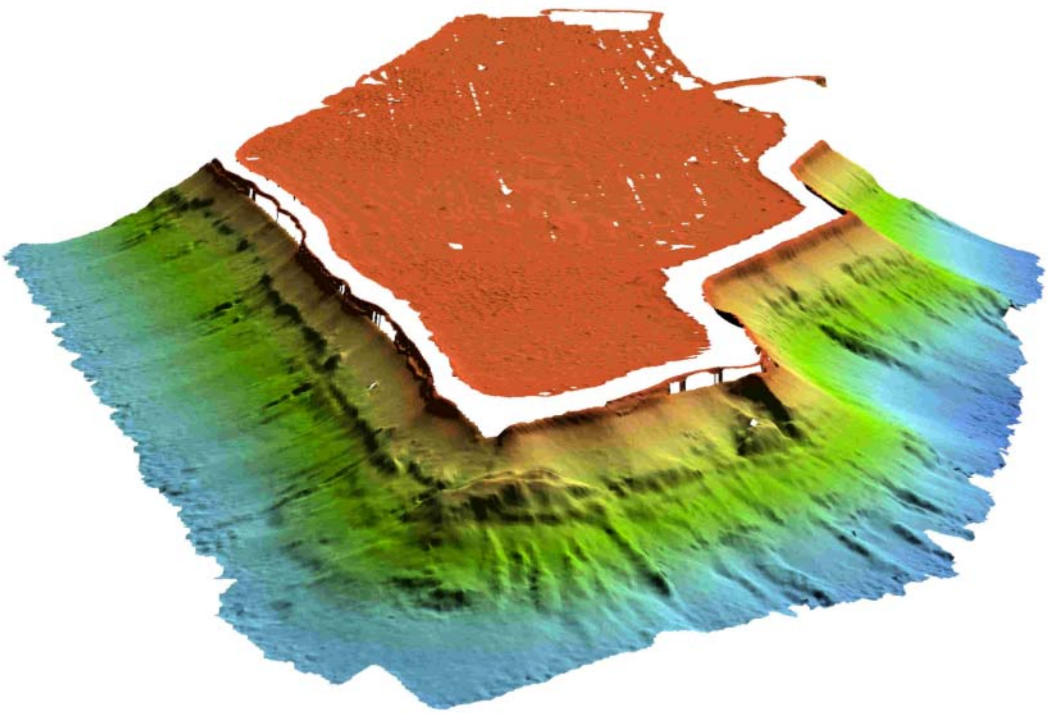
EU EDF 9 – SOPAC Project Report 117
Reducing Vulnerability of Pacific ACP States

REPUBLIC OF MARSHALL ISLANDS TECHNICAL REPORT
High-Resolution Bathymetric Survey of Majuro
Fieldwork undertaken from 18 to 27 July 2006

October 2008



Three-dimensional perspective image of Majuro Atoll looking east.

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TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

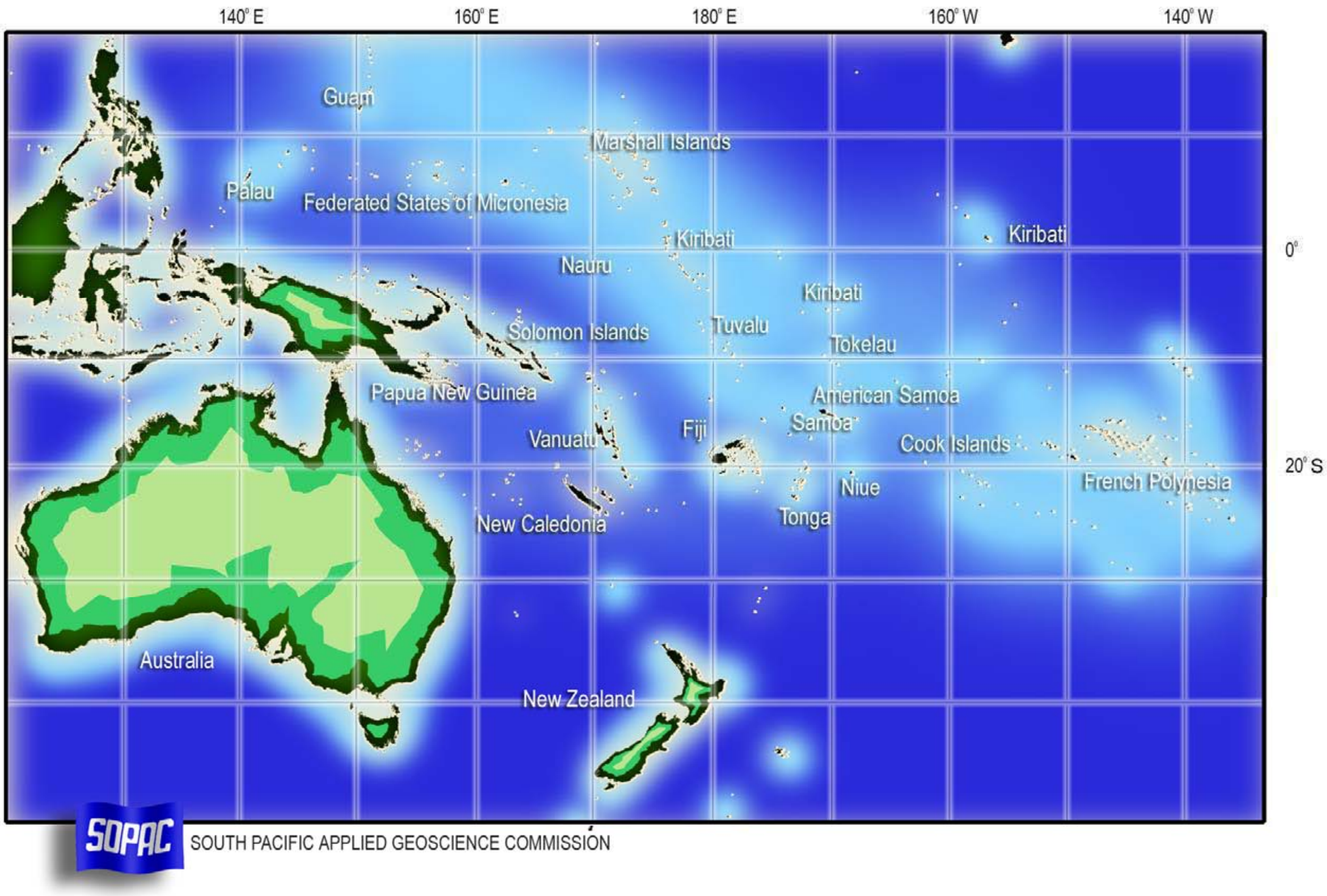


Figure 1. Location map of Pacific Island countries and territories constituting SOPAC.

Acronyms and their meaning

ACP	African, Caribbean, and Pacific
ADCP	Acoustic Doppler current profilers
ARGO	Array for real-time geostrophic oceanography
ASCII	American standard code for information interchange
CD	Chart datum
CTD	Conductivity – temperature – depth
DEM	Digital elevation model
DTM	Digital terrain model
EEZ	Exclusive economic zone
GDEM	Generalised digital environmental model
GEBCO	General bathymetric chart of the oceans
GPS	Global positioning system
LAT	Lowest astronomical tide
MBES	Multibeam echosounder
MRU	Motion reference unit
MSL	Mean sea level
NTC	National Tide Centre
PI-GOOS	Pacific Islands global ocean observing system
RTK	Real-time kinematic GPS (centimetre accuracy)
SMNT	Seamount catalogue
SOPAC	Pacific Islands Applied Geoscience Commission
SPCZ	South Pacific convergence zone
SRTM	Shuttle radar topography model
TAO	Tropical atmosphere ocean array
UTM	Universal transverse Mercator
WGS	World geodetic system

EXECUTIVE SUMMARY

Kruger, J. and Kumar, S. 2008: High-Resolution Bathymetric survey of Majuro, Republic of Marshall Islands. *EU EDF 9 – SOPAC Project Report 117*. Pacific Islands Applied Geoscience Commission: Suva, Fiji, vi + 39 p. + 2 charts.

The Pacific Islands Applied Geoscience Commission (SOPAC) carried out a marine survey for Majuro Atoll in the Marshall Islands. The objective was to investigate the seabed and provide information about water depths in and around the atoll using a multibeam echosounder (MBES)

This report describes a high-resolution bathymetric survey carried over a period of 10 days from 18 to 27 July, resulting in the acquisition of 752 km of multibeam echosounder data.

The survey achieved good coverage of the seafloor in the lagoon within the survey area from approximately 10 to 70 m water depths. The eastern nearshore area of the reef slope was mapped from approximately 10 m depth to an average offshore distance of 5 km, reaching water depths of some 2200 m. The seafloor terrain was found to be highly irregular with an average slope of 31º. The survey data was supplemented with data previously collected by SOPAC.

The resultant data compilation was used to produce bathymetry charts of Majuro at a scale of 1 : 50 000. The compiled bathymetry dataset reveals the main morphological features of the seabed in the lagoon and also around the eastern offshore areas. These new bathymetric maps provide a descriptive picture of the ocean bottom terrain, vividly revealing the size, shape and distribution of underwater features. They can serve as the basic tool for scientific, engineering, marine geophysical and environmental studies, as well as for marine and coastal resource management.

1. INTRODUCTION

1.1 Background

A marine survey for Majuro lagoon and parts of the offshore was carried out. The objective was to investigate the seabed and provide information about water depths using a multibeam echosounder (MBES). The present report describes the results of the MBES survey. This work was initiated by the SOPAC/EU Reducing Vulnerability of Pacific ACP States Project, under the European Development Fund.

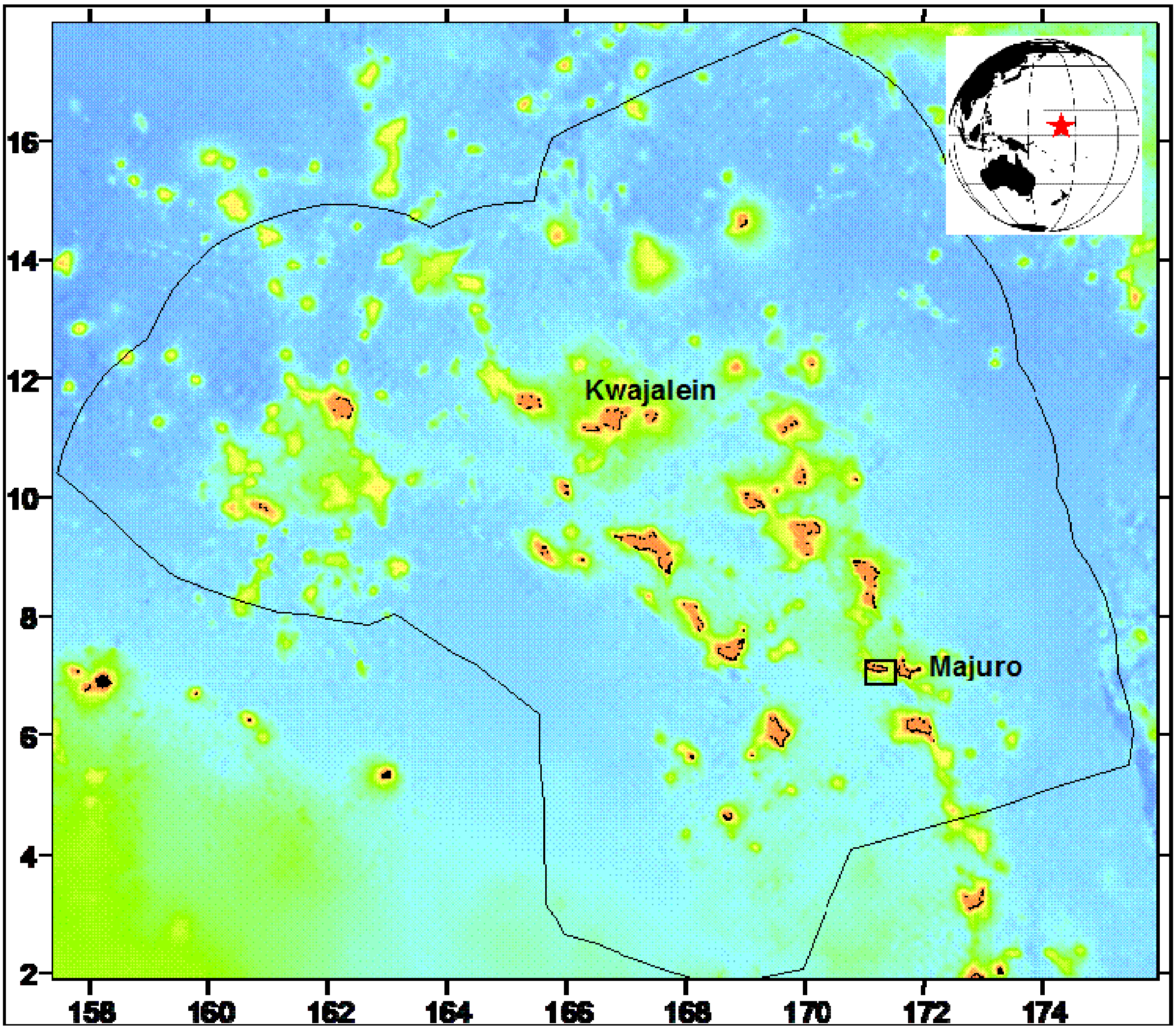


Figure 2. Bathymetric map of Marshall Islands showing the atolls and approximate position of the exclusive economic zone. Bathymetric data are predicted water depths, with shallow to deep shown in red to blue (Smith and Sandwell 1997).

1.2 Geographic Situation

The Republic of the Marshall Islands (RMI) comprises approximately 1225 low-lying islets which make up the 29 atolls and five low-elevation islands. Its total land area is 181 square kilometres with a maximum height of 3 metres above sea level. The archipelagic islands are spread over a vast area of ocean in two roughly parallel island chains. The eastern group is the Ratak (Sunrise) Chain and the western is the Ralik (Sunset) Chain. Selected geographic characteristics of Majuro are provided in Table 1.

Table 1. Summary of Geography of Majuro

Location	171°12′ E and 7°09′N
Land area	The atoll is elongate in shape, extending 40 km from east to west and 9.7 km from north to south with an approximate land area of 181.3 km^2.
Coastline	The lagoon is enclosed by an almost continuous reef flat with some passages on the middle west of the north rim, in which a 3.2 km wide and 9.1–18.3 m deep passage is located to the west of Calin islet. Most islets are on the eastern half of the north rim, and east, south and southwest rims. The islets on the south rim have been connected by causeways. The lagoon has a surface area of about 344 km^2 and an average depth of about 46 m, descending to a maximum depth of 67 m (Manoa Mapworks 1989; Wilson et al. 1990; Holthus et al. 1992).
Tides	Semi-diurnal with pronounced diurnal inequalities (i.e. two tidal cycles per day of unequal tidal range). Predicted mean range and mean spring range at Majuro Atoll are 1.13 m and 1.62 m respectively (US Department of Commerce).
Climate	Predominant influence is from the northeast trade winds; temperature variations are slight with northern islands being slightly cooler than the southern. Rainfall varies from north to south; Ujelang has an average of 2030 mm per annum while Jaluit, further south, has twice that amount. Mean temperature is 27°C.
Exclusive Economic Zone, EEZ	2 131 000 km^2

1.3 Geological Setting

The atolls of Marshall Islands consist of circular to elliptical chains of small carbonate islands associated with a coral-reef platform encircling a shallow, central, seawater lagoon. The atoll islands, which typically consist of reef debris and atoll sediments, are exposed or emerged portions of a thick carbonate platform that has formed on top of a subsided and submerged volcanic edifice.

The Marshall Islands sit atop the Pacific Plate and are thought to represent a senescent volcanic chain produced by a long-inactive hotspot (Scott and Rotondo 1983). Unlike the nearby linear volcanic island chains in the Pacific, the volcanoes that underlie the present-day Marshall Islands are widely scattered and do not exhibit any apparent age linearity.

1.4 Previous Bathymetry Compilations

Bathymetric maps are topographic maps of the sea floor, giving a descriptive picture of the ocean bottom terrain. With an exclusive economic zone (EEZ) of approximately 2 131 000 km^2, the available bathymetric data is limited and the exact nature of seafloor is poorly known. Most available bathymetric data originates from sparse single-beam soundings from oceanographic cruises, and since the early 1990s, from MBES systems as well as satellite-derived predicted depth.

A search for public Multibeam data on NOAA'S national geophysical data centre (http://www.ngdc.noaa.gov) and the seamount Catalogue, SMNT (earthref.org) in February 2008 produced the scientific cruises for the area of interest shown in Table 2 and Figure 3.

Table 2. Public Multibeam Datasets for Majuro

Ship	Survey ID/instrument	Year
RV *Washington*	RNDB12WT/SeaBeam	1988–1989
RV *Washington*	RNDB11WT/SeaBeam	1988
RV *Washington*	RNDB10WT/SeaBeam	1988
RV *Washington*	RNDB13WT/SeaBeam	1989
RV *Washington*	TUNE09WT/SeaBeam	1992
RV *Washington*	TUNE08WT/SeaBeam	1992
RV *Melville*	AVON02MV/SeaBeam2000	1999
RV *Melville*	AVON01MV/SeaBeam2000	1999

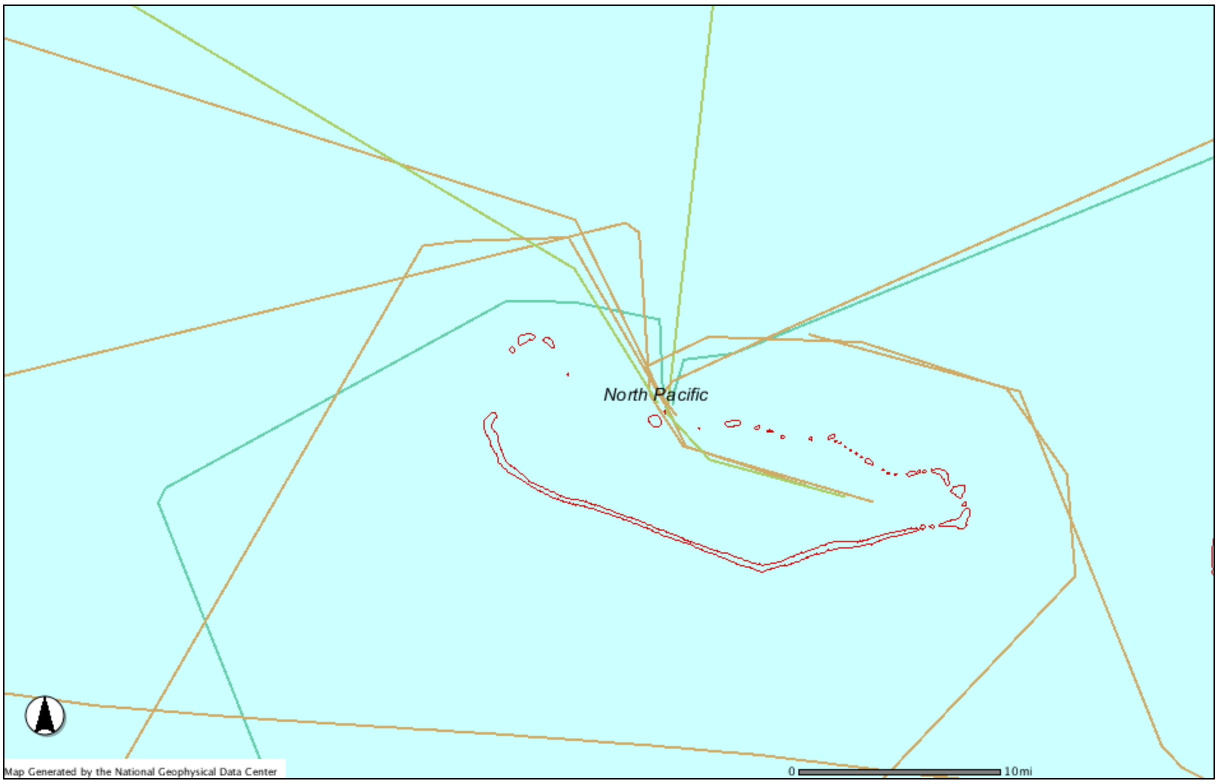


Figure 3. Oceanic cruise plots for Majuro Atoll

SOPAC carried out a series of marine surveys in the Majuro lagoon from 1994. Bathymetry data collected in 1994 and 2002 are provided in Figure 4. The summary of the surveys is provided in Table 3.

Table 3. Summary of SOPAC Bathymetric Survey.

Year of Survey	Area Surveyed	Survey Methods	Reference
1994	Western end of Anemwanot islet to the east of Ejit islet	Some 30 km of single-channel bathymetry (De 719e Raytheon precision echo sounder)	Smith (1995)
2002	Eastern portion of the lagoon from the airport to Uliga in the east, the inner margin of lagoon from Peace Park to Laura and the northern margin from Calalin Channel to Rita.	Some 478 km of high-resolution multibeam bathymetry (Reson 8101 echo sounder)	Smith & Collen (2004)

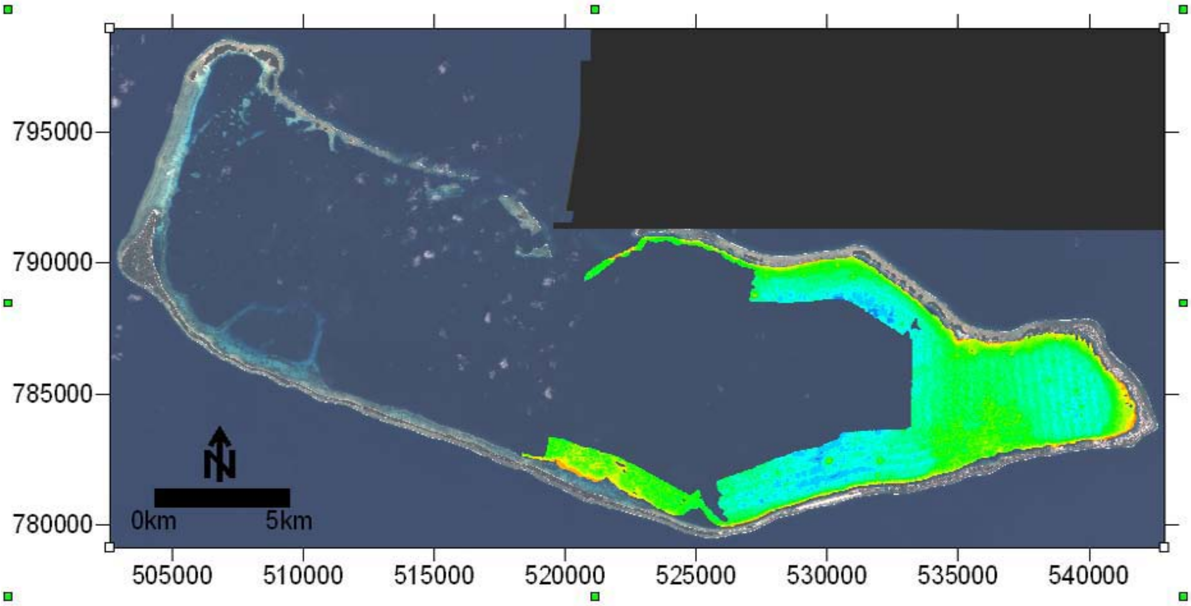


Figure 4. Map showing the 1994 and 2002 MBES bathymetry coverage by SOPAC.

2. RESULTS

2.1 Bathymetry and Backscatter

The MBES bathymetry acquired during this survey is shown on chart ER117.1 at a scale of 1 : 50 000 and contoured at intervals of 100 m. The multibeam backscatter data acquired for the lagoon during this survey is shown on chart ER117.2 at a scale of 1 : 25 000. The grid files, as well as charts, meta data, and report are available through the SOPAC Geonetwork site. The report and full-size charts are also available from the SOPAC virtual library. Links to these sites can be found on www.sopac.org.

Bathymetric and backscatter data provide information on the depth and morphology of the seafloor, as well as the shape and size of submarine features. Three bathymetry derivatives (slope angle maps, shaded relief maps, and three-dimensional rendered surfaces), were used in addition to the high-resolution bathymetry and backscatter data to aid visual interpretation of the seabed morphology. These terms are summarised in Table 4 below, and images are shown in Figure 5 to Figure 8.

Table 4. Bathymetric Derivatives and Multibeam Backscatter

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.
Backscatter	The MBES records echo strength data (reflected energy) that can be presented as seabed backscatter maps, similar to sidescan sonar mosaic. The backscatter image shows information on the composition of the seafloor. For example, soft marine muds absorb part of the sound energy, thereby muting the reflected signal, whereas a strong echo may indicate a rock outcrop or coral reef.

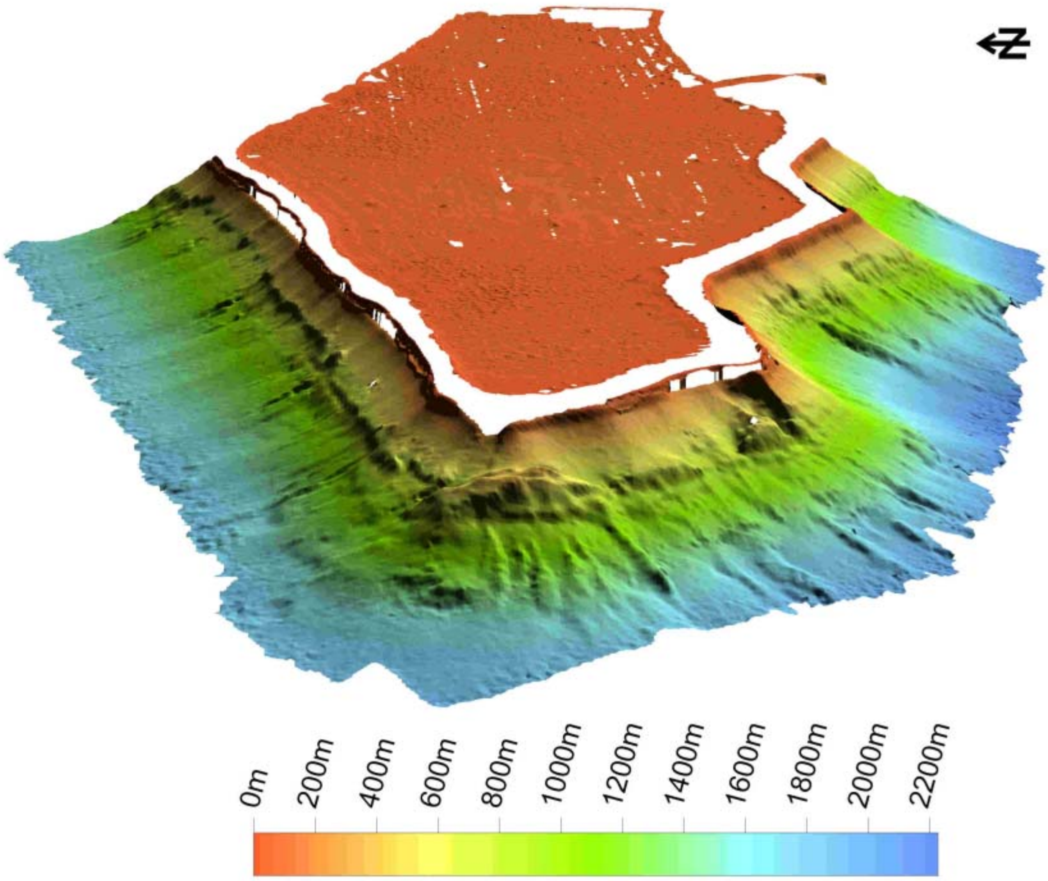


Figure 5. Three-dimensional perspective image of Majuro atoll looking west.

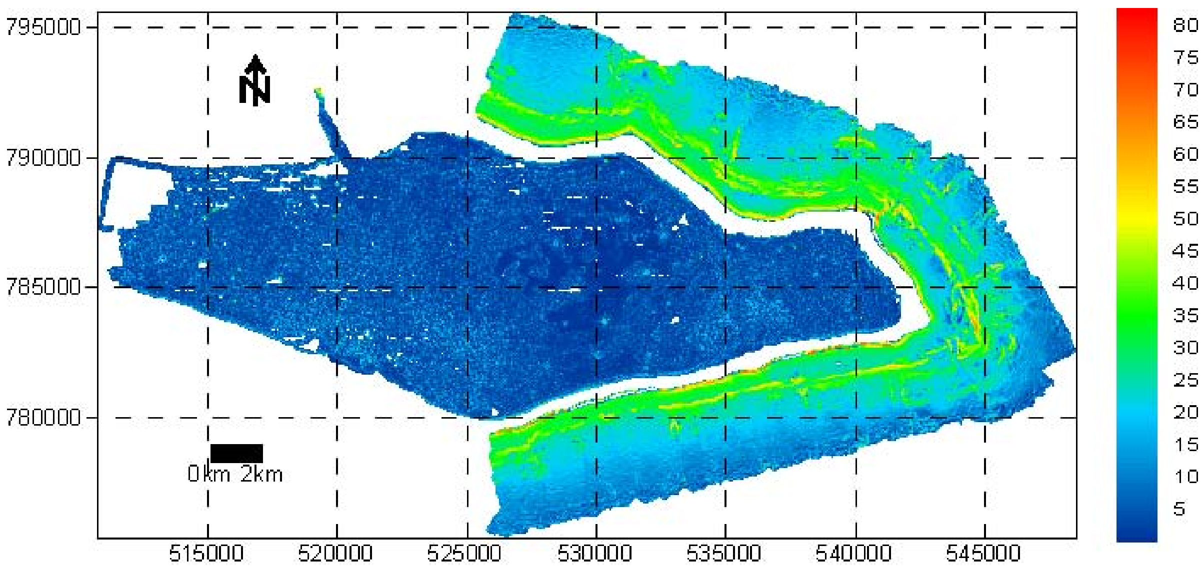


Figure 6. Gradient slope angle map of the Majuro seabed generated from 50 m (offshore) and 15 m (lagoon) gridded bathymetry. Red indicates higher slope angles and blue indicates near horizontal seafloor.

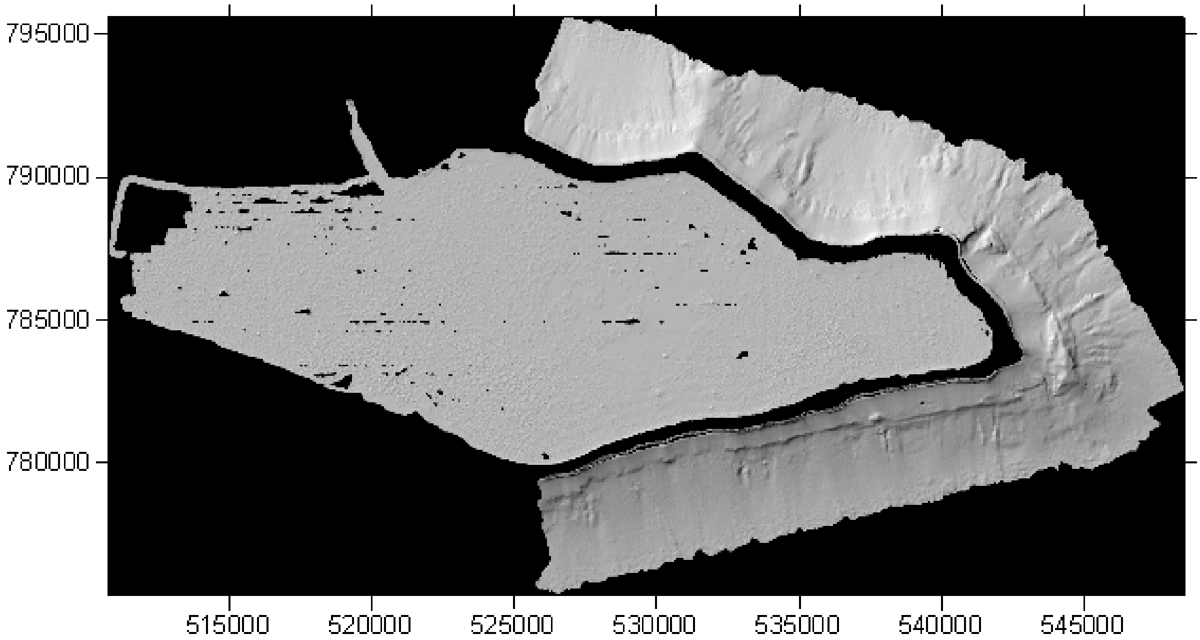


Figure 7. Shaded relief map of Majuro's lagoon and nearshore bathymetry. Sun illumination from the northwest.

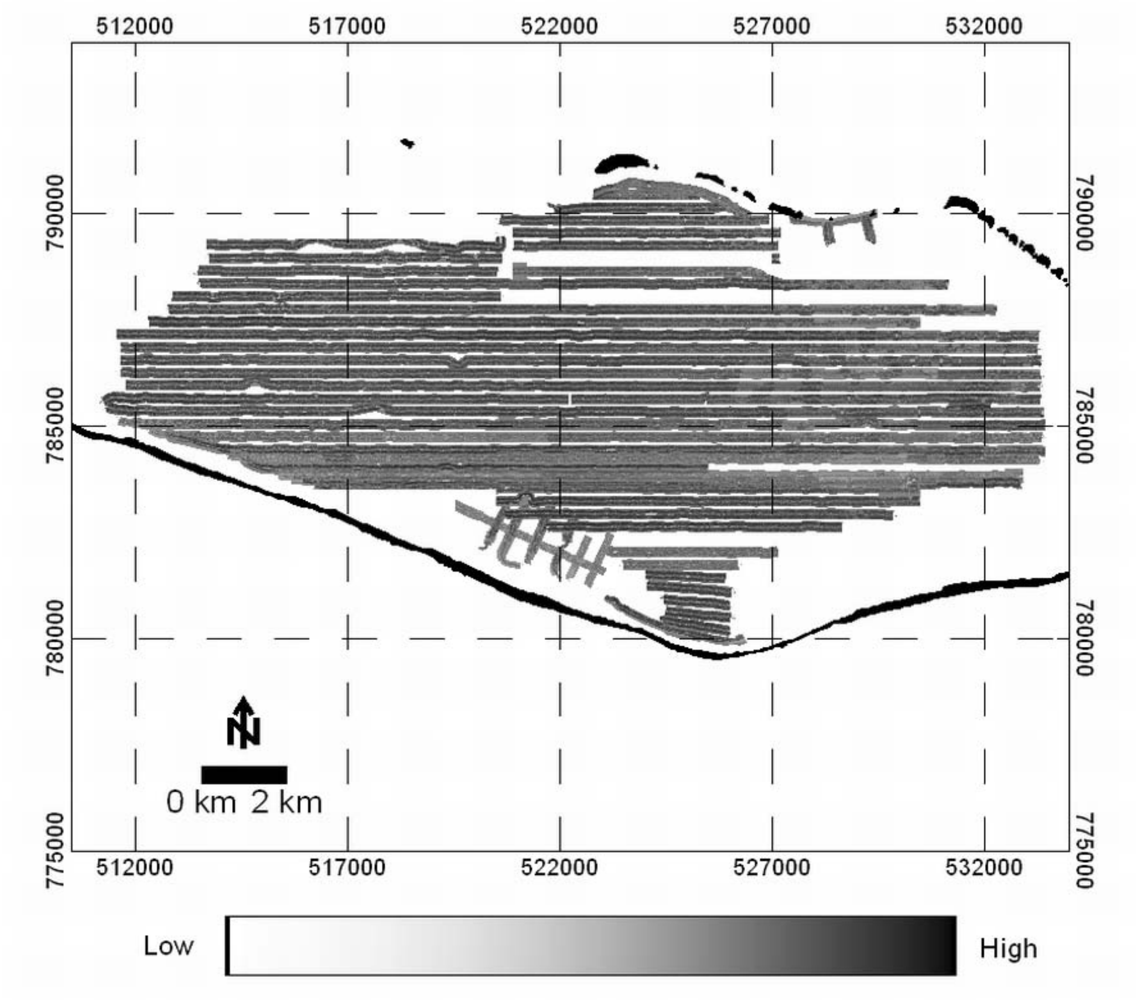


Figure 8. Map showing the MBES backscatter mosaic of the Majuro lagoon floor. Land is shown in black. Low to high backscatter intensity is shown from white to black.

2.2 Morphological Features

The high-resolution MBES data, bathymetric derivatives, and backscatter (in case of the lagoon) described in the section above, were used to interpret broad habitats in geomorphic terms of the lagoon and the eastern offshore flank as shown in Figure 9 and Figure 11, respectively. The classification used in Figure 9 makes use of the terms and nomenclature endorsed by the International Hydrographic Organisation (IHO 2001) as defined in the table below.

Geomorphic feature	Definition
Apron	A gently dipping featureless surface, underlain primarily by sediment, at the base of any steeper slope.
Canyon	A relatively narrow, deep depression with steep sides, the bottom of which generally has a continuous slope, developed characteristically on some continental slopes.
Escarpment	An elongated and comparatively steep slope separating gently sloping areas.
Knoll/Hill/Peak	A small isolated elevation.
Pinnacle	Any high tower or spire-shaped pillar or rock or coral, alone or cresting a summit. It may extend above the surface of the water. It may or may not be a hazard to navigation.
Reef	Rock/Coral lying at or near the sea surface that may constitute a hazard to surface navigation.
Ridge	A long, narrow elevation with steep sides.
Shelf	Zone around an island extending from the low water line to a depth at which there is usually a marked increase of slope towards oceanic depths.
Slope	Slope seaward from the shelf edge to the upper edge of a continental rise or the point where there is a general reduction in slope.

The nearshore bathymetry of Majuro shows a terrace below the fringing reef platform. It is approximately 100 m wide with an average water depth of 300 m. Below this terrace the seabed slopes at angles of 30–40º to a depth of approximately 1500 m. Depths to 1900 m are characterised by much gentler slopes of 0–20º. A bathymetric high is observed at the south-eastern end of the atoll in water depth of 400 m.

Few small channels on the southern side of the atoll are seen to be originating at the base of the terrace while a channel on the northern side seems to be cutting through the terrace. Around the southern and northern parts in waters greater than 1200 m, the seafloor appears to be quite featureless. A few submarine slumps and ridges are seen originating at around 1400 m at the north-eastern side of the atoll. The extent of the slump extends beyond the limit of the bathymetric survey.

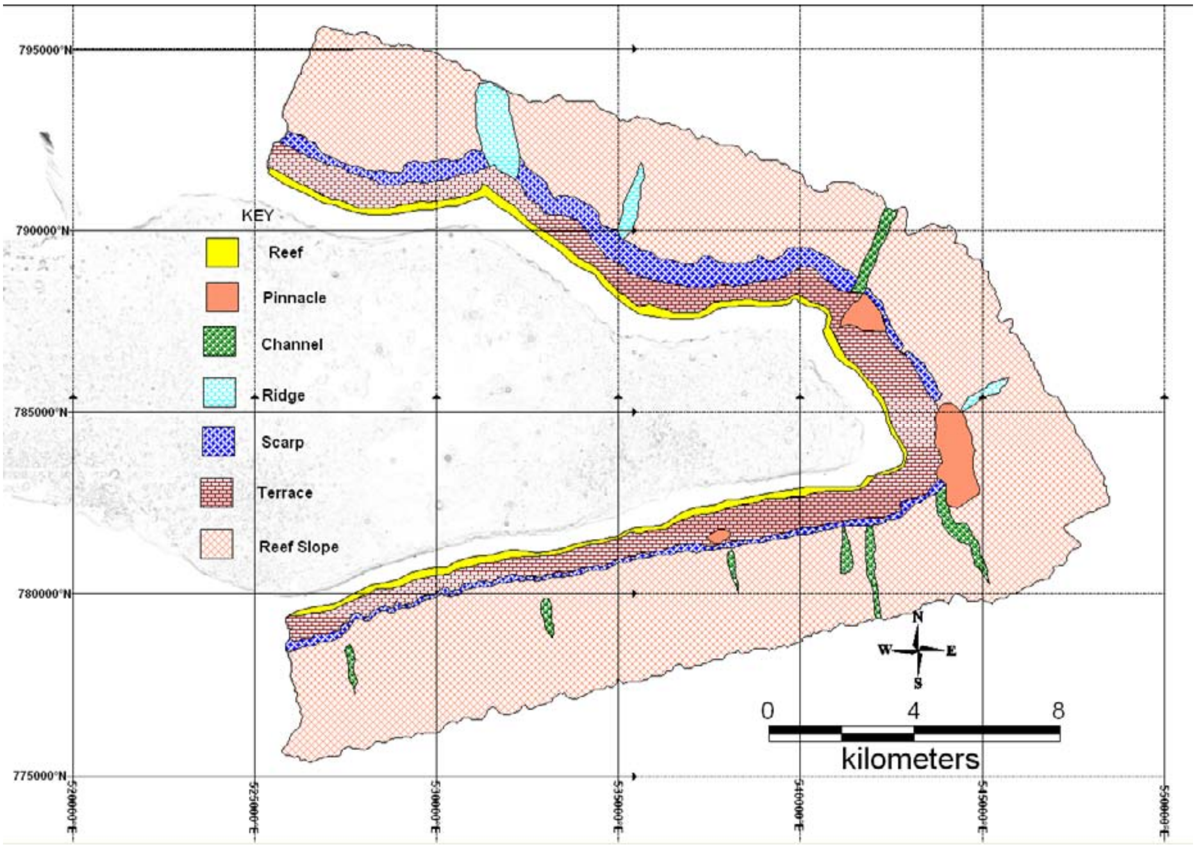


Figure 9. Interpreted offshore seabed morphology of Majuro on a shaded relief image illuminated from the North.

The distribution of surficial sediments and sedimentary environments in Majuro lagoon were investigated using high-resolution bathymetry, backscatter, seismic profiling and sediment data. Shallow-water multibeam data were acquired using Reson 8101, together with the backscatter data. Seismic profiling was accomplished with the DataSonics SBT 200 system. The analogue data was recorded on an EPC 1650 graphic recorder with a sweep frequency of 125 milliseconds (ms). The seismic data was interpreted and is presented in a separate report (Woo & Kumar in press).

Surficial sediment samples, used to verify the backscatter and bathymetry data, were collected using a Van Veen grab sampler, and analysed for grain size. The data analyses and results are presented in a separate report (Tawake & Kumar 2008). These sediment samples were spatially limited to the inner reef rim slopes. Tonal changes in the backscatter mosaic (Figure 10) help determine sediment type in the lagoonal area. Light tones indicate low backscatter caused by generally fine grained sediment or soft bottom or an acoustic shadow; dark tones indicate high backscatter caused by generally coarser-grained sediment. No sediment samples or seabed samples were available for the lagoon proper or depths below 10 m. The interpretation shown in Figure 11 is therefore preliminary and largely based on expert opinion. SOPAC is planning a ground truthing survey for Majuro lagoon for 2008, or early 2009.

A large proportion of the mapped lagoon floor comprised numerous mounds interpreted to be Halimeda mounds from seismic profiles, giving the seabed a rough and hummocky bathymetric fabric (Figure 12). In the deepest parts of the lagoon the seafloor appears quite flat and consists of fine to medium sand (Smith and Collen 2003). These mounds measure on average approximately 200 m across and 10 m high (Figure 12 and Figure 13).

Scattered isolated pinnacles within the lagoon are presumed coral heads. An irregular area of 6x6 km, centred on 529 900 E, 786 400 N, in the eastern portion of the lagoon is mapped as flat, fine to medium sand in Figure 11. This area exhibits a relatively flat and featureless seafloor with occasional depressions. Wind-driven waves, storm erosion, and tidal currents rework the seafloor in the lagoon. Coarser-grained sediment is abundant in shallow depths where the sediment is winnowed by waves and currents. Fine grains are transported from these high-energy environments and deposited in low-energy environments where bathymetry is smooth and water depths are moderate to deep. Sorting and reworking of sediments is taking place throughout the sedimentary environment. Most of the nearshore areas of the lagoon are composed of gravelly sediments and is classified as sediment aprons. Sediment aprons dominate around the northern and eastern inner reef rim edges of the lagoon. A thin veneer of sand is believed to cover bathymetric mounds near the entrance channel.

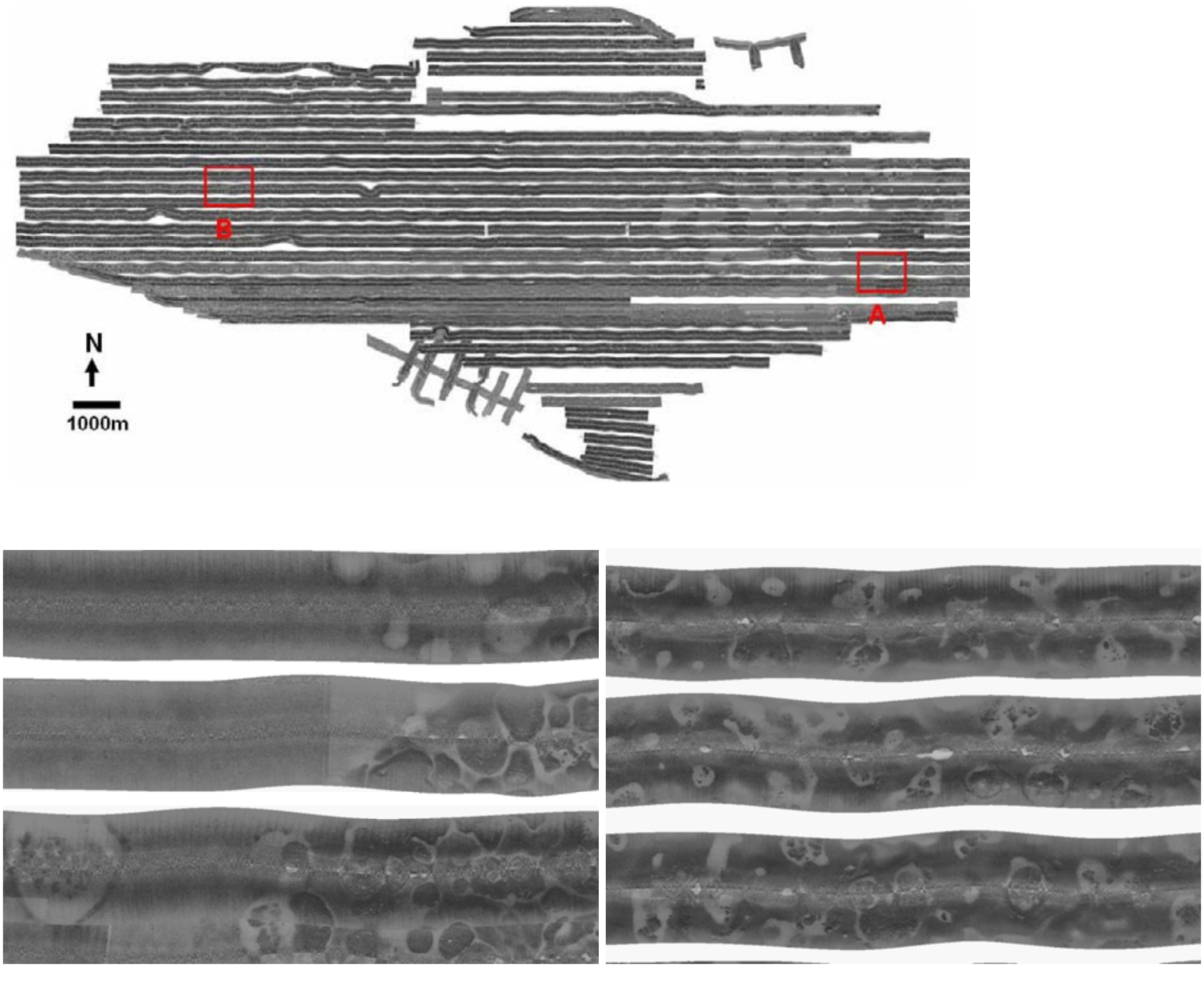


Figure 10. Majuro lagoon multibeam backscatter mosaic, with backscatter of boxes A and B.

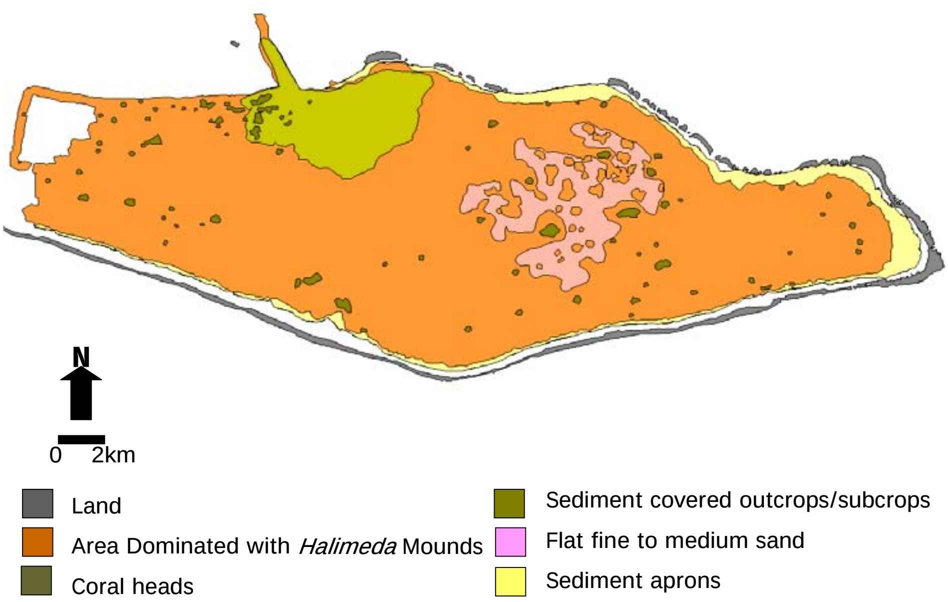


Figure 11. Preliminary interpreted habitat map of the Majuro Lagoon. An already planned ground-truthing survey of the lagoon floor will be used to update the broad habitats shown in this map.

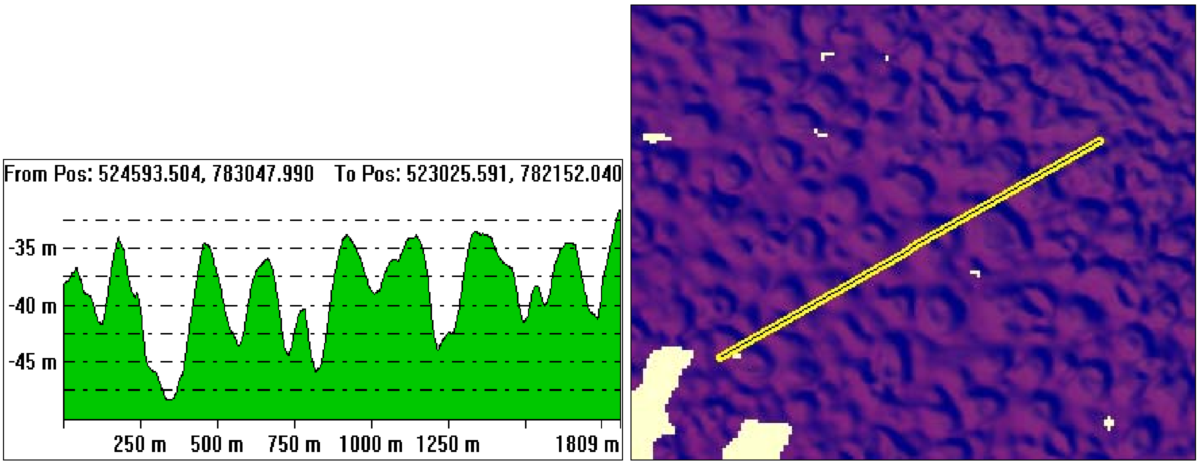


Figure 12. Cross-section across the lagoon seafloor, presumed Halimeda mounds, showing associated hummocky bathymetry.

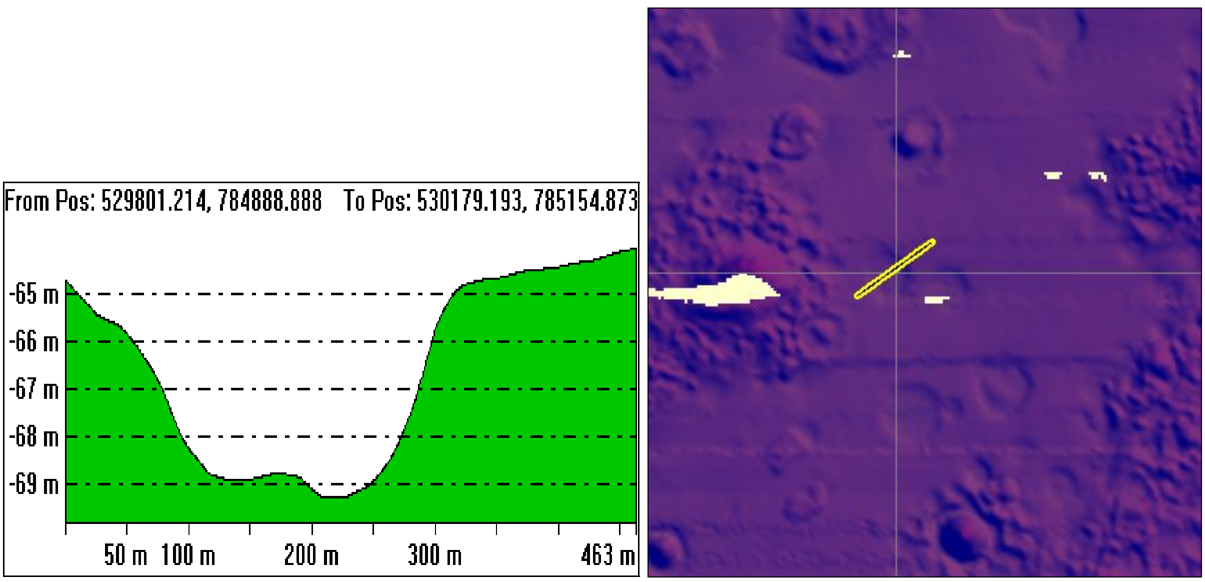


Figure 13. Cross-section across a depression in the deep flat part of the lagoon, with the associated bathymetry.

3. DATA ACQUISITION AND PROCESSING

3.1 Survey Particulars

Survey vessel: RV *Summer Spirit*

Fieldwork date: 18 to 27 July 2006

Equipment used: Reson 8160, deep water MBES, Reson 8101 shallow-water MBES

All dates and times in this report are given in the local Majuro time zone (12:00h GMT = 24:00h local).

3.2 Field Personnel

SOPAC: Robert Smith (Chief Scientist), Salesh Kumar (Technical Officer), Ed Saphore (Electronic Technician)

Vessel: Brian Hennings (Master), Tomasi (Officer), Sakiusa (Engineer), Ram Reddy (Cook)

3.3 Geodetic Reference System

Survey results were mapped in terms of the geodetic reference system shown in Table 5.

Table 5. Geodetic Reference System

Geodetic datum	WGS84	
Ellipsoid	WGS84	
	Semi-major axis (a)	6378137.000
	Inverse flattening (1/f)	298.257223563
Projection	UTM zone 59 north	
	Projection type	Transverse Mercator
	Reference latitude	00° 00' 00.000" North
	Central meridian	171° 00' 00.000" East
	Origin false easting	500000.0000
	Origin false northing	10000000.0000
	Scale factor	0.9996000000
	Grid unit	metres
Geodetic transformation	From WGS84 (GPS satellite datum) to UTM 59 North	
	Source coordinate system	WGS84
	Target coordinate system	UTM 59 North
	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 Vessel Description and Static Offsets

Details regarding the survey vessel are shown in Figure 14 and on page 15.

Figure 14. The chartered survey vessel RV Summer Spirit*.*

3.5 Positioning Control

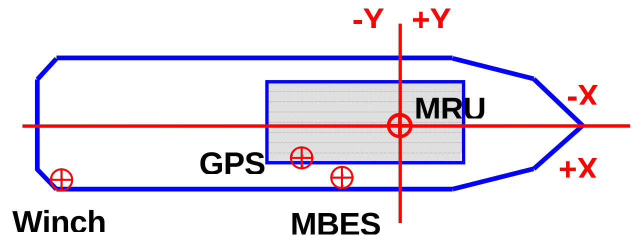
The vessels reference point (X=0, Y=0, Z=0) was the motion reference unit (MRU) position at the waterline. Positioning was by stand-alone GPS, using an Ashtech Aquarius dual-frequency P-code receiver. A good satellite constellation status was observed throughout the survey. The patch test was conducted in Suva, Fiji, using RTK GPS.

3.6 Survey Computer

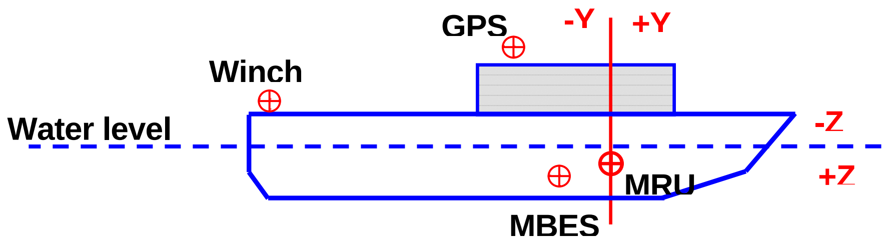
The survey computer was a Windows 2000 PC running Hypack 4.3. This computer was used for continuous on-line data logging and computation of positioning and digital bathymetry. The package also provided a line control display for the helm. The on-line operator continuously monitored a range of quality control parameters.

An off-line Hypack 4.3A 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 full-size charts (841 x 1189 mm).

ensor	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	1.82
Positioning Antenna (GPS)	1.92	–6.92	–6.29
Multibeam Echo Sounder (MBES)8160	0.86	–3.96	1.52
Multibeam Echo Sounder (MBES)8101	–2.15	–2.82	1.34
Winch	–14.29	1.92	3.00



Vessel	
Name	Summer Spirit
Length overall	25 m
Breadth (mid)	6 m
Draft (mid)	2.5 m
Displacement	65 t
Port of registry	Brisbane
Registration No.	IQ115Q
Call Sign	3DTF
Vessel Type	Mono-hull motor yacht



Not to scale

3.7 Multibeam Echosounder

A Reson SeaBat 8160 and 8101 multibeam echosounder (MBES) was temporarily installed on MV *Summer Spirit*, 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 pre-operational calibration (patch test and bar check) were performed in accordance with procedures contained in USACE (2002). The main instrumental and operating parameters are listed below.

Instrumentation Item	Reson SeaBat 8160	Reson SeaBat 8101
Transducer mount	Starboard hull-mounted	Port side hull-mounted
Motion reference unit	TSS DMS 2-05 Dynamic Motion Sensor	TSS DMS 2-05 Dynamic Motion Sensor
Gyro	SG Brown Meridian Surveyor Gyro Compass	SG Brown Meridian Surveyor Gyro Compass
Sound velocity probe at transducer	Installed	N/A

Operating Parameters	Reson SeaBat 8160	Reson SeaBat 8101
Transducer frequency	50 kHz	240 kHz
General water depth	10–2500 m	0–250 m
Average ship's speed	7 knots (3.6 m/s)	7 knots (3.6 m/s)
Transmit power	Variable 1–16	Variable 1–16
Pulse length	Variable 0.5–10.0 ms	Variable 0.5–10.0 ms
Horizontal coverage	Approximately two times water depth	Approximately two times water depth
No of beams / beam spacing	126 / 1.5 °	101 / 1.5 °
Ping rate	Variable, maximum of 4 Hz	Variable, maximum of 4 Hz

Dynamic Offset Calibration	Vanimo, 12/06/2006. Reson 8101	Suva, 25/04/2006. Reson 8160
Roll correction	–1.60	–1.30
Pitch correction	–2.00	–1.00
Yaw correction	–1.00	0.00
GPS Latency correction	0.00	0.40
Gyro correction	Not determined	Not determined

3.8 Multibeam Echosounder Data Processing

Upon return to the SOPAC office in Suva, Hypack 4.3A software was used for the post-processing of the MBES survey data. The production of contour maps was done using surfer 8.05 software. The processing and gridding sequences are listed in Table 6 and Table 7.

Table 6. Post-Processing Sequence

Phase 1	Tidal and sound velocity corrections. Navigation checked for poor GPS positioning.
Phase 2	Removed poor-quality beams (quality<3) and outliers from individual survey lines.
Phase 3	Applied 4th standard deviation filter to remove outliers from median depth. Further manual cleaning of outliers.
Output	ASCII XYZ file using actual positions of median sounding depths in the project coordinate system.

Table 7. Map Production Sequence

Input	XYZ output data from Hypack reduced to 1 mm at charting scale (e.g. 50 m grid size for a chart at 1 : 50 000).
Surface Model	XYZ output data were gridded using the Kriging method in Surfer 8.05. Data gaps were interpolated using three times the grid spacing.
Output	DXF contours, PDF chart, backdrop images, and DTM model in the project coordinate system.

Various levels of smoothing were applied to the contours and DTM, which gave a realistic impression of the seabed without removing any real features from the data set.

3.9 Multibeam Backscatter

The MBES records echo strength data (reflected energy) that can be presented as seabed backscatter maps, similar to sidescan sonar mosaic, or backscatter image, showing information on the composition of the seafloor. The backscatter signal recorded along with the MBES data was of good quality in the lagoon and was therefore processed and interpreted. Processing was done using a custom Python script developed at SOPAC by Dr Yosup Park, with technical and financial assistance from the Korean Foundation for International Cooperation of Science and Technology, KICOS. Final resolution of the mosaicked geotiff image was 0.2 m per pixel.

3.10 Tidal Information

Soundings were reduced to the Majuro Datum defined as 1.0510 m below mean sea level (MSL 11/68 – 5/69), and 2.6535 m below the fixed height of Benchmark MAR 2 (Figure 15), using observed water levels from the Majuro Atoll tide gauge provided by the Australian Bureau of Meteorology (http://www.bom.gov.au/oceanography/) through the South Pacific Sea Level and Climate Monitoring Project (http://www.pacificsealevel.org/).

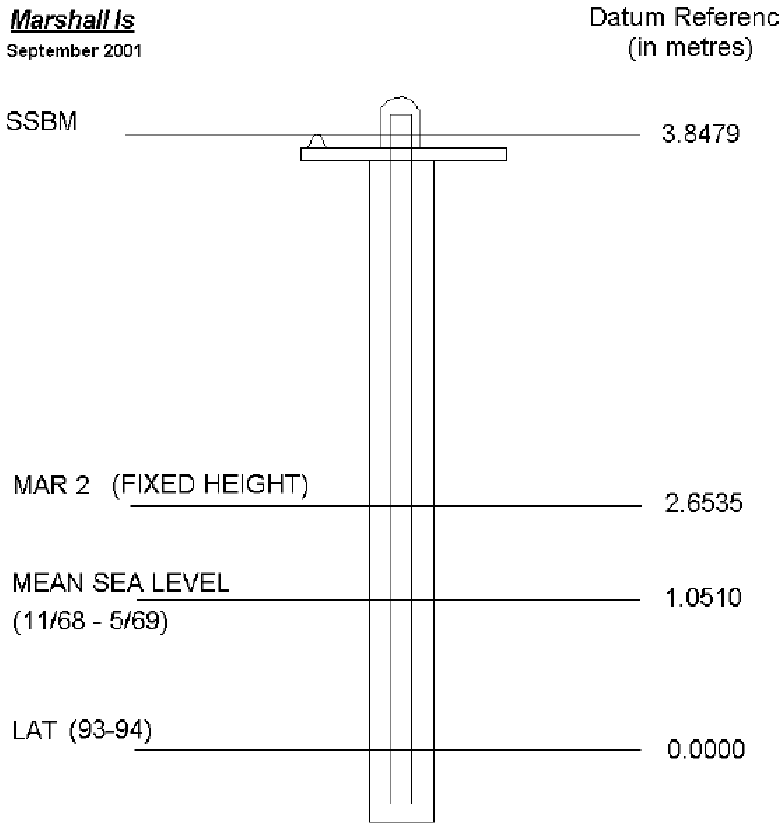


Figure 15. SEAFRAME tide gauge datum definition and other geodetic levels at Majuro (from NTFA 2005).

3.11 Sound Velocity Profiling

The accuracy of the depth soundings depends in part on the variation of the speed of sound with water depth. Sound velocity profiles are therefore required in order to find the correct depth and location of water depth soundings. The speed of sound in seawater varies with temperature, salinity and depth, and was determined by measuring the conductivity, temperature and depth (CTD) through the water column. The main instrumental, operational, processing parameters are listed below.

CTD Instrumentation	
Make	SeaBird Electronics
Model	SeaCat 19+ (self-powered, self-contained)
Serial number	4716
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	Average data into 1 m depth bins. No filtering was applied.
Output	Processed data is saved in ASCII text format with the file name date_location_bin.cnv.

The CTD profile details are listed in Table 8, and locations are shown in Figure 16.

Table 8. CTD Profile Details

Profile location	Date	Time	Easting	Northing	Depth (m)
South-side offshore	23/07/06	12:45	525852.9	77768.9	1100
Offshore-Calalin	24/07/06	16:27	525656.74	793093.7	1180
South of Calin pass	26/07/06	16:53	522385.26	787311.26	46.5
Central lagoon	26/07/06	17:43	533392.53	787225.99	54

The on-board CTD probe could only be operated to maximum depth of 400 m due to restrictions on the wire rope length. The ship-based profile data were complemented with an external source of sound velocity data, in order to ensure corrections for depth soundings exceeding 400 m. This source consisted of predicted sound velocity profile from the Generalised Digital Environmental Model (GDEM). The GDEM is a global climatology model developed by the U.S Naval Oceanographic Office and provides a monthly temperature, salinity, and sound velocity profiles on a global ¼ degree grid (https://128.160.23.42/gdemv.html). Parameters of this source are shown in Table 9.

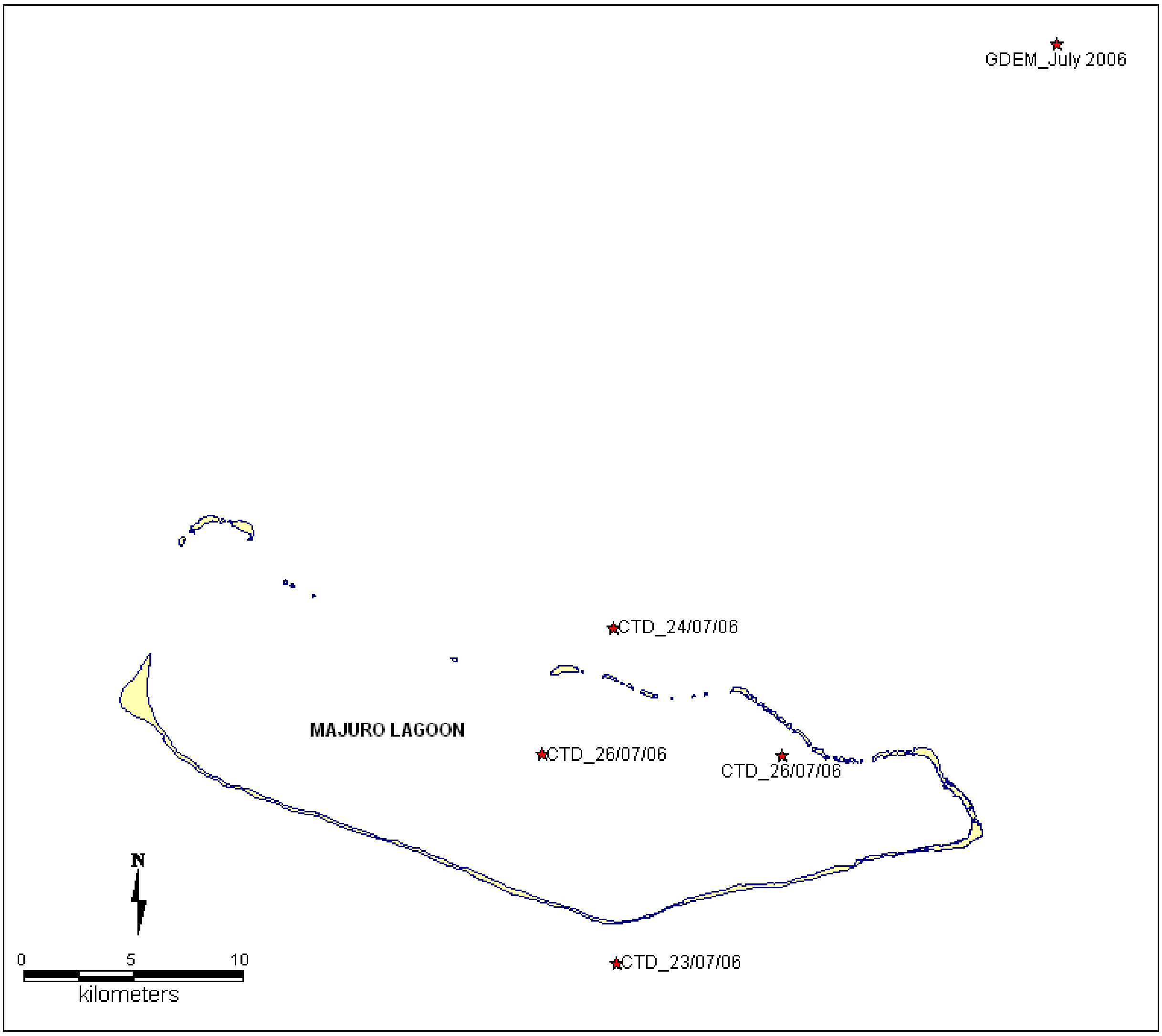


Figure 16. Map showing the locations of CTD and GDEM profiles.

Table 9. Generalised Digital Environmental Model Data (GDEM)

Data file version	3.0, URL accessed on 3/04/2006
Date	Monthly average for July
Latitude	7.25 N
Longitude	171.25 E
Easting	545979.62
Northing	819831.92
Available data	Depth, temperature, salinity, sound velocity
Bin size	From 10 to 100 m, increasing with depth
Maximum depth	2400 m

The final sound velocity profiles used to correct MBES data were therefore a construction from two sources as summarised in Table 10. A plot of the sound velocity data of the various sources is shown in Figure 17.

Table 10. Sound Velocity Profiles

Sound Velocity Data Source	Water Depth
CTD casts	0 to < 400 m
GDEM model	400 to 2400 m

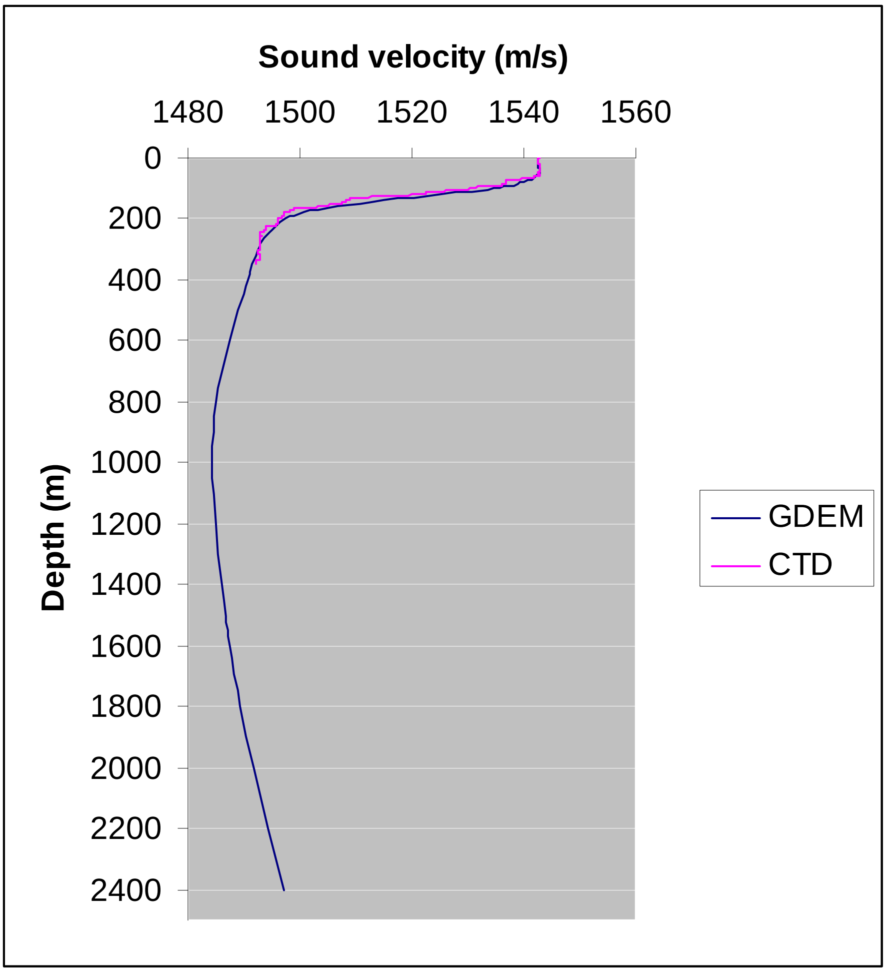


Figure 17. Example plot showing the sound velocity profiles used for MBES data correction.

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Generalised Digital Environmental Model. GDEM. https://128.160.23.42/gdemv/gdemv.html

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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 a 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 consequently 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 measurements 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 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 depth increases. The relevant survey orders are listed in Table A1.1, with multibeam surveys conducted by SOPAC generally falling into orders 2 and 3.

Table A1.1. Recommended Accuracy of Survey Orders

Survey order	Application	Recommended 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 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 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 A1.1). The swath of seabed covered by this transmit beam is typically 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. The 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.

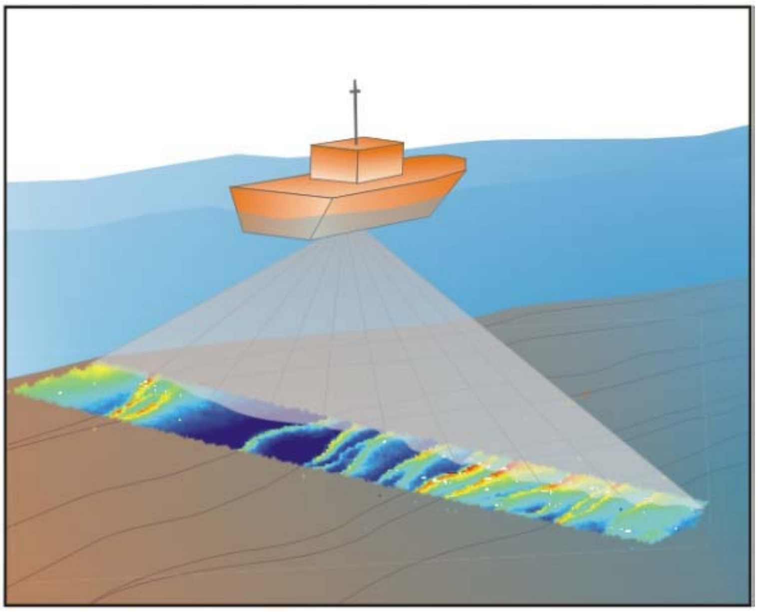


Figure A1.1. Conceptual illustration of bathymetric data acquisition with a multibeam echosounder, MBES (source: http://www.rcom.marum.de, accessed 10/01/2007)

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" (Table A1.2) that 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.

Table A1.2. Values for Calculating Error Limits for Depth Accuracy.

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 error of ± 1.1 m.

An 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.

A1.3 Error budget analysis for 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 may be accurate 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. 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 and 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. 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	Uncertainties 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 listing above, it is estimated that the measured depths in 20 m have an accuracy of ± 1.5 m. 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.

A1.4 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 bottom 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 furthermost point imaged. 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 a larger projected footprint as the water depth increases. 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.

Table A1.3. Projected Footprint Size under Varying Water Depths

Water depth	SeaBat 8160 (deep water) 50 kHz, 126 beams at 1.2 °		SeaBat 8101 (shallow water) 240 kHz, 101 beams at 1.5 °	
(m)	Inner footprint, nadir (m)	Outer footprint (m)	Inner footprint, nadir (m)	Outer footprint (m)
20	0.4	5.8	0.5	3.5
50	1.0	14.4	1.3	17.6
100	2.1	28.8	2.6	35.3
200	4.2	57.6	5.2	70.6
500	10.5	143.9	N/A	N/A
1000	20.9	287.9	N/A	N/A
1500	31.4	431.8	N/A	N/A

Table A1.2 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 of the order of the average beam footprint size, typically 10% of the water depth.

A1.5 Multibeam echosounder backscatter

The MBES records echo strength data (reflected energy) that can be presented as seabed backscatter maps, similar to sidescan sonar. The final sidescan sonar mosaic, or backscatter image, shows information on the composition of the seafloor. The backscatter intensity is largely a function of the properties of the superficial seafloor material, particularly the physical shape of individual components, and the angle of incidence of the sonar beam as it encounters a reflective surface. For example, soft marine muds absorb part of the sound energy, thereby muting the reflected signal, whereas a strong echo may indicate a rock outcrop or coral reef.

The effectiveness of this system can be gauged primarily by the following variables: range, detectability, resolution and plotting accuracy. Range is a fundamental property and is governed by the water depth in the survey area, as the system is ship mounted. The range will affect the other variables; with an increase in range generally degrading the other three.

Resolution, both vertical and horizontal, is affected by most of the factors mentioned. Resolution is directly affected by the data density, and has been discussed in detail above. In favourable weather conditions and a water depth of 20 m, the backscatter data can often show objects that might ideally be measured to the nearest metre horizontally. Ship-mounted sidescan sonar systems are generally not suitable to measure height of a detected object. Under poor sea conditions and a water depth of 100 m however, the data may fail to show a one-metre diameter pipeline on the seafloor, more so if ship track is perpendicular to the pipe rather than parallel. Similarly, resolution between adjacent objects would be less accurate still.

It has been shown that the detectability is determined by a number of factors, none of which are very easy to quantify. In practical terms detectability is determined by the shape, attitude, size and hardness of the target, its range, the vessel's speed, the complexity and reflection strength (i.e. backscatter) of the surrounding seabed and the water depth. Water depth, together with the prevailing weather, largely determines the amount of interference from sea and vessel noise. In some circumstances transient factors, such as the presence of fish shoals can further reduce detectability.

Plotting accuracy is also problematic, and the limitations that apply are the same as those mentioned under horizontal and bathymetric positioning above.

Sonar images (backscatter) are typically resolved with a pixel size of 5% of the water depth.

Appendix 2 – Ship Track and Data Coverage

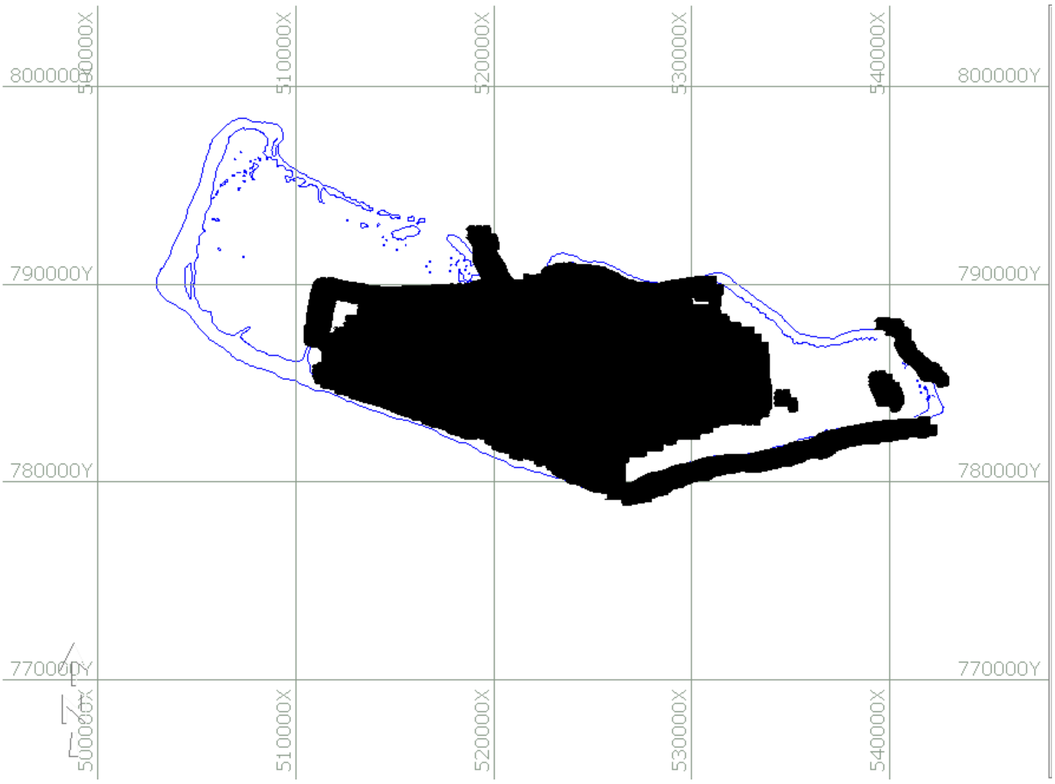


Figure A2.1. Map showing the SOPAC/EU MBES Reson 8101 5-m grid coverage for Majuro.

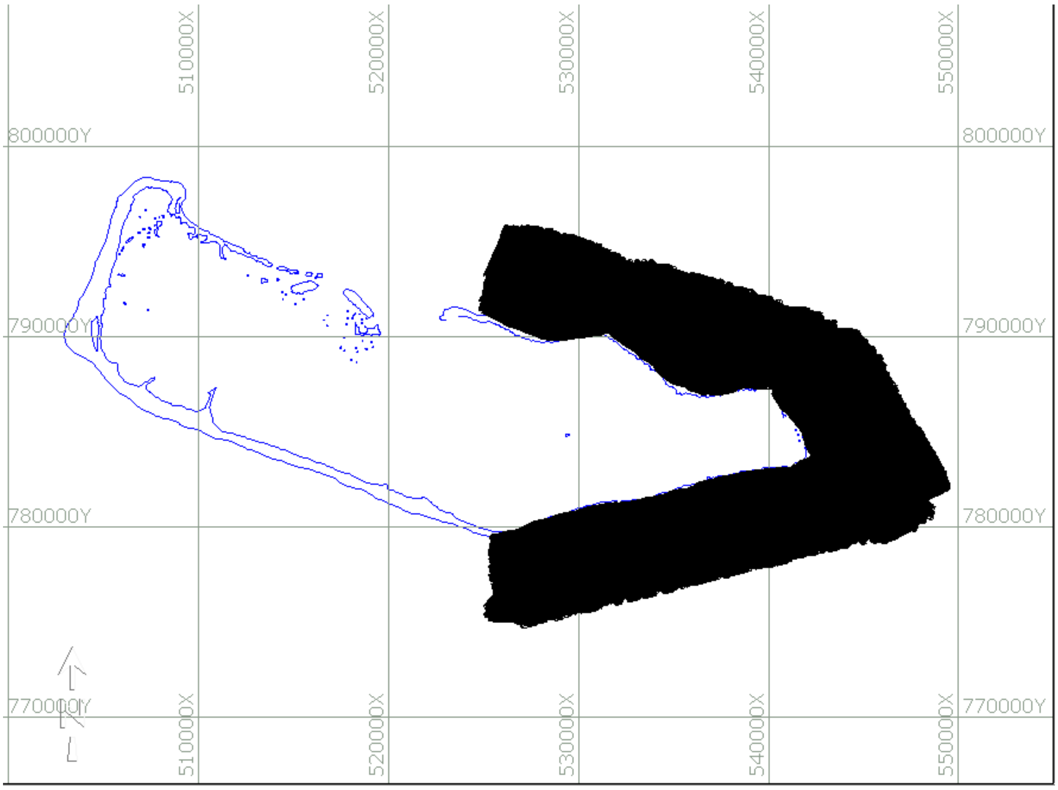


Figure A2.2. Map showing the SOPAC/EU MBES Reson 8160 coverage for Majuro. Data density varies from a few metres in the shallow nearshore to tens of metres in the deeper offshore area.

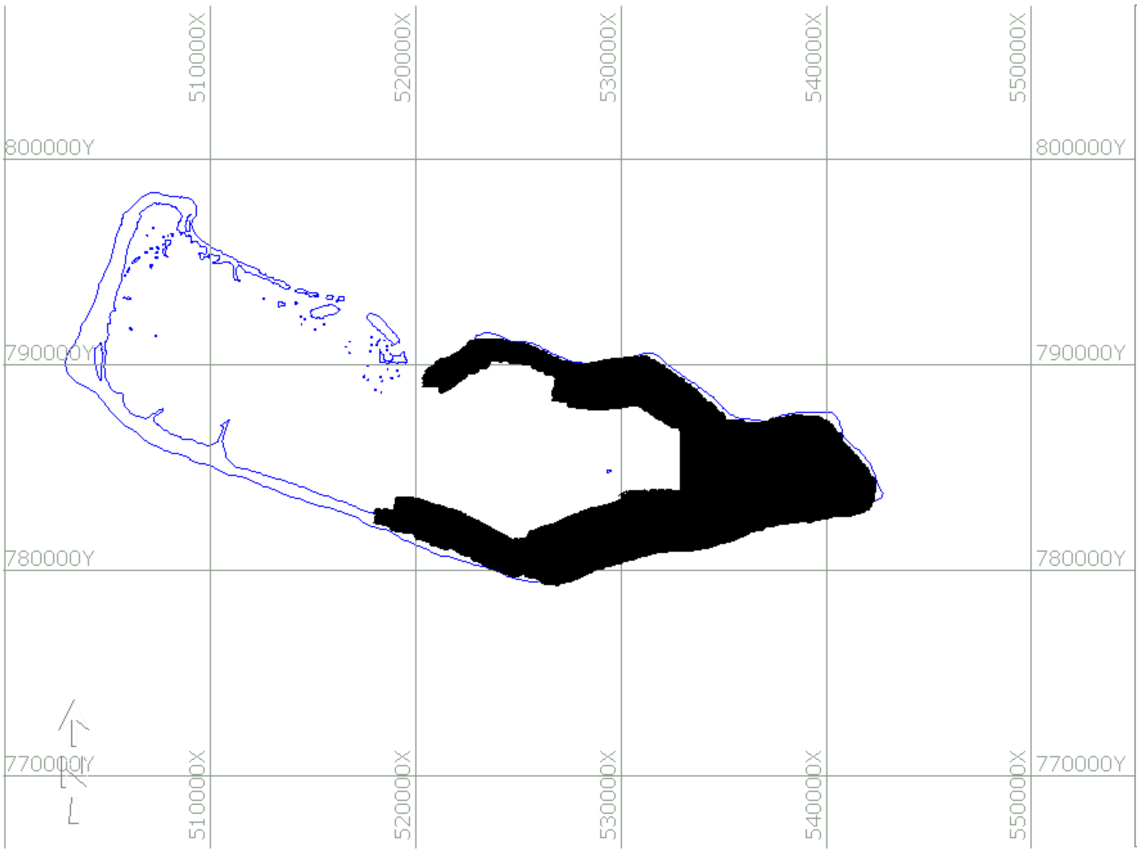
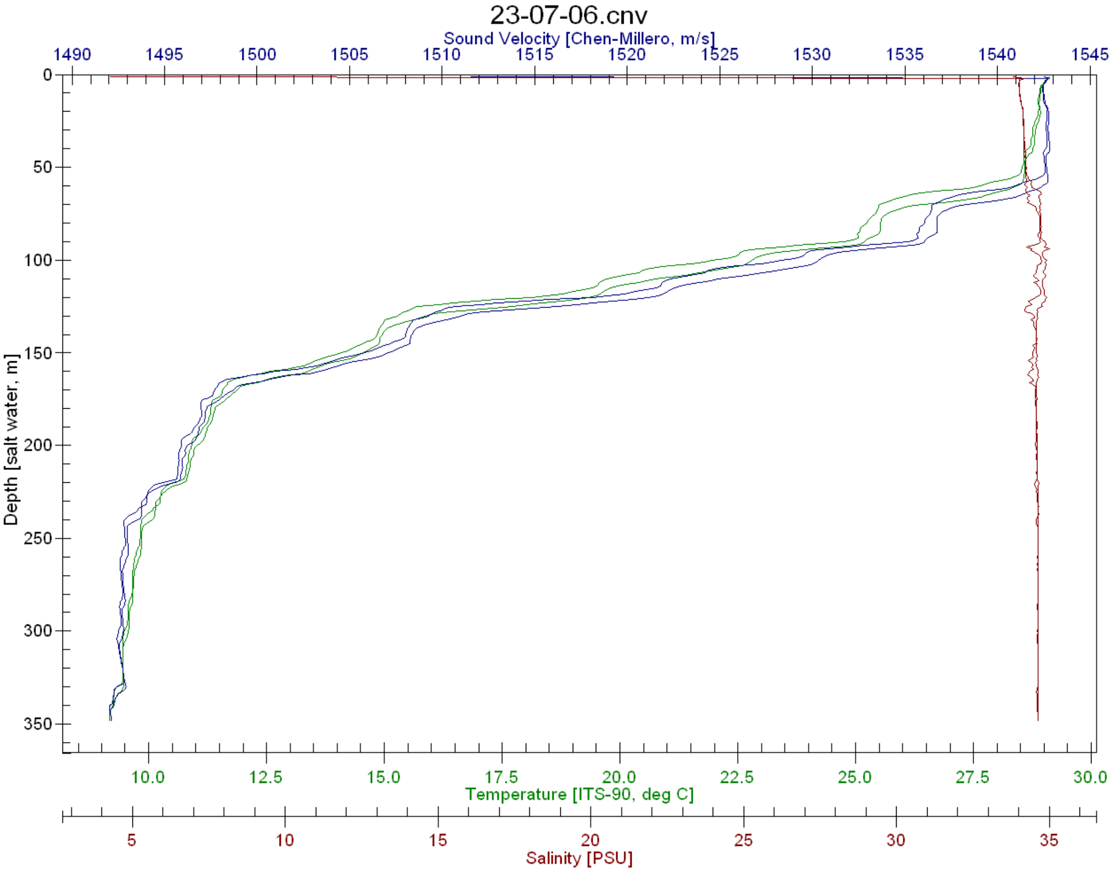
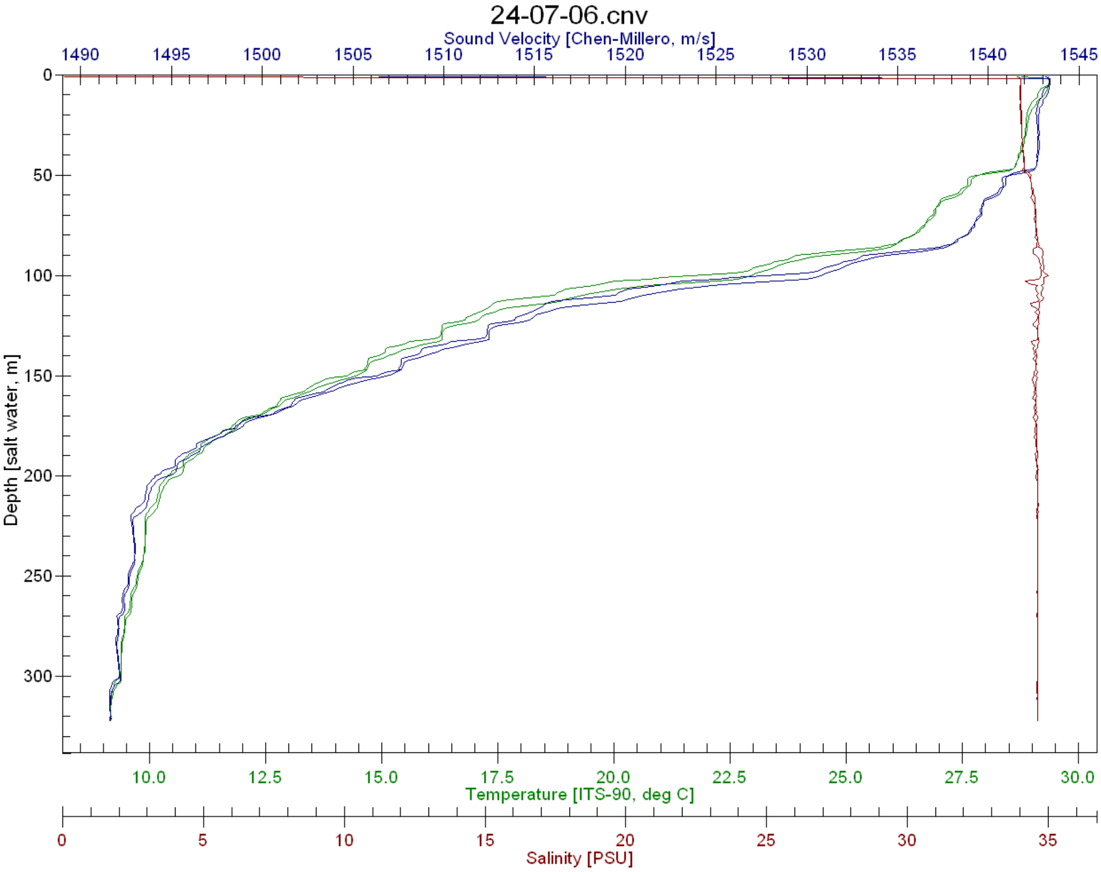
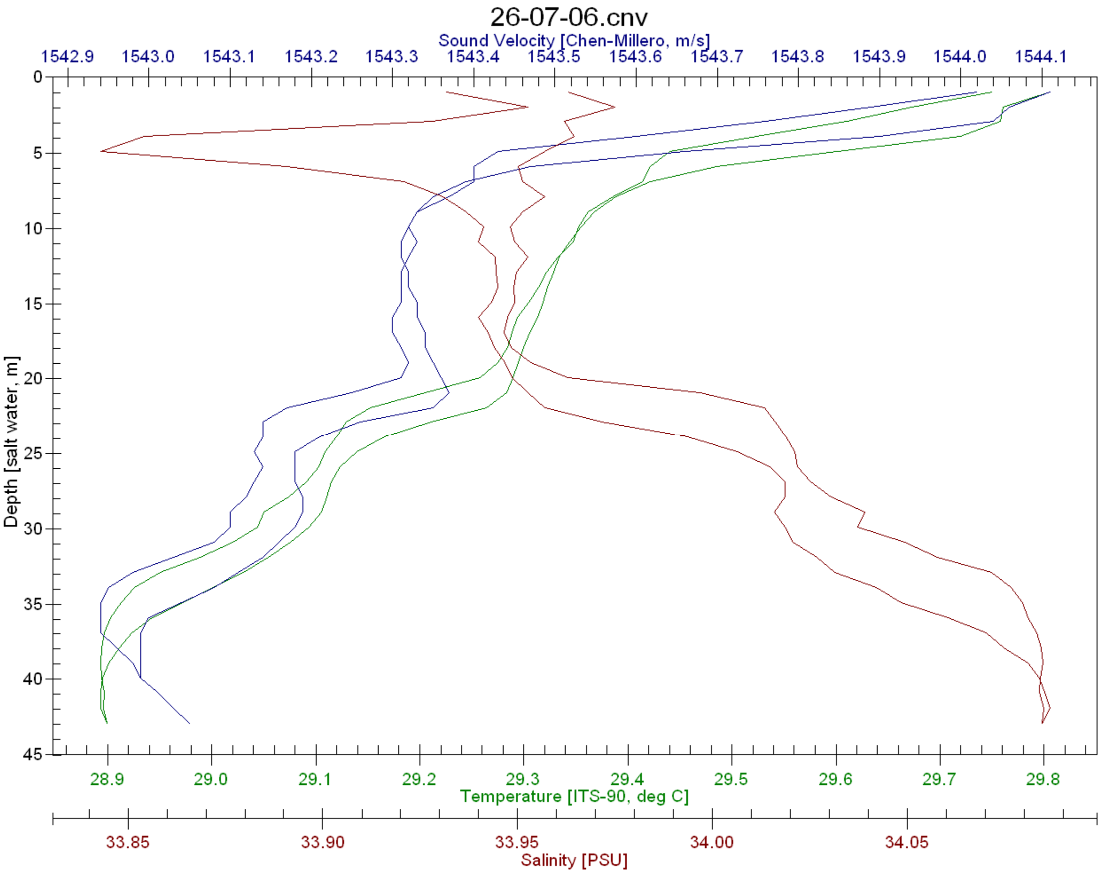


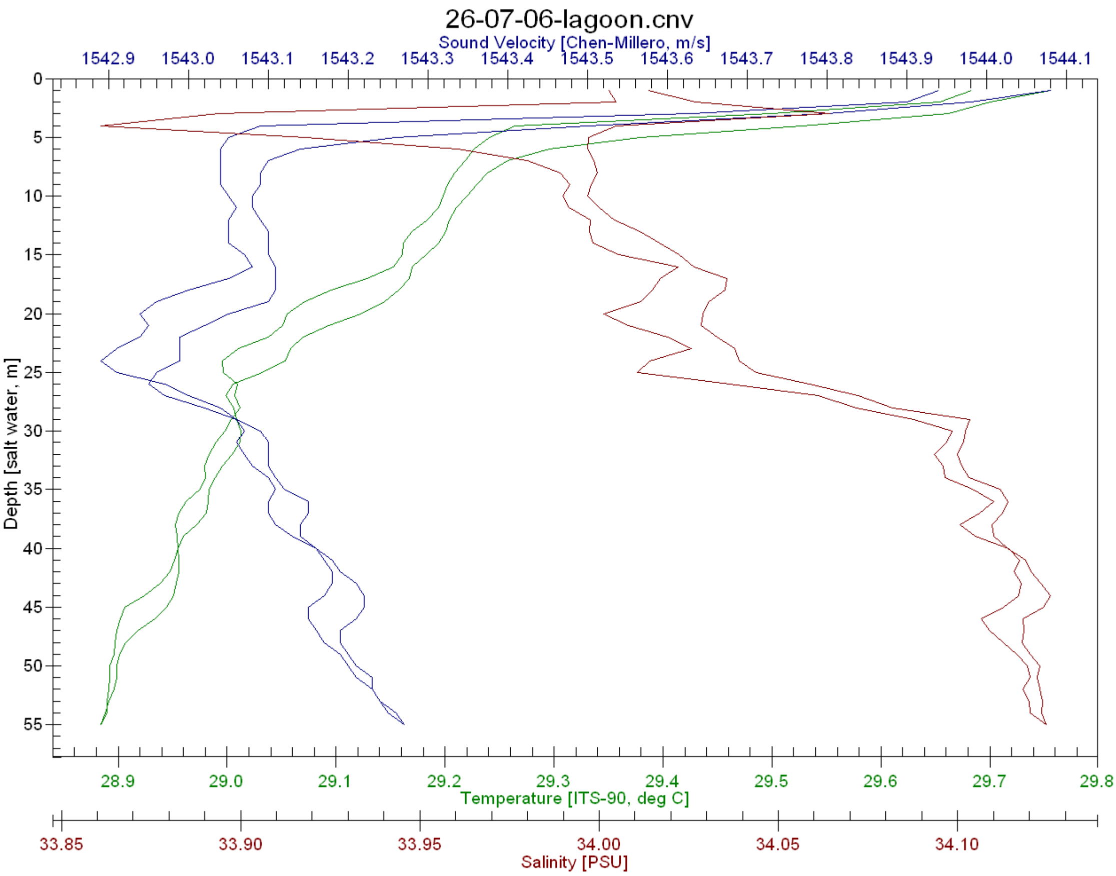
Figure A2.3. Map showing the SOPAC/EU 1995 MBES Reson 8101 coverage for Majuro.

Appendix 3 – CTD Profiles






26-07-06.cnv
Sound Velocity [Chen-Millero, m/s]
1542.9 1543.0 1543.1 1543.2 1543.3 1543.4 1543.5 1543.6 1543.7 1543.8 1543.9 1544.0 1544.1
Depth [salt water, m]
0 5 10 15 20 25 30 35 40 45
28.9 29.0 29.1 29.2 29.3 29.4 29.5 29.6 29.7 29.8
Temperature [ITS-90, deg C]
33.85 33.90 33.95 34.00 34.05
Salinity [PSU]


26-07-06-lagoon.cnv
Sound Velocity [Chen-Millero, m/s]
1542.9 1543.0 1543.1 1543.2 1543.3 1543.4 1543.5 1543.6 1543.7 1543.8 1543.9 1544.0 1544.1
Depth [salt water, m]
0 5 10 15 20 25 30 35 40 45 50 55
28.9 29.0 29.1 29.2 29.3 29.4 29.5 29.6 29.7 29.8
Temperature [ITS-90, deg C]
33.85 33.90 33.95 34.00 34.05 34.10
Salinity [PSU]

Appendix 4 – High-Resolution A0 Charts, Majuro 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 A4 representations follow.)

Chart No	Title	Scale	Drawing No.
1	Majuro, Bathymetry	1 : 50 000	ER117.1
2	Majuro lagoon multibeam backscatter	1 : 25 000	ER 117.2

Appendix 5 – SOPAC Multibeam Online Line Log (8101)

	Installation Offsets			Calibration Offsets			
Device	X	Y	Z	Yaw	Pitch	Roll	Lat
GPS	1.92	-6.92	-6.29				0.00
Gyro				N/A			0.00
MRU	0.00	0.00	1.28		0.00	0.00	0.00
MBES Head	-2.15	-2.82	1.34	-1.00	-2.00	-1.60	0.00

Hypack Project:	RMI-MAJURO
Country:	RMI-MAJURO
Area:	MAJURO
Vessel:	R.V.Summer Spirit
MBES System:	8101 RESON
Positioning:	

Patch test performed in Vanimo, PG, 12/06/06

Date	Location	Line No.	Time SOL	Time EOL	Fix SOL	Fix EOL	HDG	SPD	Filename (.HSX)	Log File (.LOG)	Line QC	Comments / Online changes
19/07/2006		2	17:21		202	219	152		002_1721			line in structual -with seismic
		2	00:00		220	226	152		002_1729			same line just stop and start
		3	17:39		227	241			003_1739			noise in data from fishing boats nearby
												acoustic noise from vessel bad
20/07/2006	Ajitake	1	14:19	14:58	366	441	289	4	001_1419			Ajeltake lnw (30 second fix)
	Ajitake	6	15:03	15:30	442	469	109	5	006_1503			60-sec fix used this line
	Ajitake	8	15:39	15:50	470	481	200.5	5	008_1539			
	Ajitake	4	15:52	16:00	482	491	31	5	004_1552			
21/07/2006	majuro lagoon	14	08:03	09:26	1	16	269	7	014_0803		sk	360 sec fix
		16	09:36	10:52	17	31	93	8	016_0935		sk	

		18	10:59	11:10	32	36	276	8	018_1059		sk	abondoned generator problem
22/06/2006	majuro lagoon	12	07:23	08:48	37	55	277	7	012_0723		sk	
		13	08:54	10:22	56	71	104	8	013_0854		sk	
		8	10:37	11:34	72	82	255	8	008_1037		sk	
		7_1	11:42	11:51	83	85	100	8	007_1142		sk	
	ajiltake	10	12:10	12:25	1	32	196	3	010_1210		AT	
		2	12;26	12:38	33	57	54	4	002_1226		AT	
		3	12:43	12:55	58	83	219	4	003_1243		AT	
		7	12:56	13:09	84	109	22	4	007_1256		AT	
		9	13:15	13:27	110	134	199	4	009_1315		AT	
		4	13:29	13:37	135	151	10	4	004_1329		AT	
		8	13:44	13:52	164	174	208	4	009_1347		AT	line 8/9 start/stop
	Ajeltake-ext	1	13:55	14:07	175	199	26	4	001_1355		AT	
	Ajeltake-ext	2	14:11	14:24	200	226	203	4	002_1411		AT	
	Ajeltake-ext	3	14:25	14:35	227	246	229	4	003_1425		AT	
	Ajeltake-ext	5	14:45	14:57	247	272	299	4	005_1445		AT	
	Ajeltake_300	2	15:49	16:03	273	277	84	7	002_1549		sk	gyro offline(ready light) 15:56 E275
		3	16:10	16;30	278	283	256	7	003_1610		sk	gyro back on..ready light16:04
		4	16:37	17:08	285	346	286	7	004_1637		sk	
23/07/2006	north lagoon end	24	07:21	08:01	347	356	269	8	024_0721		sk	
	Calalin Channel	25	08:02	08:20	357	362	28	8	025_0802		sk	Gyro ready light out e359 back e360
	Calalin Channel	23	16:45	17:03	455	459	172	7	023_1644		sk	

	lagoon	23	17:04	17:53	468	471	80	7	023_1704		sk	
24/07/2006	lagoon	22	06:43	07:21	472	481	273	8	022_0643		sk	
	offshore-southside	12	12:30	13:34	535	555	75	7.9	012_1229			line file offshore-east
		13	14:49	15:07	566	572	320	5	013_1449			top infill window in data
			Running 8101 inside lagoon									
	8101	25_1	17:27	18:09	591	600	89	8	25_1.raw			central-300 lnw
25/06/2006	lagoon	16	06:59	08:35	601	622	266.6	8.1	016_0659		sk	Central.lnw
	lagoon	17	08:38	10:12	623	643	90	8	017_0838		sk	
	lagoon	18	10:18	11:45	644	663	276	8	018_1018		sk	
		19	11:48	13:12	664	682	91	8	019_1148			
	area2	1	13:37	14:09	683	748	265	4	001_1337		sk	sesimic as well
	area2	4	14:20	14:25	750	761	358	4	004_1420		sk	sesimic as well
	area2	2	14:34	14:39	762	773	355	4	002_1434		sk	sesimic as well
	area2	3	14:49		774	777	13	4	003_1449		sk	problem with seismic e777
	lagoon	26	15:15	15:41	778	784	274	8	026_1515		sk	
		27	15:43	16:10	785	792	86	8	027_1543		sk	
		28	16:12	16:38	793	799	274	8	028_1612		sk	
		29	16:40	17:05	800	806	90	8	029_1640		sk	
	seismic line	3	17:28	17:35	807	823	348	3	003_1728		sk	rerun seismic line 3
26/07/2006	lagoon	14	06:57	08:28	824	843	274	8	014_0657		sk	
		15	08:29	10:03	844	864	52	8	015_0829		sk	e857 gps spike

		20	10:10	11:13	865	878	270	8	020_1010		sk	program crash end line restart
		20	11:24	11:50	879	886	270	8	020_1124		sk	
	around entrance ch	28_1	11:52	12:45	887	899	var	var	28_1		sk	
		27	12:51	13:28	900	908	var	var	027_1250			
		26	13:30	14:02	909	916	86.7	7	026_1330			
		25_1	14:07	14:39	917	924	268	7.4	25_1A			
		24	14:42	15:16	925	932	84	7	024_1442			
		23	15:19	15:58	933	942	270	7	023_1519			
		22	16:03	16:48	943	953	90	7	022_1603			
		21	17:01	17:43	954	963	90	7.9	021_1701			
27/07/2006	southern endof lagoon	11	06:57	08:32	964	984	279	8	011_0657		sk	central-300 lnw
	central-300 lnw	32	08:41	09:57	985	1001	94	8	032_0841		sk	central-300 lnw
	central-300 lnw	33	10:05	11:17	1002	1017	280	8	033_1005		sk	central-300 lnw
	central-300 lnw	7	11:21	12:21	1018	1032	109	8	007_1121			central-300 lnw
	central-300 lnw	6	12:37	13:18	1033	1042	270	7.5	006_1237			central-300 lnw
	central-300 lnw	5	13:24	13:52	1045	1050	90	8	005_1324			
	central-300 lnw	39	14:08	14:24	1051	1056	misc		039_1408			line start opp Peace Park
	central-300 lnw	38	14:32	14:39	1057	1059	105	8	038_1432			
	central-300 lnw	37	14:41	14:48	1060	1062	275	8	037_1441			
	central-300 lnw	34	14:51	14:58	1063	1065	98.5	8.1	034_14:51			
	central-300 lnw	36	15:00	15:09	1066	1068	270	7.5	036_1500			
	central-300 lnw	1	15:11	15:19	1069	1071	90	8.1	001_1511			
	central-300 lnw	21	15:50	16:38	1072	1083	270	7.7	021_1550			

	central-300 lnw	misc	17:14	17:15	1084	1086	33.5		30_1			miscellanoues line on route to line 30-1
	central-300 lnw	30_1	17:32	17:41	1087	1092	90	8	30_1			
		31	17:48	17:58	1093	1096	264	8.4	31_1748			
		32	18:00	18:14	1097	1100	73	8	32_1800			
28/07/2006	miscellanous		08:38	08:47	1101	1104			000_0838			vel 0n system set to 1544m/sec
	bar-check											average measured vel lagoon 1543.8
20/07/2006	ajeltake	1	10:48						001_1048			
		2	10:52						001_1052			
		3	11:09						002_1109			
		4	11:28						003_1128			
		5	11:41						004_1141			
		6	12:15						001_1245			
		7	12;38						002_1238			
		8	12;57						003_1257			

SOPAC MULTIBEAM ONLINE LINE LOG (8160)

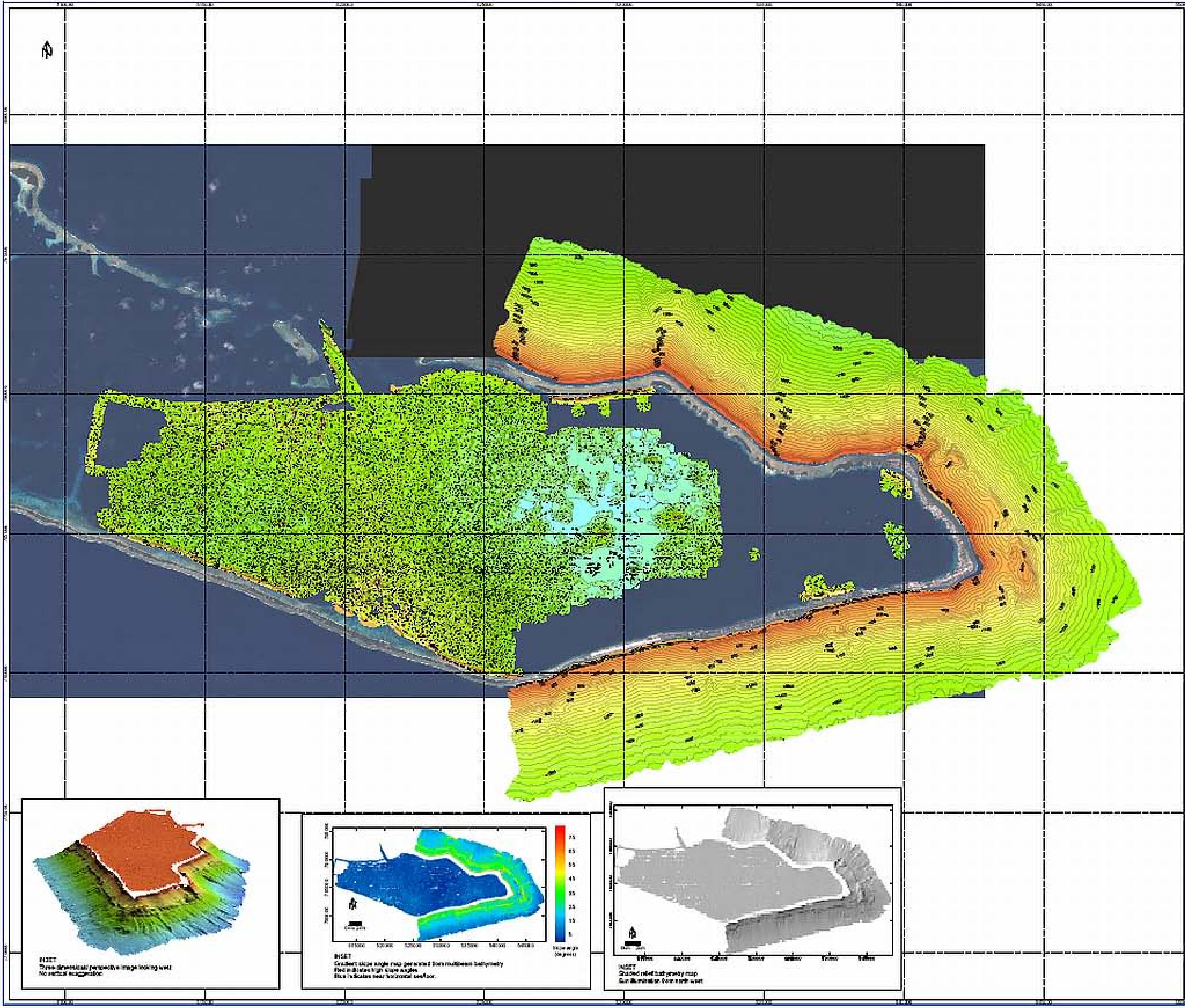
	Installation Offsets			Calibration Offsets			
Device	X	Y	Z	Yaw	Pitch	Roll	Lat.
GPS	1.92	-6.92	-6.29				0.40
Gyro				N/A			0.00
MRU	0.00	0.00	1.28		0.00	0.00	0.00
MBES Head	0.86	-3.96	1.52	0.00	-1.00	-1.30	0.00

Hypack Project:	
Country:	RMI
Area:	Majuro
Vessel:	Summer Spirit
MBES System:	8160
Positioning:	Stand Alone GPS

Patch test performed in Suva on 25/04/2006

Date	Location	Line No.	Time SOL	Time EOL	Fix SOL	Fix EOL	HDG	SPD	Filename (.HSX)	Line QC	Comments / Online changes
23/07/2006	offshore north end	2	08:57	10:00	363	377	103	8	002_0857		Line file offhore-east
		3	10:11	10:34	378	383	138	7.7	003_1011		noisy data -appears turbulence at the corner
		4	10:40	10:44	384	386	386		004_1039		gyro -ready light out abort..
		4	11:04	12:26	387	405	266	6.8	004_1104		restart although gyro light out on @ 11:28:56
		5	12:56	14:27	406	425	70	7	005_1256	sk	
		7	14:28	15:02	426	434	44	7	007_1427	sk	

		1	15:14	16:20	435	453	267	7	001_1514	sk	
24/07/2006	offshore	2	08:18	08:25	482	485	116	7	002_0818	sk	engine problem 08:25
		2	08:35	10:05	486	505	105	5	002_0835	sk	E489 gps spike
		8	10:07	10:48	506	515	172	7	008_1007	sk	
		6	10:50	12:17	516	536	217	7	006_1050	sk	
		11	13:48	13:58	556	559	255	7.4	011_1347		window -infill line 11
		10	14:19	14:35	560	565	327	8	010_1419	sk	
		9	15:13	16:19	573	590	262	7	009_1513	sk	



LEGEND

Bathymetric contours in metres

Colour Banding Bathymetry Metres Ocean	Colour Banding Bathymetry Metres Lagoon
50	10
300	20
550	30
800	40
1050	50
1300	60
1550	70
1800	80
2050	90
2300	100

NOTES

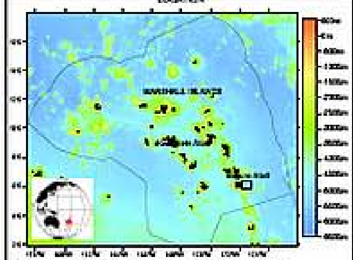
Observed soundings have been reduced to Chart Datum using the Admiralty Tide Tables (Majuro Atoll), Volume 4, 2008, Pacific Ocean, UK Hydrographic Office.

Date of Survey	16/07 to 29/07/08
Acquisition system 1	Reson SeaBat 8160 multibeam echosounder
Acquisition system 2	Reson SeaBat 8101 multibeam echosounder
Collection software	Hypack 4.3
Processing software	Hypack 4.3A
Data presentation	Surfer 8.00
Survey vessel	M.V. Summer Spirit
Date of Survey	22/07 to 29/07/2002 (western lagoon)
Acquisition system	Reson SeaBat 8101 multibeam echosounder
Collection software	Hypack
Processing software	Hypack
Data presentation	Surfer 8.00
Survey vessel	Local vessel

Backdrop image is a rectified IKONOS satellite image taken on 29/05/2001

NOT TO BE USED FOR NAVIGATION

LOCATION



Solid line illustrates approximate boundary of Marshall Islands EEZ.
Bathymetry from: S2004 bathymetry - Marks, K.M., and W.H.F. Smith, 2006.
An evaluation of publicly available global bathymetry grids. Marine Geophysical Researches, 27, 19-34.

GEODETIC INFORMATION

Geodetic datum	WGS84
Ellipsoid	WGS84
Projection	UTM Zone 59 North
Horizontal positioning	Stand alone GPS

SCALE

Scale 1 : 53 000

0 1000 2000 3000 4000
Metres

A3 Original

SOPAC

PACIFIC ISLANDS APPLIED GEOSCIENCE COMMISSION
Private Mail Bag, GPO, Suva, Fiji Islands
www.sopac.org

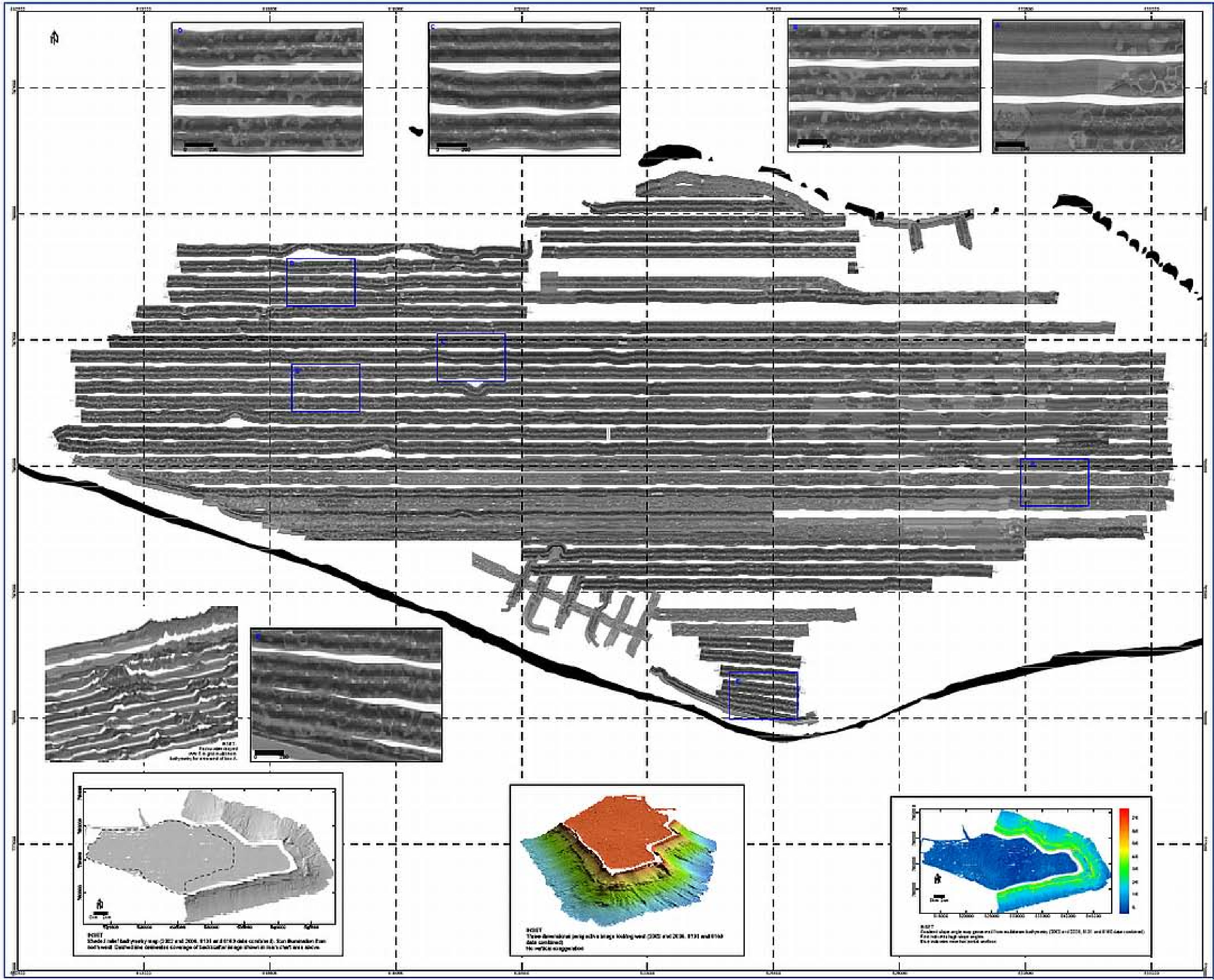
SOPAC/EU Project
Reducing Vulnerability of Pacific ACP States

DRAWING TITLE

MARSHALL ISLANDS
MAJURO

BATHYMETRY

Drawn by: Jens Kruger and Salesh Kumar.
Report Reference: ER117. Drawing No.: ER117.1



LEGEND

Land

Backscatter Magnitude

Low

High

NOTES

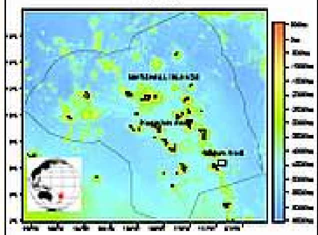
Observed soundings have been reduced to Chart Datum using the Admiralty Tide Tables (Majuro Atoll), Volume 4, 2006, Pacific Ocean, UK Hydrographic Office.

Date of Survey	[illegible]
Acquisition system	Reson SeaBat 8101 multi beam echosounder
Collection software	Hypack 4.3
Processing software	Hypack 4.3A
Data presentation	Surfer 8.02
Survey vessel	MV Summer Spirit

Original Backscatter mosaic at a resolution of 0.2 m / pixel. Boxed insets are shown at 1 : 4 000

NOT TO BE USED FOR NAVIGATION

LOCATION



Solid line illustrates approximate boundary of Marshall Islands EEZ.

GEODETIC INFORMATION

Geodetic datum	WGS84
Ellipsoid	WGS84
Projection	UTM Zone 59 North
Horizontal positioning	Standalone GPS

SCALE

Scale 1 : 35 000

Metres

A4 Original

PROJECT TITLE

SOPAC

PACIFIC ISLANDS APPLIED GEOSCIENCE COMMISSION

Private Mail Bag, GPO, Suva, Fiji Islands

www.sopac.org

SOPAC-EU Project

Reducing Vulnerability of Pacific ACP States

DRAWING TITLE

MARSHALL ISLANDS
MAJURO LAGOON

MULTIBEAM BACKSCATTER