" latitude, W159°46'49.08729" longitude, and a height 133.399 m relative to the EGM96 geoid model.

3.6 Survey Computer

The survey computer was a Windows XP PC running Hypack 2008. This computer was used for continuous on-line data logging and computation of positioning and digital bathymetry. The package also provided a line control display for the helm. The on-line operator continuously monitored a range of quality control parameters.

An off-line Hypack 2008 package was used in the office for replaying and post-processing of track data and bathymetry. An A0 plotter was available for the production of charts.

3.7 Multibeam Echosounder

A Reson SeaBat 8101 multibeam echosounder (MBES) was temporarily installed on the vessel *Orongo*, and used to provide swath bathymetry data. A MBES provides high-resolution information about the depth of water from the surface to the seafloor in a water body.

The main instrumental and operating parameters are listed below.

Instrumentation	
Multibeam echosounder	Reson SeaBat 8101
Transducer mount	Portside pole-mounted
Positioning	RTK GPS by Thales Aquarius system
Motion reference unit	TSS DMS 2-05 Dynamic Motion Sensor
Gyro	SG Brown Meridian Surveyor Gyro Compass
Sound velocity probe at transducer	Installed

Operating Parameters	
Transducer frequency	240 kHz
General water depth	10–300 m
Average ship's speed	7 knots (3.6 m/s)
Transmit power	Variable 1–16
Pulse length	Variable 0.5–10.0 ms
Horizontal coverage	Approximately two times water depth
No of beams / beam spacing	126 / 1.2 °
Ping rate	Variable

Dynamic Offset Calibration	18/04/2008
Roll correction	1.00
Pitch correction	–1.00
Yaw correction	–9.00
GPS Latency correction	–0.40
Gyro correction	0.20

The patch test to determine the dynamic offset values was conducted on 18th April, before the start of the survey.

3.8 Multibeam Echosounder Data Processing

On return to the SOPAC office in Suva, Hypack 2008 software was used for the post-processing of the MBES survey data. Post-processing is a form of data reduction, which involves checking, calibration, cleaning and preparation necessary to convert raw measurements into a form suitable for analysis, application and presentation. The product of post-processing is in the form of ASCII listings of gridded easting, northing, and depth (XYZ) points. Gridded XYZ points from Hypack were used in Surfer 8.05 to produce final charts and figures. The processing and chart production sequences are listed below.

Post-processing Sequence	
Phase 1	Correct for heading, heave, roll, pitch, navigation errors. Apply tidal and sound velocity corrections.
Phase 2	Filter to remove poor-quality beams and spikes. Manual editing to remove outliers from individual survey lines.
Phase 3	Apply filters were appropriate to remove outliers from median depth and / or further manual cleaning of outliers.
XYZ Output	ASCII XYZ files (easting, northing, depth) are in the project coordinate system. The final output consisted of a file that includes all post-processed sounding points, as well as files of reduced points at appropriate grid dimensions.

Chart Production Sequence	
XYZ to grid	XYZ data are reduced and gridded to approx. 1 mm (0.1%) at the charting scale (e.g. 50 m grid size for a chart scale of 1 : 50 000).
Digital terrain model (DTM)	A surface model is created from the grid. A search radius of approximately three times the grid spacing is used to fill data gaps. The DTM is also blanked against regions that contain no valid data such as land and reef areas.
Chart output	DXF contours, PDF chart, backdrop images, and DTM model in the project coordinate system.

3.9 Singlebeam Echosounder

An Odom Echotrac CVM singlebeam echosounder (SBES) was temporarily installed on the Cook Island Ministry of Marine Resources, MMR, vessel, and used to provide single point soundings (Figure 20). A SBES provides information about the water depth. The main instrumental and operating parameters are listed below.

Instrumentation	
Singlebeam echosounder	Echotrac CVM
Transducer mount	Port side pole mounted
Positioning	RTK GPS provided by Trimble R8 system
Sound velocity probe at transducer	N/A. CTD casts were used to determine SV.

Operating Parameters	
Transducer frequency	200 kHz
General water depth	5 m
Average ship's speed	4 knots
Transmit power	Variable
Pulse length	Auto pulse length
Ping rate	Variable

Offset Calibration	01/05/2008
Bar check	0.265 m
GPS Latency correction	Not determined

Figure 20. SBES setup on MMR vessel. Note the Trimble R8 GPS on top of the transducer pole (actual transducer is out of sight). The laptop running Hypack 2008 is seated ontop of the Echotrac CVM topside unit. The equipment was powered by 12V battery with an AC inverter.

3.10 Singlebeam Echosounder Data Processing

On return to the SOPAC office in Suva, Hypack 2008 software was used for the post-processing of the SBES survey data. The processing and chart production sequences are listed below.

Post-processing Sequence	
Phase 1	Apply tidal and sound velocity corrections.
Phase 2	Filter to remove poor-quality beams and spikes. Manual editing to remove outliers from individual survey lines.
XYZ Output	ASCII XYZ files (easting, northing, depth) are in the project coordinate system. The final output consisted of a file that includes all post-processed sounding points.

3.11 Tidal Information

Observed soundings from the MBES were reduced to the Chart Datum using details for Aitutaki given in the Admiralty Tide Tables (ATT), Volume 4, 2008, Pacific Ocean, UK Hydrographic Office. The ATT defines CD to be 0.44 m below MSL (Figure 21). The bench mark (BM), referred to on the nautical chart NZ955 no longer exists. The only remaining BM established by the RNZN *Monowai* in 1986 was the BM 31, located at 7913997.80 E and 415725.27 N on Arutanga wharf. Vertical datum definitions relative to BM 31 could not be obtained (S. Caie pers. comm.). During the survey a Trimble RTK GPS R8 system and a temporary tide gauge were used to establish relationships between the various datums as shown in Figure 21.

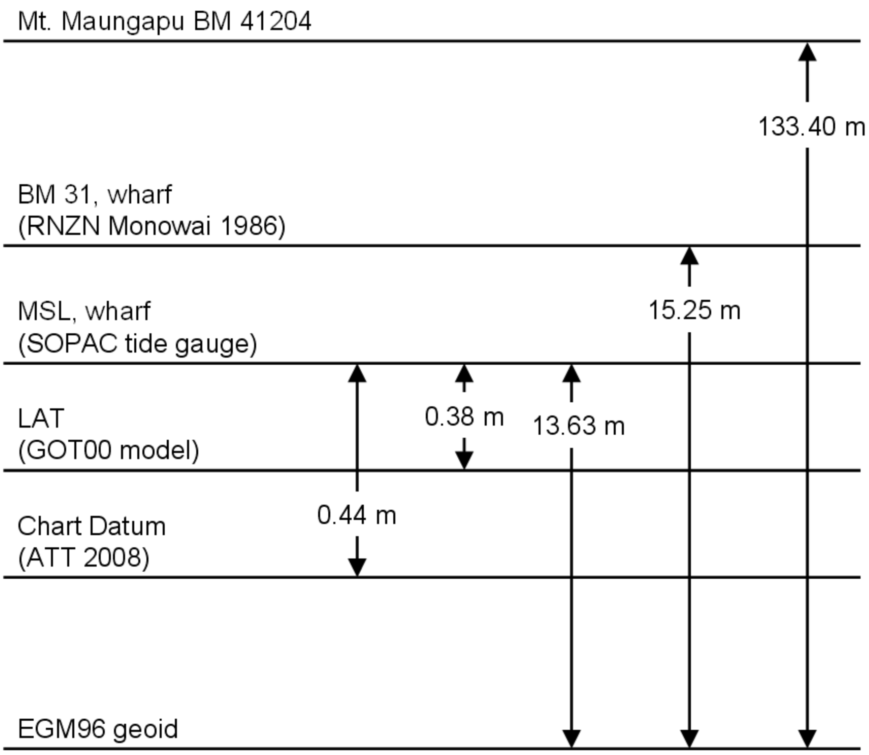


Figure 21. Diagram showing the tidal datums at Arutanga wharf. See text for details.

The temporary tide gauge was deployed at the Arutanga wharf near the northern edge of the basin at location 415715.43 E, 7913973.39 N; and set to log water elevations every 14 minutes. These observed water elevations were used to reduce SBES soundings to CD as shown in Figure 21.

The observed water elevations recorded by the temporary tide gauge at Arutanga wharf are plotted in Figure 22. Due to a power malfunction the tide gauge only recorded data for a total of 23 full days, which did not allow for a tidal harmonics analysis. Also shown on Figure 22 are water levels computed from the ATT and the global tide model GOT00. The data from GOT00 were kindly provided by the Australian Bureau of Meteorology (M. Davis pers. comm.). The graph shows that predictions derived from the ATT generally provide a better match to the observed levels compared to the global model GOT00. Interesting to note in Figure 22 are the elevated water levels recorded by the SOPAC temporary tide gauge for the period from 25 April to 2 May 2008.

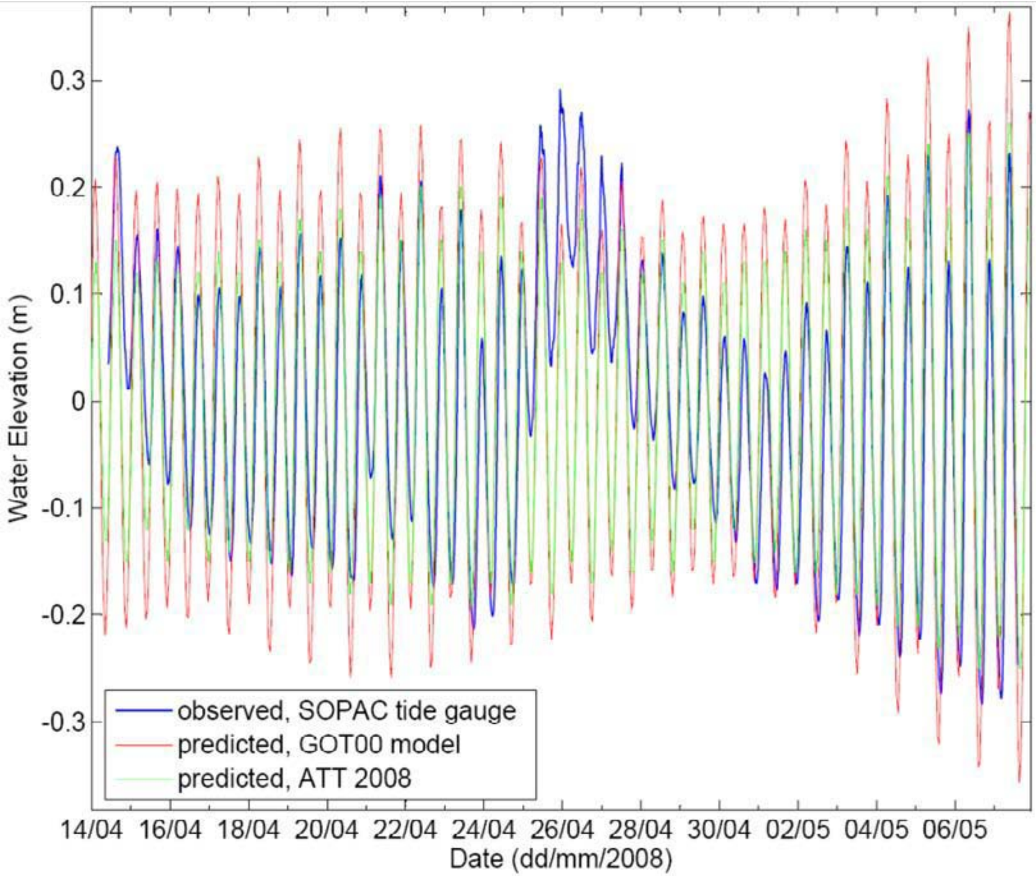


Figure 22. Graph showing observed and predicted water levels for Aitutaki from 14 April to 7 May 2008. Mean removed from tide gauge data. See text for detail.

The period of elevated water levels inside the lagoon coincided with a large offshore swell event (Figure 23). A temporary wave gauge deployed on the open ocean reef slope on the eastern side (location 423599 E, 7908443 N) as part of this project recorded significant wave heights of 4.5 m, and peak wave periods of 15 s on 25 April. This event levelled off to relatively normal conditions on 2 May, with significant wave heights of 1 m, and peak wave periods of 11 m. The swell event is also evident from NOAA Wave Watch III (WWIII) hindcast data shown on Figure 23. The WWIII data was kindly provided by the New Zealand National Institute of Water and Atmospheric Research (R. Gorman pers. comm.). This shows that water levels inside the lagoon can be considered to be generally above those of the surrounding open ocean and that extreme events are controlled by offshore wave pumping (Callaghan et al. 2006).

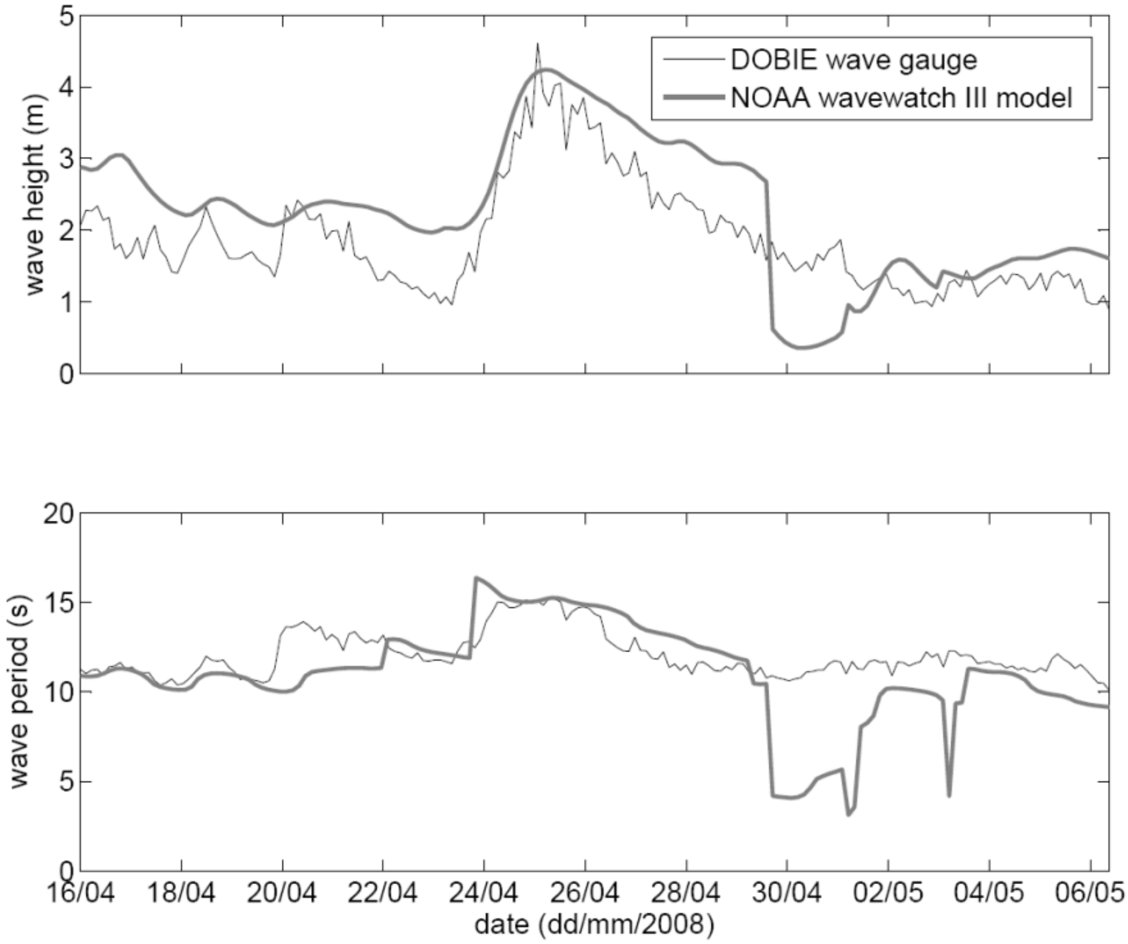


Figure 23. Graphs showing significant wave heights and peak wave periods incident on the eastern side of Aitutaki. Observed data from a temporary SOPAC wave gauge correlates well with offshore wave statistics provided by NOAA's hindcast model WaveWatchIII. The sudden drop in model heights and periods during the course of 29 April is presumed to be due to a crash and subsequent cold start of the NOAA model (R. Gorman pers. comm.). See text for details.

3.12 Speed-of-Sound Profiling

The accuracy of the depth soundings depends in part on the variation of the speed of sound with water depth. This is because the acoustic beams pass through a water column that has varying properties (causing refraction). The sound speed structure of the water column is determined from the measurement of temperature, salinity and depth (with a Conductivity, Temperature and Depth sensor – CTD). The main instrumental, operational, processing parameters are listed below.

CTD Instrumentation	
Make	SeaBird Electronics
Model	SeaCat 19+ (self-powered, self-contained)
Serial number	2795
Depth rating	3000 m

Operating Parameters	
Sample rate	1 scan every 0.5 s
Maximum depth	Limited to 400 m due to wire rope length
Data recorded	Profiles of conductivity, temperature, and pressure

Data Processing	
Positioning	The profile position was taken at the GPS antenna near the start of the downcast. Vessel drift may have been significant (~500 m) over the duration of the profile.
Data conversion	Converted raw data (.hex) to a .cnv file. The following values are output from the recorded data: Pressure, dbar Depth, m (derived using salt water at local latitude) Temperature, deg C (ITS-90) Salinity, psu (derived) Density, kg m^{-3} (derived) Sound velocity, m/s (derived using Chen and Millero 1977)
Bin average	Averaged data into 1 m depth bins. No filtering was applied.
Output	Processed data was saved in ASCII text format with the file name date_location_bin.cnv.

The CTD profile details are listed below. The summaries of the CTD profile data in graphical form are shown in Appendix 3 (MBES 3 and MBES 4 profile data are not shown due to corrupt files).

Profile location	Date	Time	Easting	Northing	Depth (m)
MBES 1	17/04/08	15:12	421513	7913043	69.31
MBES 2	19/04/08	10:45	411022	7907887	24.71
MBES 3	09/04/08	12:56	414144	7915081	461
MBES 4	21/04/08	13:26	424238	7908607	122
SBES 1	04/05/08	12:28	419660.102	7913319.64	6
SBES 2	04/05/08	13:01	415166.45	7912366.11	4
SBES 3	05/05/08	11:26	419614.56	7913793.37	8.48
SBES 4	05/05/08	14:47	419604.96	7910530.57	4.68

As noted above, the on-board CTD probe could only be operated to a maximum depth of 400 m, due to restrictions on the wire rope length. Appropriate sound velocity corrections were therefore limited to soundings of up to 400 m water depth.

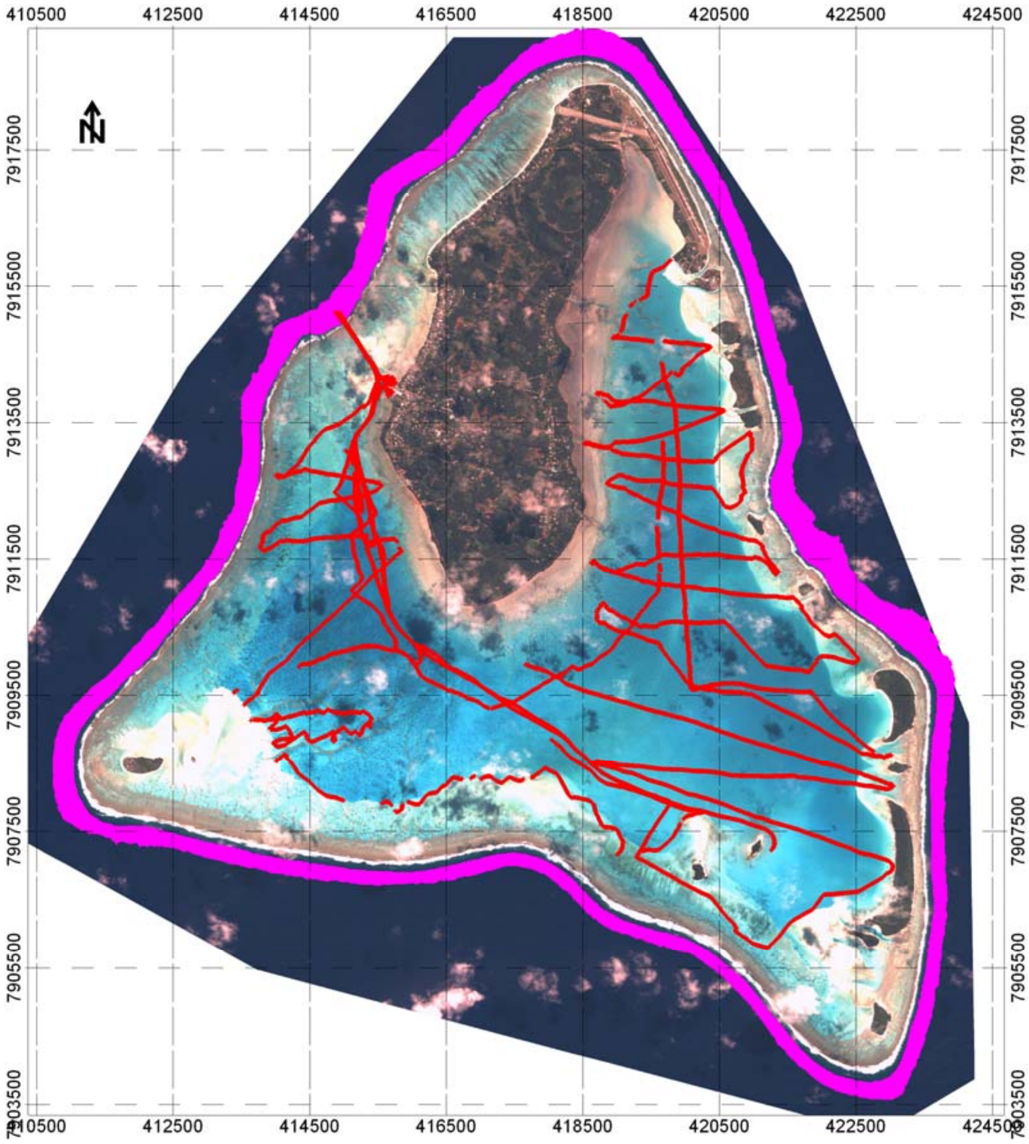


Figure 24. Map showing the locations of CTD profiles in Aitutaki.

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APPENDICES

Appendix 1 – Statement of Accuracy and Suitability for Charting

Bathymetric maps are topographic maps of the sea floor. The bathymetric map serves as the basic tool for performing scientific, engineering, marine geophysical and environmental studies. The information presented in this report and enclosed charts are intended to assist persons and authorities engaged in recreation, tourism, marine resource related industries, hydrographic mapping, coastal development, trade and commerce, sovereignty and security, and environmental management. It is therefore important that users be informed of the uncertainties associated with the data and with products constructed from it. The following is an outline of the survey equipment used and the operating principles, including limitations and estimates regarding the data accuracy.

A1.1 Horizontal positioning

The methods used to acquire survey data will affect the final product accuracy. The global positioning system, GPS, uses radio signals from satellites that orbit the earth to calculate the position of the GPS receiver. Stand alone GPS has an estimated accuracy as good as approximately 10 m, depending on satellite configuration and atmospheric conditions. In addition to this, equipment and measurement errors also need to be considered.

A general rule of thumb is that surveys should be conducted with a positioning accuracy of 1 mm at the scale of the chart. Therefore, at a chart scale of 1 : 10 000, the survey would be required to be accurate to 10 m.

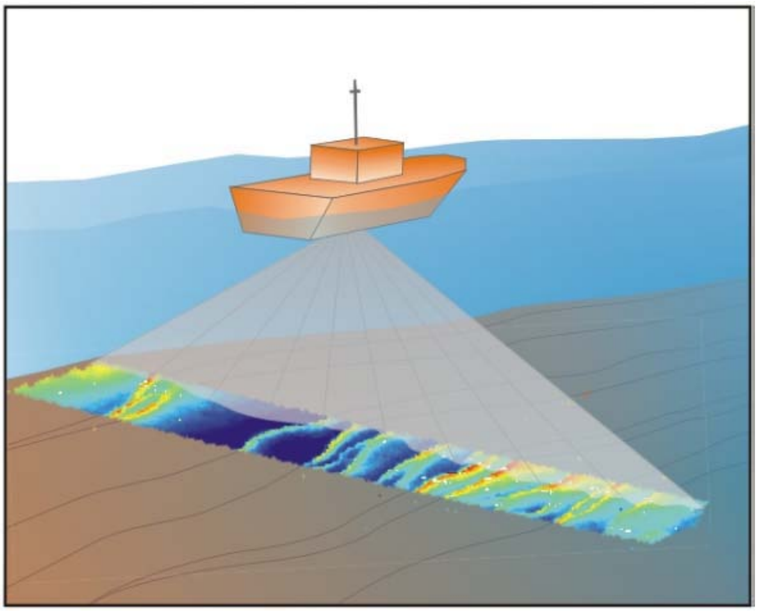
The present S-44 4th Edition Standard of the International Hydrographic Office (IHO) includes a depth-dependent factor that takes into account the added uncertainty of the positions of soundings from multibeam echo sounder (MBES) systems as water depth increases. The relevant survey orders are listed below, with multibeam surveys conducted by SOPAC generally falling into orders 2 or 3.

Survey order	Application	Recommended horizontal accuracy
Order 1	Harbours and navigation channels	5 m + 5% of depth
Order 2	Depths < 200 m	20 m + 5% of depth
Order 3	Depths > 200 m	150 m + 5% of depth

For the purpose of this survey, it was assumed that the use of stand-alone GPS provided adequate precision in terms of horizontal position. Therefore, it is not recommended to interpret nearshore data at scales larger than 1 : 10 000, or a grid size smaller than 10 m. For areas with water depths greater than 200 m, a charting scale of at least 1 : 50 000 is recommended.

A1.2 Depth measurements

Bathymetric maps provide information about the depth of water from the water surface to the seabed. Through the use of detailed depth contours and full use of bathymetric data, the size, shape and distribution of underwater features are clearly revealed. The depth is measured using a ship-mounted multibeam echo sounder. The MBES transducer produces an acoustic pulse designed as a fan that is wide in the across-track and narrow in the along-track direction (Figure). The swath of seabed covered by this transmit beam is typically more than twice the water depth. The pulse of sound emitted from the MBES travels through the water column and is reflected back as an echo and received as numerous narrow beams by the receiving elements of the MBES. The measurements are time based, and by using the speed of sound in seawater each time is converted first to a range and then, knowing the beam angle, to a depth. The distance to the seabed is then combined with the movement of the vessel to stabilise it into a real-world framework. This framework is then positioned to provide XYZ soundings for each beam's interaction with the seabed. A series of these swaths are then combined to produce a three-dimensional representation of the seafloor topography.



FigureA1.1. Conceptual illustration of bathymetric data acquisition with a multibeam echosounder, MBES (source: http://www.rcom.marum.de, accessed 10/01/2007).

The accuracy of the MBES system is critically dependent on the corrections applied for vessel motion (heave, pitch, roll, yaw, and heading). However, the absolute accuracy of single beam and multibeam bathymetry depends on several factors that are not easy to determine. For single beam data, probably the principal errors that may be introduced are due to topographic features falling between survey lines. Multibeam systems give far better coverage.

The S-44 4th Edition Standard of the IHO lists values “a” and “b”, which should be introduced into the following equation to calculate the error limits for depth accuracy:

$\pm\sqrt{a^2 + (b \times d)^2}$, where d = depth.

Survey order	Application	Constants
Order 1	Harbours and navigation channels	a = 0.5 m, b = 0.013
Order 2	Depths < 200 m	a = 1.0 m, b = 0.023
Order 3	Depths > 200 m	a = 1.0 m, b = 0.023

For example, the IHO recommends that a near-shore coastal survey (Order 2) in water depths of 20 m should have a maximum depth error of ±1.1 m.

A MBES has, as any other measuring instrument, an inherent limit in its achievable accuracy. The total measurement accuracy, i.e. the uncertainty in the depth and location of the soundings, also depends upon the errors of the auxiliary instruments such as the motion reference unit, the gyro compass, and the measurements of the speed of sound through the water column. The sea state at the time of the survey also contributes significantly to the quality of the data. The possible accuracy of the measured depths may be estimated by considering the following main error sources.

Error budget analysis for measured depths	
Measurement	The nadir-beam bottom detection range resolution of the multibeam system has a maximum limit of 0.1 m (Reson, 2002). However, multibeam systems are particularly susceptible to errors in the far range (outer beams), and detection is estimated at ± 0.3 m plus 0.5 % of the depth. Errors also include the detection of the sea floor due to local variations of depth within the beam footprint, especially in the outer beams, and a varying density of the bottom material. This may be significant if a relatively low frequency transducer is used on soft marine muds in shallow water.
Transducer draft	The transducer depth below the water line may be determined to ± 0.1 m. However, the draft of the vessel due to the variability in vessel loading, e.g. fuel and fresh water storage, was not determined. It is estimated that this introduced a water depth independent error of up to ± 0.2 m. Dynamic draft errors, e.g. vessel squat, may also be significant.
Sound velocity	The sound velocity profiles measured by the conductivity-temperature-depth sensor (CTD) probe did not reach full survey depths in waters exceeding 400 m water depths. An inaccurate sound path from the transducer to the bottom and back will affect not only the observed depth of water, but also the apparent position of the observed sounding. This error is presumed to exceed 0.5% of the water depth beyond the direct CTD measurements. In order to minimise this error, ARGO and GDEM data may be used to supplement the CTD data.
Heave	This error is directly dependent on the sea state, the sensitivity of the motion sensor and installation parameters. The MRU installation did not account for the offset distance between MRU, the centre of gravity, and the MBES transducer mount. However, the software was able to perform lever arm calculations and heave compensation during post-processing, and the vertical error is assumed to be significant only in heavy seas.
Tide/water level	Errors due to tides may be significant, especially where predicted tides some distance from the survey area are used. Perhaps ± 0.3 m for uncertainty in tidal datum need to be considered.

From the table above, it is estimated that the measured depths in 20 m are typically accurate to about ± 1.1 m (± 0.3 m root mean square). However, the complete bathymetric model, or digital terrain model (DTM), is based on some form of interpolation between the sampled depths from several survey lines. Consequently, the total uncertainty associated with a bathymetric model will include uncertainties due to horizontal positioning, and uncertainties introduced by the interpolation process, and will therefore be larger than the depth sounding uncertainty.

A1.3 Multibeam echosounder data density

The density of data used to construct a bathymetric grid is an important factor in its resolution – the denser the data, the higher the resolution that can be achieved. Sounding density is critical in terms of seabed feature detection and delineation. The two main factors that control the potential bathymetric target resolution capability of a multibeam echosounder are the distance between individual soundings (both in the cross-track and along-track dimensions), and the footprint size. The footprint is the area on the seabed covered by the sound pulse.

Footprint size is a function of range, beam angle, and receiver and transmitter beam widths. A high sounding density and small footprint will result in higher resolution data. Conversely, the target detection capability is going to decay as a result of a growing projected beam footprint and decreasing data density.

The along-track spacing is controlled by the ping rate, which in turn is limited by the two-way travel time from the source to the seafloor. The maximum across-track spacing depends again primarily on the range, but also on the equiangular beam spacing. The size of the beams received by the MBES system is between one and one and a half degrees. This means that a system mounted on a ship will have an increasing projected footprint size with increasing water depth. The footprint will also be larger at the outer beams than at the centre of the swath, as the range and incident angles increase with distance from the nadir beam. It is possible to have local variations of depth within the beam footprint, causing vertical error and affecting amplitude detection.

The table below shows a summary of the projected beam footprint size under varying water depths for the two MBES systems currently in use by SOPAC. It should be noted that the higher frequency system (SeaBat 8101) is not appropriate for applications in waters deeper than 200 m. Due to the constant beam width; the sounded area varies according to the depth and slope, which results in a variable data density in the survey area.

Water depth	SeaBat 8160 (deep water) 50 kHz, 126 beams at 1.5 °		SeaBat 8101 (shallow water) 240 kHz, 101 beams at 1.5 °	
(m)	Inner footprint at nadir (m)	Outer footprint at 65º (m)	Inner footprint, nadir (m)	Outer footprint (m)
20	0.5	2.8	0.5	3.5
50	1.3	7.0	1.3	17.6
100	2.7	14.0	2.6	35.3
200	5.3	28.0	5.2	70.6
500	13.3	69.9	N/A	N/A
1000	26.7	139.8	N/A	N/A
1500	40.0	209.8	N/A	N/A
2000	53.4	279.7	N/A	N/A

The table above assumes a horizontal seabed, and shows the variation in across-track footprint size with water depth and beam angle. The sounding density and swath width will also vary when surveying steep slopes, or highly incised margins, as the footprint size varies strongly with topography. Therefore, deeper sections have larger projected footprints and fewer data point. This has the effect that a bathymetric feature whose lateral dimensions are less than the beam footprint size will not be resolved.

It should also be noted that the along-track resolution usually exceeds the across-track resolution due to ping rates, especially in deep water. Since ping rates are limited by the two-way travel time. Rates for water depths of 20 m and 1500 m are 12.9 and 0.2 pings per second, respectively. Using maximum ping rates, or when surveying in deep water, the same area may be measured with the outer beams for several pings, which may give inconsistent sounding data due to the poor repeatability on uneven seabed. In order to take into account depth-dependent point density, it is generally accepted to grid bathymetric data at a resolution that is on the order of the average beam footprint size, typically 10% of the water depth.

Appendix 2 – Echosounder Coverage

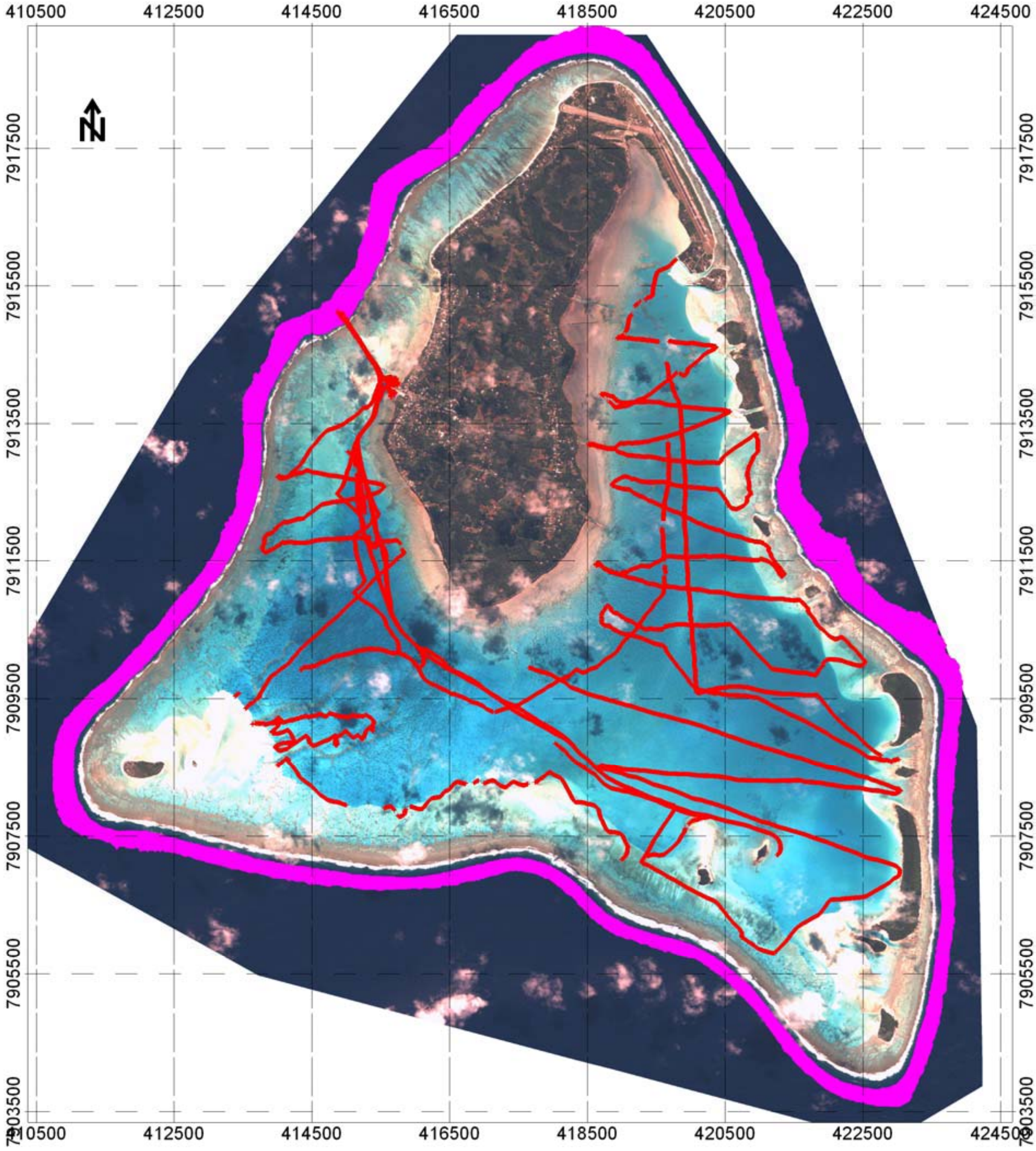
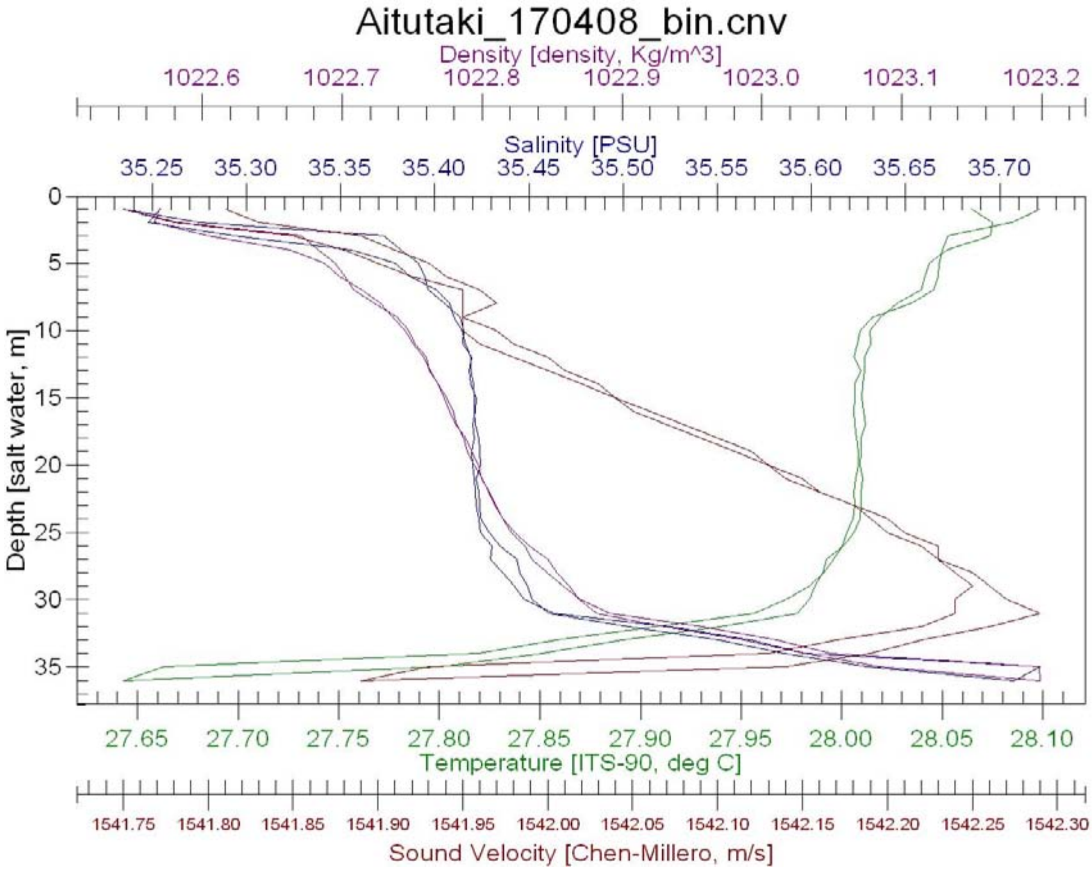
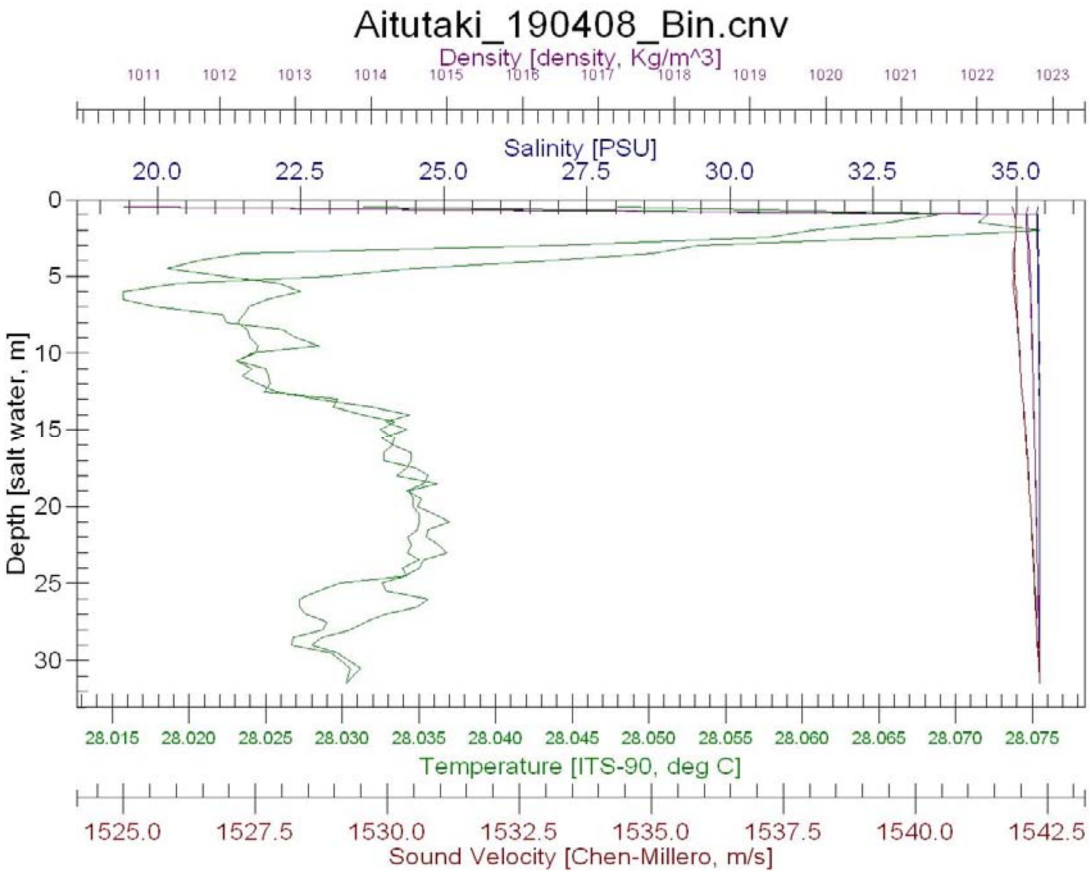
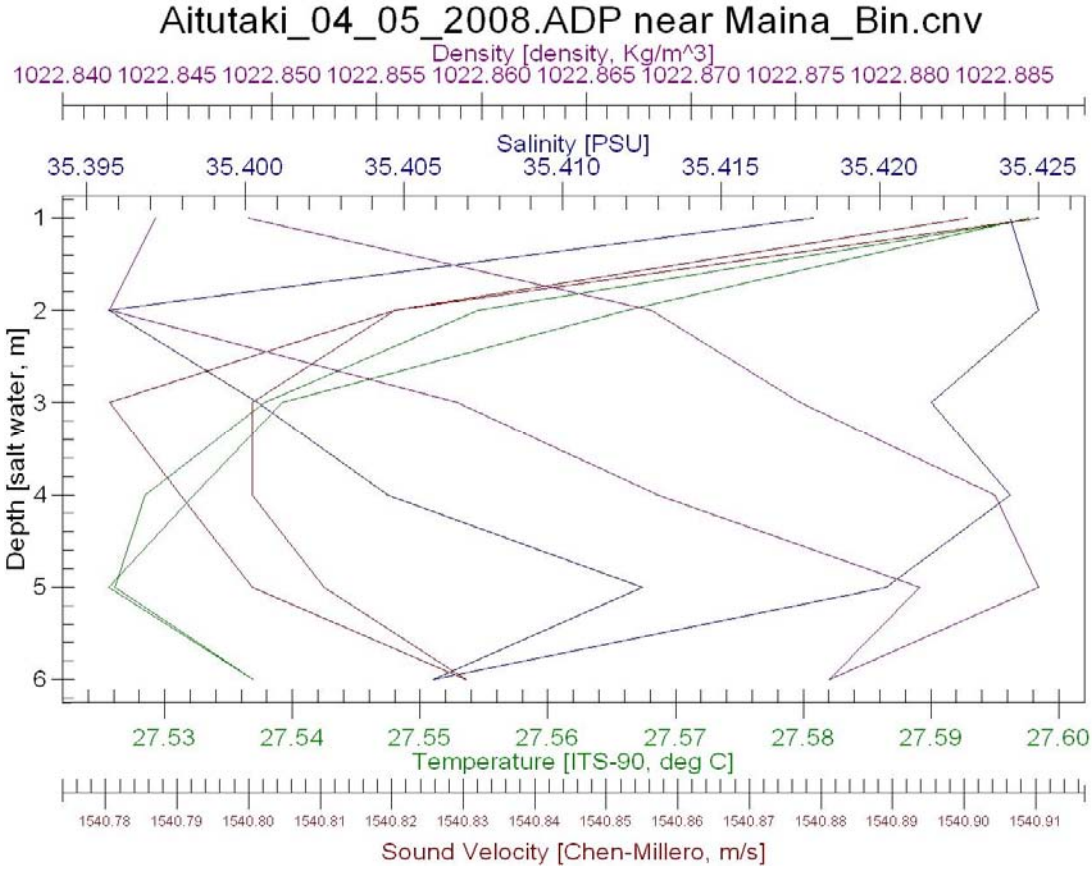


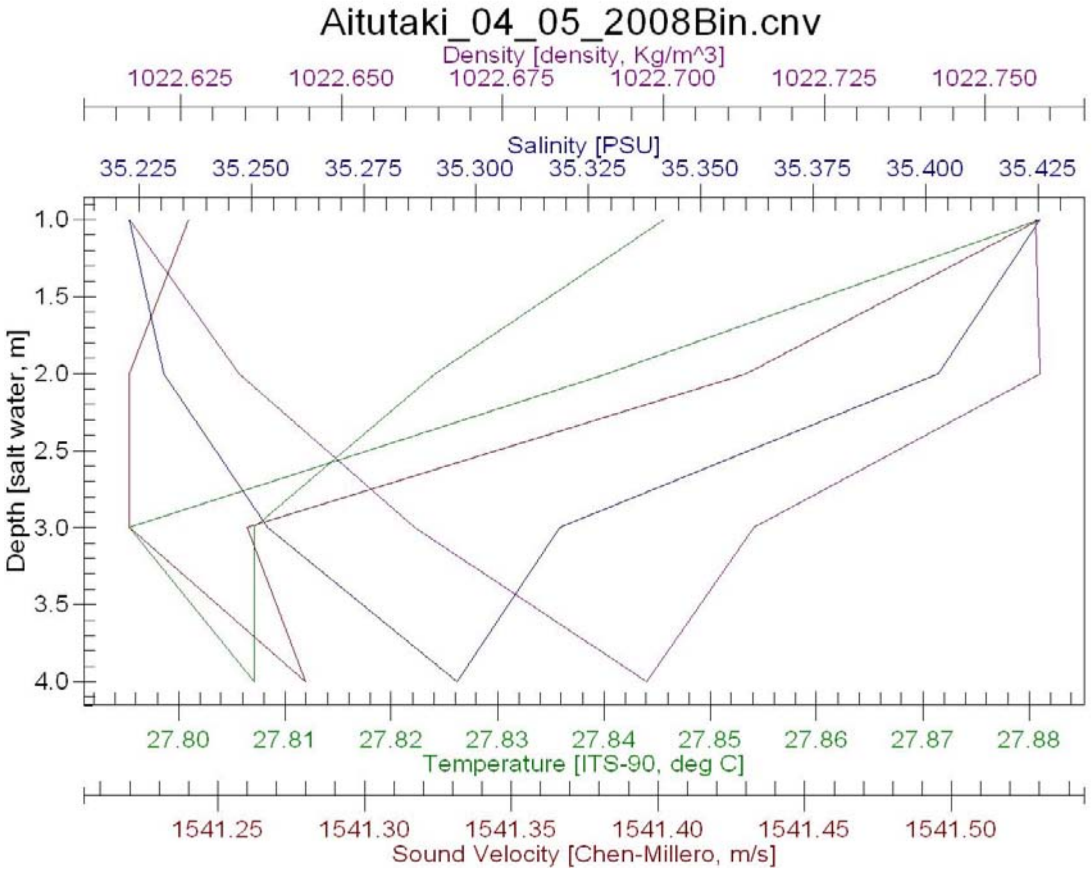
Figure A2.1. Map showing SOPAC/EU MBES coverage (in pink) around Aitutaki and SBES coverage (in red) in the lagoon.

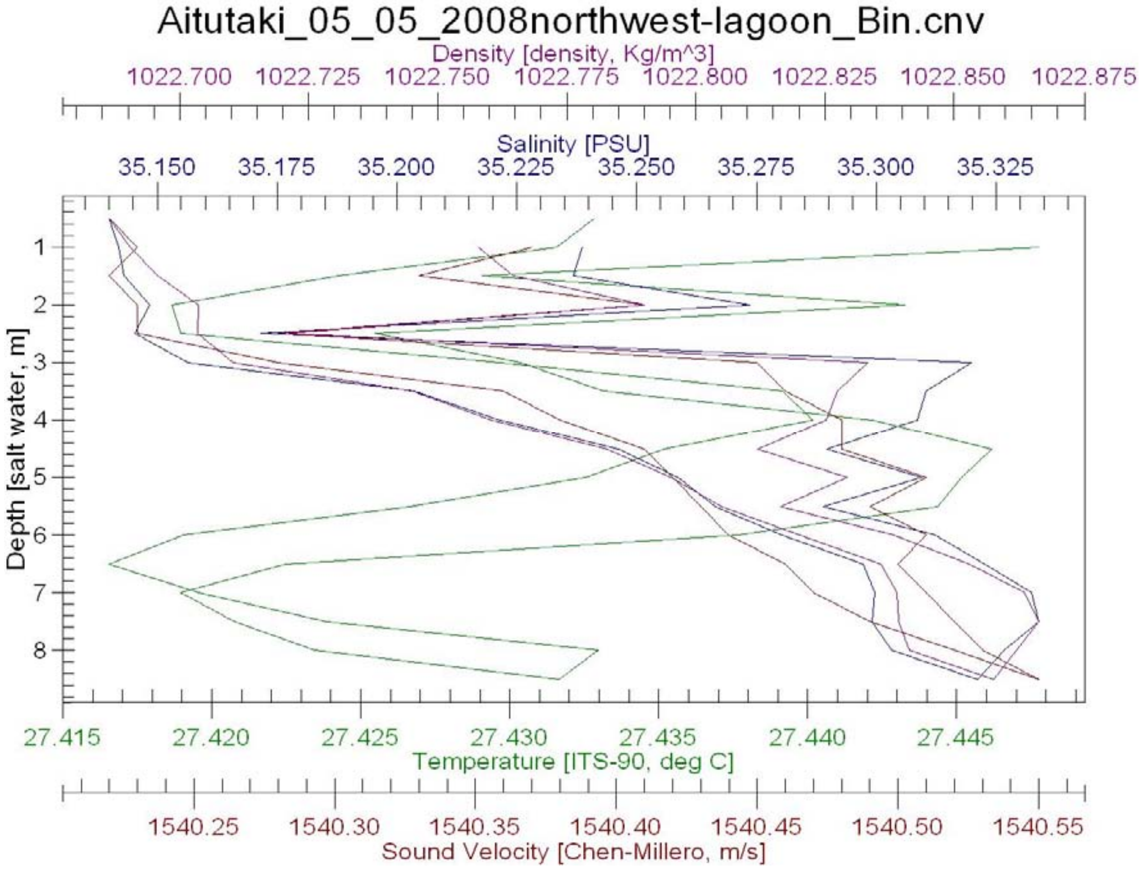
Appendix 3 – CTD Profiles

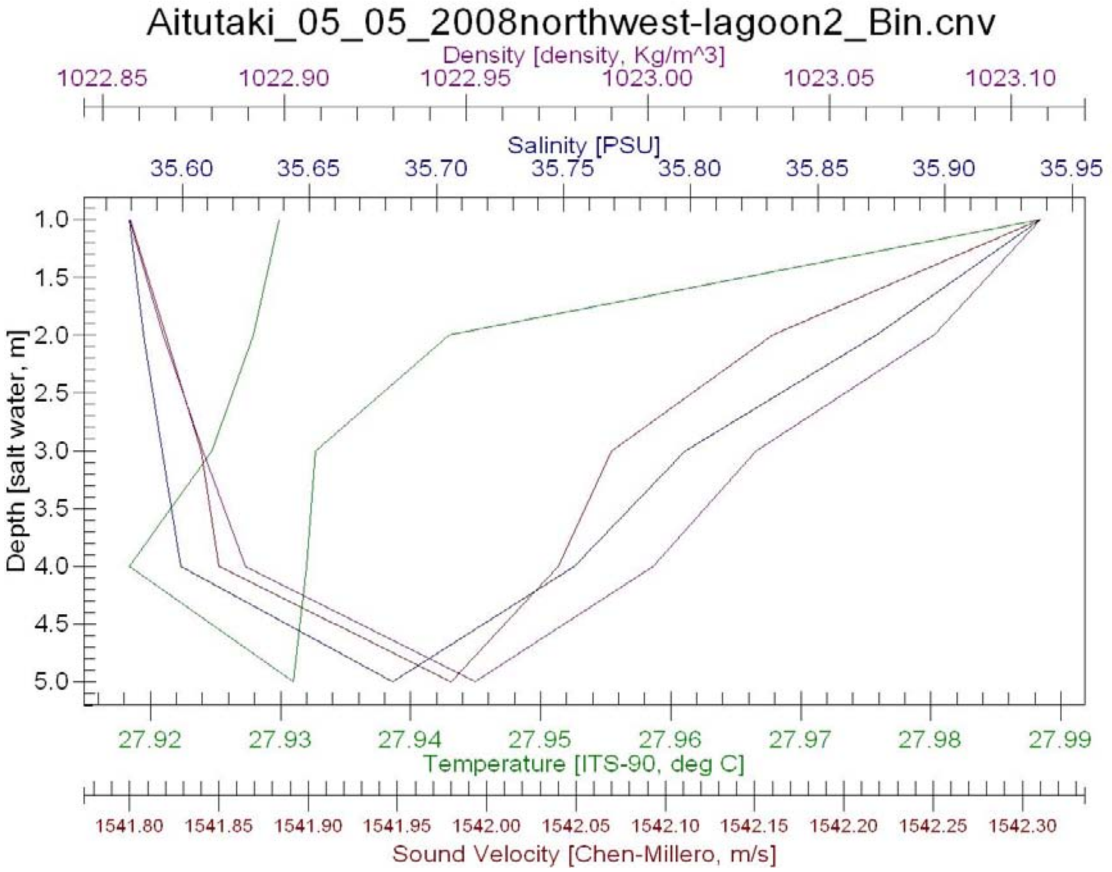





Aitutaki_04_05_2008.ADP near Maina_Bin.cnv
Density [density, Kg/m^3]
1022.840 1022.845 1022.850 1022.855 1022.860 1022.865 1022.870 1022.875 1022.880 1022.885
Salinity [PSU]
35.395 35.400 35.405 35.410 35.415 35.420 35.425
Depth [salt water, m]
1 2 3 4 5 6
27.53 27.54 27.55 27.56 27.57 27.58 27.59 27.60
Temperature [ITS-90, deg C]
1540.78 1540.79 1540.80 1540.81 1540.82 1540.83 1540.84 1540.85 1540.86 1540.87 1540.88 1540.89 1540.90 1540.91
Sound Velocity [Chen-Millero, m/s]


Aitutaki_04_05_2008Bin.cnv
Density [density, Kg/m^3]
1022.625 1022.650 1022.675 1022.700 1022.725 1022.750
Salinity [PSU]
35.225 35.250 35.275 35.300 35.325 35.350 35.375 35.400 35.425
Depth [salt water, m]
1.0 1.5 2.0 2.5 3.0 3.5 4.0
27.80 27.81 27.82 27.83 27.84 27.85 27.86 27.87 27.88
Temperature [ITS-90, deg C]
1541.25 1541.30 1541.35 1541.40 1541.45 1541.50
Sound Velocity [Chen-Millero, m/s]

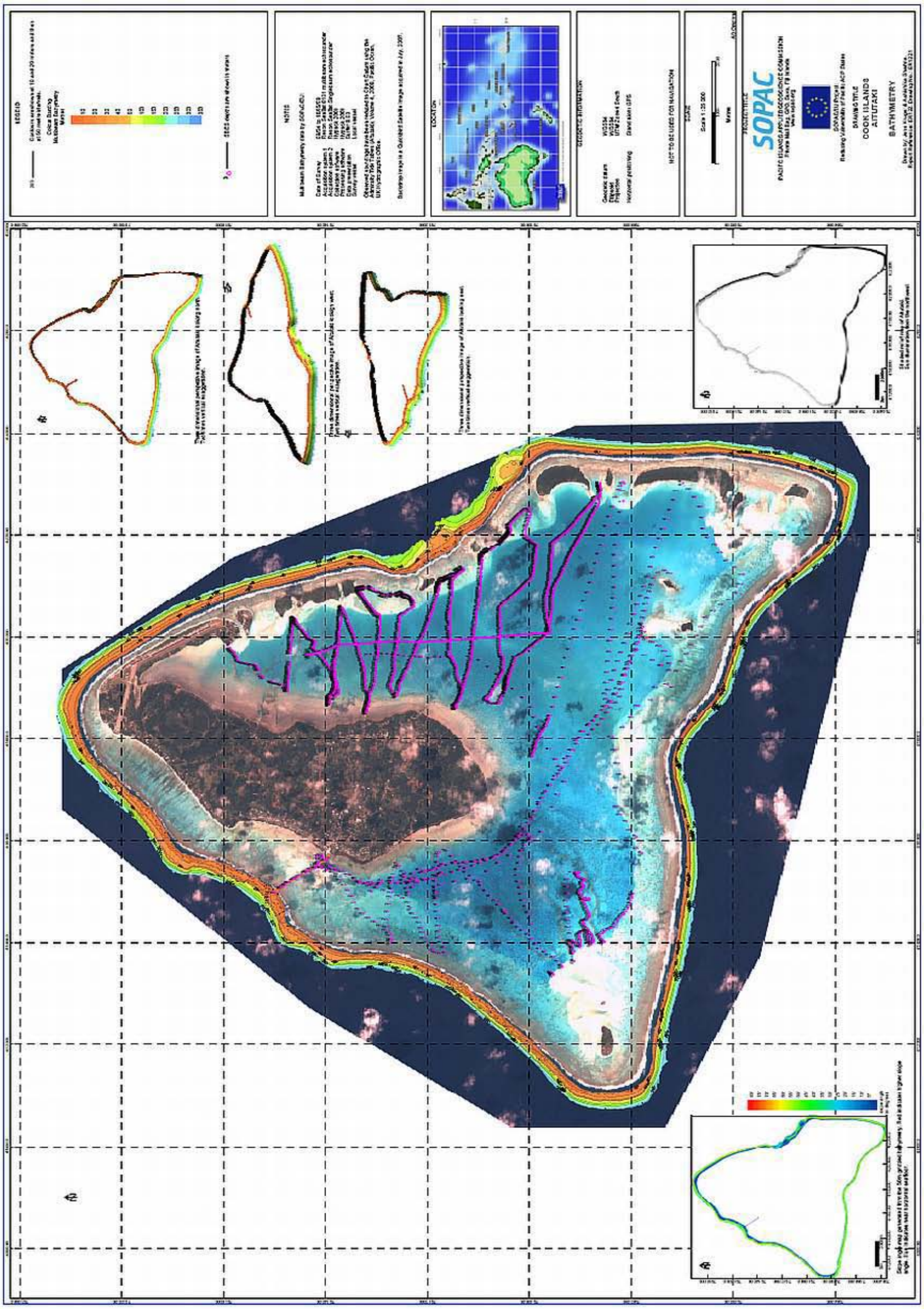

Aitutaki_05_05_2008northwest-lagoon_Bin.cnv
Density [density, Kg/m^3]
1022.700 1022.725 1022.750 1022.775 1022.800 1022.825 1022.850 1022.875
Salinity [PSU]
35.150 35.175 35.200 35.225 35.250 35.275 35.300 35.325
Depth [salt water, m]
1 2 3 4 5 6 7 8
27.415 27.420 27.425 27.430 27.435 27.440 27.445
Temperature [ITS-90, deg C]
1540.25 1540.30 1540.35 1540.40 1540.45 1540.50 1540.55
Sound Velocity [Chen-Millero, m/s]


Aitutaki_05_05_2008northwest-lagoon2_Bin.cnv
Density [density, Kg/m^3]
1022.85 1022.90 1022.95 1023.00 1023.05 1023.10
Salinity [PSU]
35.60 35.65 35.70 35.75 35.80 35.85 35.90 35.95
Depth [salt water, m]
1.0 1.5 2.0 2.5 3.0 3.5 4.0 4.5 5.0
27.92 27.93 27.94 27.95 27.96 27.97 27.98 27.99
Temperature [ITS-90, deg C]
1541.80 1541.85 1541.90 1541.95 1542.00 1542.05 1542.10 1542.15 1542.20 1542.25 1542.30
Sound Velocity [Chen-Millero, m/s]

Appendix 4 – High-Resolution A0 Chart, Aitutaki Bathymetry

Charts are available from SOPAC, and can be downloaded from its website (www.sopac.org). Full size is 841 x 1189 mm. (Low-resolution representation shown).

Chart No	Title	Scale	Drawing No.
1	Aitutaki, Bathymetry	1 : 25 000	ER122.1



Appendix 5 – SOPAC Multibeam Online Log

Operating Parameters
Model: MBES 8101
Sample rate:
Final Bin Size:
Remarks:

Hypack Project Name: Aitutaki Mairne Survey
Country: Cook Islnds
Area: Aitutaki
Vessel: Orongo
MBES System: 8101
Positioning: LRK

Date	Location	Line No.	Time		Fix		HD G	SPD	Filename (.HSX)	Log File (.LOG)	Line QC	Comments / Online changes
			SOL	EOL	SOL	EOL						
17/04/2008	patch test	2		15:35			161	5.82	001_1531		sk	roll calibration line
	patch test	2	15:36	15:41			351	3.72	002_1536		sk	roll calibration line
	patch test	1	15:45	15:47			67.8	4.44	001_1545		sk	latency calibration
	patch test	1	15:56	16:00			112	2.19	001_1555		sk	latency calibration
	patch test	2	16:06	16:07			255	4.53	002_1606		sk	pitch calibration
	patch test	2	16:09	16:11			81.4	4.5	002_1609		sk	pitch calibration
	patch test	0	16:19	16:21			115	4.53	000_1619		sk	yaw calibration
18/04/2008	wharf to passage		08:35	11:45			300	1.9	000_0835		sk	loggimng form wharf area to passage and outside of reef.
			08:49	08:59			280	3.8	000_0849		sk	
			09:01	09:09			299	2	00_0900		sk	
				09:31			143	3.78	000_0920		sk	into passage
	test in lagoon		10:04	10:15			301.6	2.04	000_1004		sk	chnaged oreintation to forward.
			10:17	10:28			304		000_1017		sk	can be used for roll correction
			10:29	10:39			232	3.95	000_1029		sk	
			00:00	00:00			103	5	000_1050		sk	back to wharf-passage line
	patch test 2nd try	0	12:40	00:00			228	4.49	000_1240		sk	roll line
		0	12:49	12:56			30	3.9	000_1249		sk	roll line

		0	13:01	13:04					000_13.01		sk	dnp
			13:16	13:19				1.34	000_1316		sk	latency
			13:25	13:27			301	4	000_1325		sk	latency
			13:38	13:39			291	3.9	000_1338		sk	pitch
			13:42	13:44			113	4	000)1342		sk	pitch
			13:50	13:52			254	3.65	000_1350		sk	yaw
			13:55	13:57			260	3.5	000_1355		sk	yawdnp
			14:02	14:03			280	3	000_1401		sk	yaw
19/04/2008	lagoon/passage	0	09:33	09:42			302.5	2.28	001_0933		AS	
			09:42	09:47			239	4.76	002_0942		AS	
			09:48	10:40					001_0947		AS	
			10:55	11p;50					002_1055		AS	
			11:50	12:45					001_1150		AS	
			12:45	09:36					002_1245		AS	
			13:40	14:34			329.3	5.52	001_1340		AS	
20/04/2008	passage		08:49	08:52			308		002_0849		sk	
	offshore		08:59	09:51			233	6.8	001_859		sk	
			09:51	10:43			110	6.23	002_0951		sk	
			10:43	11:37			140	6.69	001_1043		sk	
			11:37	12:35			349	6.48	002_1137		sk	
			12:35	12:52			244	7	001_1235		sk	
			13:12	14:06			194	6	002_1311		sk	
			14:06	15:01			103	6.72	001_1406		sk	
			15:01	15:10			50	7.56	002_1501		sk	fish on line
			15:16	16:05			4.6	7	001_1516		sk	
			16:05	17:02			357	7.18	002_1605		sk	
	passage		17:38								sk	
21/04/2010	passage	2	11:13	11:21			276	2	002_1113		sk	
			11:26	11:51			12	6.2	001_1126		sk	

			12:07	12:43			6	6.3	002_1207		sk	very heavy swells,waves across the deck
			12:43	13:16			6.3	5	001_1243		sk	
			14:40	15:23			5.34	6.4	002_1440		sk	
			15:23	15:34			6.4	260	001_1523		sk	last line for the day
22/04/2008	passage	2	10:19	10:30			2	283	002_1019		sk	
			10:32	11:26			265	6	001_1032		sk	
			11:27	12:20			86	5.8	002_1127		sk	
			12:20	12:55			127	5.7	001_1220		sk	lost navigation
			13:02	13:23			8	6	002_1302		sk	