

# BATHYMETRY OF NEAR-SHORE ZONES IN RONGELAP ATOLL, MARSHALL ISLANDS USING SATELLITE IMAGERY

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**Abstract** – Large-scale mapping of remote coral reefs requires a sensor that offers imagery with the spatial, spectral, and radiometric resolution suitable for processing large datasets of shoreline and near-shore regions. This study tests the viability of ASTER imagery in deriving accurate bathymetry of near-shore zones in Rongelap, an atoll in the Marshall Islands. A depth estimation algorithm was developed by calculating the ratio between two bands of reflectance data from the ASTER image and estimates depth of the near-shore zones based on the ratio. A dataset of geopositioned *in situ* measurements using RTK-GPS was obtained with sonar and sounding lines to a depth of 30m. The depth estimates were then compared to the *in situ* depth readings as a basis for determining accuracy and sensitivity of the ASTER-based ratio algorithm. The results from the ASTER-based ratio algorithm indicate the importance of using blue band reflectance data in satellite-based bathymetric modelling.

**Keywords** – Bathymetry, Zone mapping, Satellite imagery, ASTER, Coastal and marine resources

## 1. INTRODUCTION

Shallow coastal bathymetric information is important for navigation, coastal managers and developers, and to better understand the functioning of shallow marine ecosystems. Bathymetry in remote parts of the Pacific, such as Rongelap Atoll in the Republic of the Marshall Islands (RMI) is relatively imprecise, and the remoteness of coral atolls hinders field measurements. The extant bathymetry data for Rongelap, as for other Pacific Atolls, is either outdated or incomplete. Bathymetry data of intertidal zones and reef crests flooded with shallow water is especially useful for habitat suitability analysis in coral reef ecosystems and fluid dynamic modelling (Peterson, 2008), but difficult access to these atolls makes field data acquisition prohibitively expensive. A method for obtaining bathymetry of Rongelap efficiently and accurately, without the logistical challenges and expense of *in situ* observation is therefore necessary.

Earlier work in satellite-derived bathymetry include a method developed for Hawaii's coral reef atolls using IKONOS satellite images (Stumpf et al, 2003). The study identified fine depth gradients in shallow areas (up to 4m deep) and in deeper regions of the atoll including the lagoon and fore reef. The algorithm uses a ratio of blue and green wavelengths and has been demonstrated to be sensitive for depths up to 25 meters.

The methodology in this paper applies the algorithm to ASTER imagery to investigate the viability of ASTER in offering comparable results in a geomorphologically similar environment. The ASTER VNIR (visible and near infrared) dataset differs from IKONOS in terms of spatial resolution (ASTER's pixels are larger at 15 m and therefore register less

spatial detail) and spectral resolution (ASTER'S VNIR imagery has no blue wavelength band).

ASTER imagery has previously been used in coral reef studies. These have included testing ASTER's ability to differentiate between water and land (Yamano et al, 2006) and its ability to map habitat types in a coral reef, to which it has achieved accuracy between 60-75%, depending on the number of habitats delineated for classification (Mumby et al, 2003).

## 2. MATERIALS and METHODS

*Study area*— The area under investigation in this paper is a 12km<sup>2</sup> region of Rongelap atoll centred at 11°11'N 166°53'E.

*Data*— Depth measurements were obtained *in situ* by sonar and sounding lines to a depth of 30 m and geopositioned using RTK GPS. Observations were corrected for local tide conditions. The ASTER image of Rongelap was recorded on January 2002 with radiance data in the VNIR bands in the green (0.52-0.60µm), red (0.63-0.69µm) and near infrared (0.78-0.86µm) wavelengths. The spatial resolution is 15 m with a radiometric resolution of 8 bits. Cloud does not exceed 15%.

*Model* – The adapted depth estimate equation for a given pixel in the ASTER imagery of Rongelap is:

$$d = \frac{m \ln(DN_g)}{\ln(DN_r)} \quad (1)$$

where d = depth in meters relative to the datum  
m = tuneable constant to scale the ratio to depth  
DN<sub>g</sub> = green band reflectance (digital number unit)  
DN<sub>r</sub> = red band reflectance (digital number unit)

The equation is universal for the water pixels in the study area.

*Method*— Atmospheric correction was executed using the FLAASH© module in ITT® ENVI, converting the radiance image to reflectance data. The depth estimate equation was implemented in ERDAS® Imagine via an algorithm modelling utility and processed with the green and red reflectance data. The depth estimate was applied to every pixel in the study area, excluding a land mask. Maximum likelihood classification was used in Imagine utilizing a subset of *in situ* measurements for classification training.

## 3. RESULTS and DISCUSSION

Figure 1a shows the seven depth classes generated with maximum likelihood classification. A small depth gradient is indicated by the shallow water classes (0-5 m) extending from

land towards the interior of the lagoon in a western direction, analogous to the reef flats and shallow water in these zones. A steep drop off is suggested on the eastern side of the atoll where a sharp demarcation between the land and deep water (>15m) is visible. Here the fore reef and deeper buttress zones are commonly found. The bathymetric classification generally corresponds to the known geomorphology of Rongelap in deeper water off shore and within the lagoon. But the initial bathymetric classification fails to detect shallow water reef pavements that surround and connect islets of dry land.

determine a bijective relationship between depth and ratio value. Beyond depths of approximately 15m, it is not possible to establish a one-to-one correspondence for reflectance ratio and depth. A ratio value therefore has a similar likelihood in being assigned to a shallow depth class and a depth class several orders away. Causes originating both in the coral reef environment and inherent to ASTER imagery itself can be responsible for this.

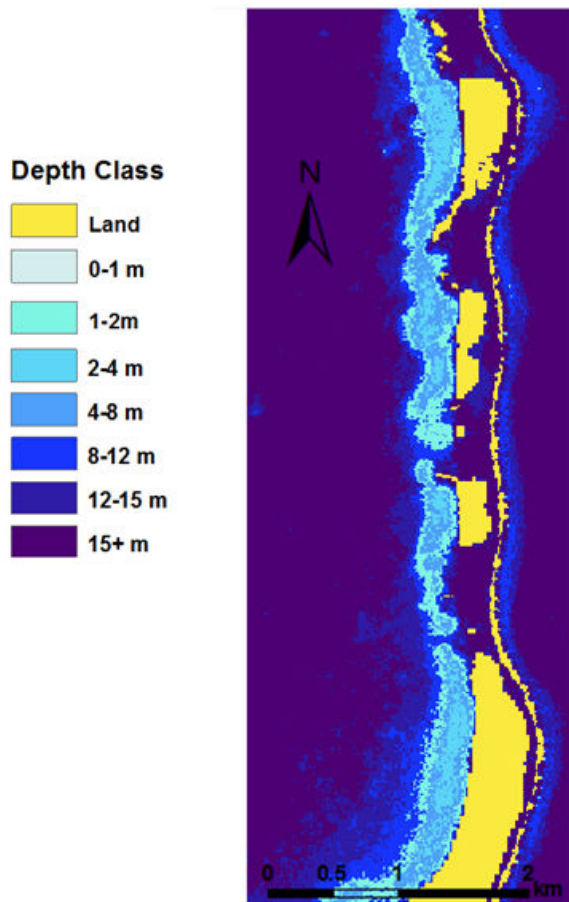


Figure 1a. Depth estimate map for Rongelap study area

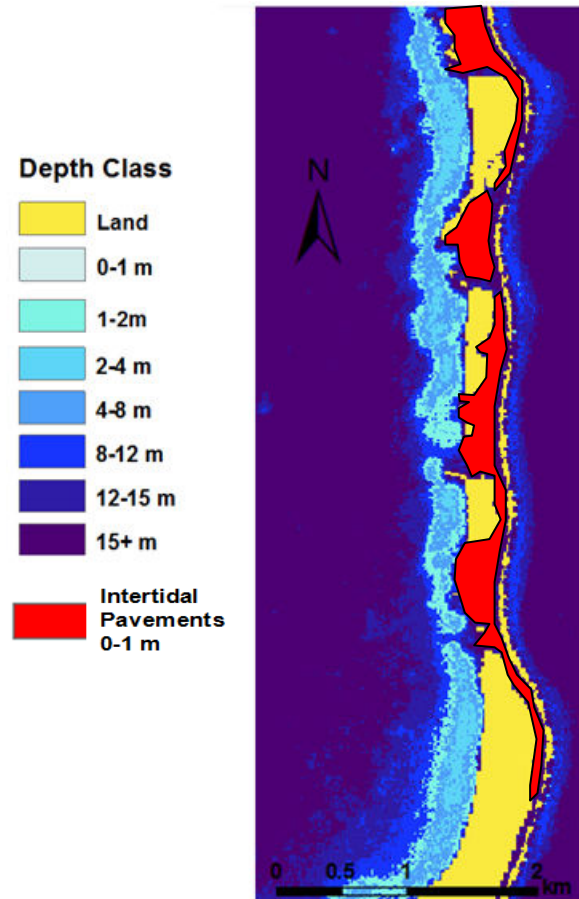


Figure 1b. Desired correction of depth estimate

Figure 1b shows a critical mark up of the simulated deep water classifications. This correction is based on the fact that islanders regularly walk to neighbouring islets at low tide. Since most bathymetric soundings are taken from boats, there has been a bias against tuning the bathymetry to suit pedestrian traffic. So an alternative utility is desired to recognize intertidal coral pavements between islets.

Ignoring the pedestrian ground truth, an assessment of the maximum likelihood classification revealed that measurements across the full range of depths (0-30m) were predicted to an accuracy of  $r^2=0.36$  ( $p<0.05$ ). This degree of accuracy may be attributed in part to the distribution of ratio values for the training dataset across the range of depths shown in Figure 2.

The anomaly of the pedestrian intertidal pavements appears to be explained by a local bifurcation in the dataset that occurs at approximately 5 m depth. Beyond this point, it not possible to

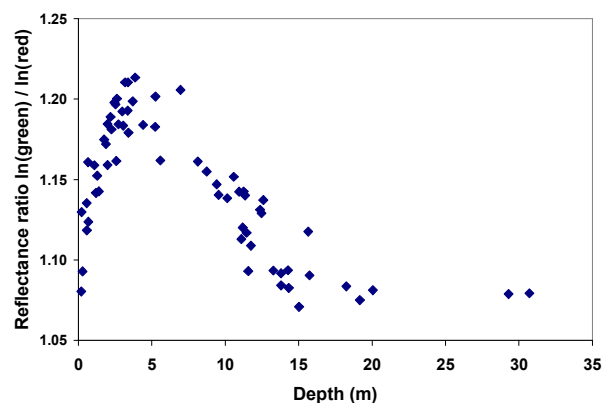


Figure 2. Reflectance ratio (green and red bands) versus depth in the Rongelap ASTER image

There is a higher absorption rate of the red wavelengths to the green in water, resulting in different depth sensitivity for each band. Figure 3 illustrates the trends for reflectance versus depth for the green, red, and near infrared bands for the training dataset. The green band remains sensitive to depth up to approximately 15m, whereas the sensitivity for the red band terminates at approximately 5m. The near infrared band shows a small degree of sensitivity in the intertidal zone (1-2m). These results suggest there is utility in both the ratio algorithm and the reflectance data for depths less than 5 m, where the intertidal zones and reef crests occur. This utility can be exploited to avoid the bifurcation of the reflectance ratio in shallow water

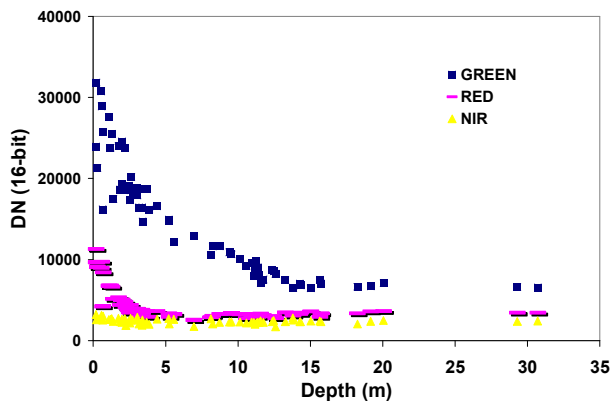


Figure 3. Reflectance for green, red and near infrared bands versus depth in the ASTER image of Rongelap

Rongelap's geomorphology causes heterogeneity of benthic habitat, substrate reflectance, and depth in the context of ASTER VNIR spatial resolution. Figure 4 shows a sample ASTER pixel in the Rongelap study area where multiple depths, and points of exposed reef flat, derived *in situ*, register the same reflectance value in the VNIR bands. For the purposes of maximum likelihood classification pixels such as this one were not included in the training dataset, but warrant future investigation if a more robust depth estimate algorithm is to be developed for ASTER.

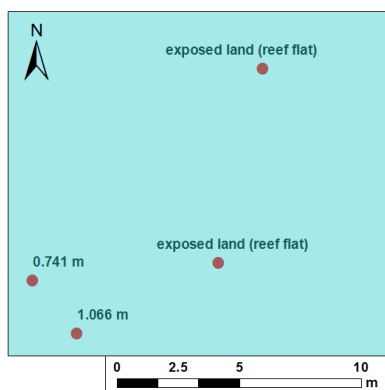


Figure 4. An ASTER pixel of Rongelap atoll with *in situ* bathymetry registering the same reflectance value for two depths and exposed land (spatial resolution 15m, rendered in ESRI® ArcMap)

Substrate reflectance will vary with tidal condition. The ASTER imagery used for analysis was recorded at a higher tide. It has been demonstrated that shorelines extracted via VNIR satellite imagery in particular are vulnerable to tides. In regions with large reef flats, the difference between shorelines derived at different tide condition, as a measure of distance from the coastline, may be expressed on the order of several magnitudes, with a strong correlation to the spatial resolution (Yamano et al, 2006).

## 5. CONCLUSIONS and RECOMMENDATIONS

The results of this study indicate that potential exists for using the depth estimate algorithm in the ASTER VNIR dataset for very shallow water (0-5m). This is based on the stable trends for ratio and band reflectance versus depths up to 5 m (Figures 2 and 3). Depths beyond this threshold either absorb these wavelengths or fail to demonstrate a bijective relationship with band reflectance, and therefore are more suitable for sensors that include blue wavelengths. The ASTER green band shows the greatest depth sensitivity at approximately 15 m. In unison with the smaller threshold for the red and near infrared bands, it may prove useful in demarcating reef crests and intertidal zones from deeper water.

The results also highlight the factors that may affect the accuracy of depth estimation, including the ASTER VNIR spatial and spectral resolution, the environmental conditions at the time of imaging, and the geomorphological influences on the reflectance data.

In general, a range of spatial resolutions is necessary to accurately map coral reefs and their environments. This is due to the distribution patterns of coral reef zones and their spatial scale, ranging from tens to hundreds of meters, and the depths and benthic communities associated with each zone [4].

Recommendations for future bathymetric mapping of Rongelap and similar atolls using ASTER imagery:

- Focusing the investigation on the shallow water zones (0-5m) for depth determination, corresponding to the utility of ASTER's spectral, spatial, and radiometric resolution in these regions
- Executing a depth analysis on multiple ASTER images at different tidal conditions, to offset the impact of substrate reflectance and changes in water radiative transfer in the intertidal zone
- Experimenting with a fusion of band data, including all three VNIR bands and possibly SWIR (short wave infrared) in determining fine demarcation between land and water, and between shallow water classes
- Exploring a synthesis of ASTER's extensive coverage of the Indo-Pacific region with higher spatial resolution datasets such as IKONOS, RapidEye, and WorldView-2

## REFERENCES

- P.J. Mumby, W. Skirving, A.E. Strong, J. T. Hardy, E. F. Ledrew, E. J. Hochberg, R.P. Stumpf & L.T. David, "Remote sensing of coral reefs and their physical environment". Marine Pollution Bulletin, Vol. 48, p.p. 219-228, 2004.
- E.L. Peterson, "ASTER bathymetry in computational fluid dynamics of Rongelap Atoll hydrodynamics, Marshall Islands", Proceedings of the 11th International Coral Reef Symposium, Vol. 1, p.p. 491-495, July 2008.

R.P. Stumpf, K. Holdried, "Determination with high-resolution satellite imagery over variable bottom types", *Limnology & Oceanography*, Vol. 48, p.p, 547-556, 2003.

H. Yamano, H. Shimzaki, T. Matsunaga, A. Ishoda, C. Mcclennen, H. Yokoki, K. Fujita, Y. Osawa & H.Kayanne, (2006) "Evaluation of various satellite sensors for waterline extraction in a coral reef environment: Majuro Atoll, Marshall Islands", *Geomorphology*, Vol. 82, p.p. 398-411, 2006.

## **ACKNOWLEDGEMENTS**

This study could not be completed without the assistance of the following individuals and agencies:

Mr. John Broadbent, Maritime Safety Queensland

College of the Marshalls Islands

Conservation Leadership Programme grant

Mr. Lucas Holden, RMIT University, Melbourne, Australia

Ms. Nicole Kiely

Marshall Islands Marine Resource Authority

NOAA Coral Reef Conservation Fund

NOAA's National Ocean Service

Mr. Marcus Reston, Victorian Partnership for  
Advanced Computing

Rongelap Atoll Local Government