BATHYMETRIC MAPPING USING A COMBINATION OF SONAR DATA AND SATELLITE IMAGERY

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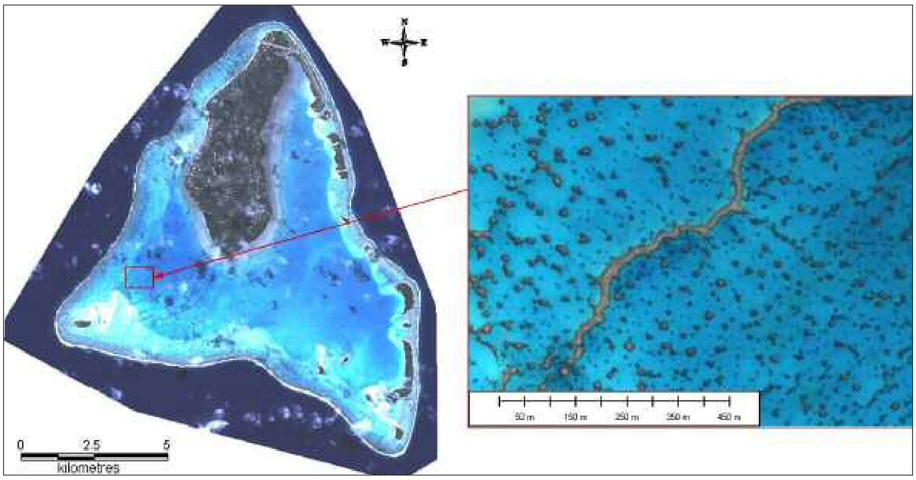
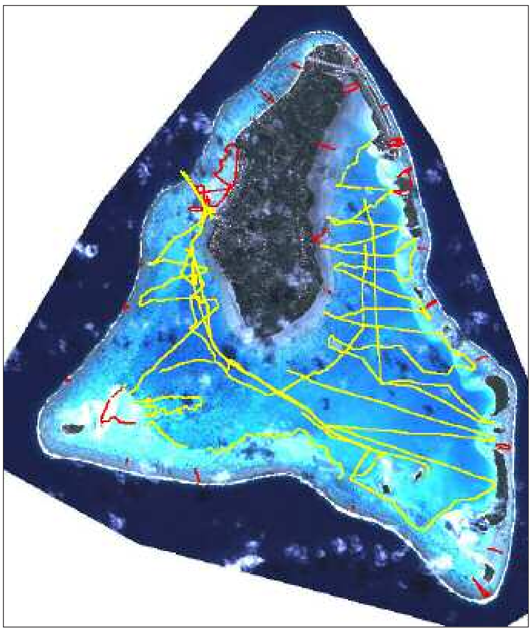
In *Fisheries Newsletter* #120 the various methods available for determining shallow water bathymetry, using either active sensors (sonar, LiDAR) or passive multispectral imagery (Landsat, QuickBird) were described. This article discusses recent work conducted in collaboration with the Pacific Islands Applied Geoscience Commission (SOPAC) to produce a high-resolution bathymetric map of Aitutaki Lagoon (Cook Islands), using a combination of single-beam sonar data, reef crest points and a QuickBird satellite image.

Aitutaki Lagoon has a surface of around 80 km^2 and depths mostly between 1 m and 7 m, not exceeding 12 m. Hundreds of patch and ribbon reefs — no deeper than 1 m — are scattered throughout the lagoon (Figure 1) and have a high influence on the lagoon's hydrology and ecosystem These structures appear clearly on a QuickBird satellite image (2.4 m resolution), yet they are costly to survey using sonar bathymetry alone, and navigation around patch reefs is hazardous.

In early 2008, SOPAC's Ocean and Islands Programme surveyed the lagoon, using a single-beam echo sounder (white tracks on Figure 2) and a real time kinematic (RTK) GPS, which provides very accurate positioning. Points were also surveyed on reef crests using RTK GPS alone (dark tracks). All depths were subsequently corrected for tides.

A QuickBird satellite image was bought by SOPAC's GIS unit and rectified so that it matches





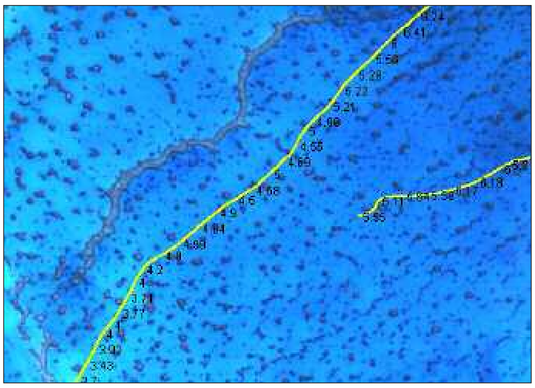
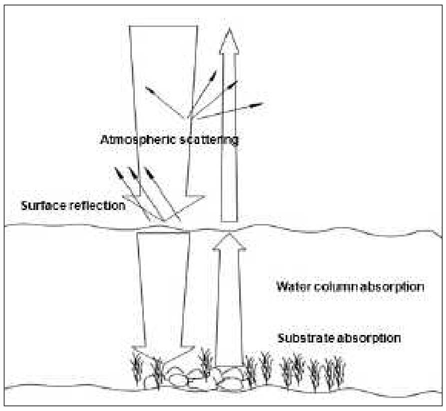


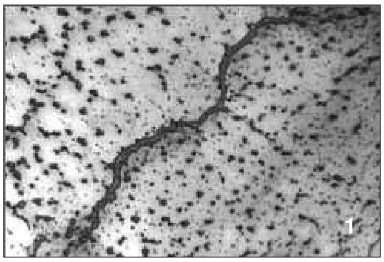
Figure 1 (top). Aitutaki Lagoon.

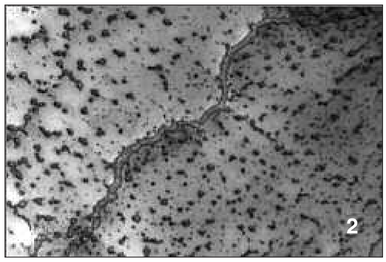
Figure 2 (bottom). Single-beam echo sounder (left, yellow) and reef crest RTK soundings (right, red).

RTK data. An atmospheric correction was applied to remove haze and other atmospheric effects.

The availability of the rectified image and soundings for various locations made it possible to determine the relationship between the colour observed on the satellite image and the measured depth, and use it to build a bathymetric map for the whole lagoon.







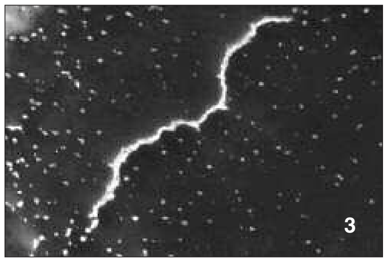


Figure 3 (top). Effects contributing to the colour observed on a satellite image.

Figure 4. QuickBird blue [1], green [2] and red [3] bands for a reef area.

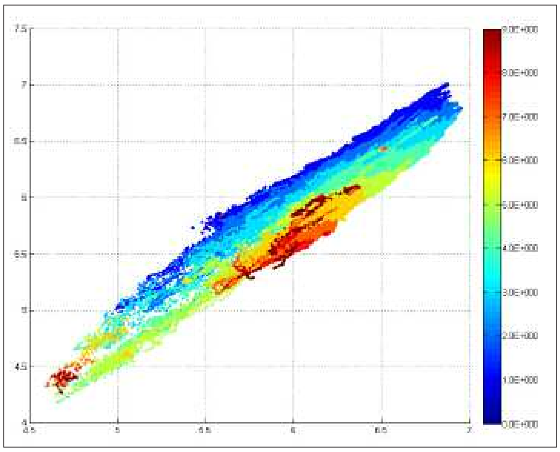


Figure 5. Measured depths for values of log (blue) and log (green).

Predicting bathymetry from a satellite image

A QuickBird image is composed of three visible bands corresponding to blue, green and red wavelengths. Only a fraction of the sunlight illuminating the area is received by the satellite sensors due to absorption, reflection and scattering by the atmosphere, the air-water interface, the water column and the bottom substrate. In particular, light is absorbed exponentially with depth, more quickly for green and red bands than for blue bands (Shifrin 1988). The green and red bands appear darker (when viewed separately) than the blue band as shown in Figure 4.

Several papers suggest using the relative absorption of two bands to determine the depth from the reflectance, and a good correlation can then be found between log (blue)/log (green) and depth (Philpot 1989; Stumpf and Holderied 2003) (see Fig. 5).

This approach gives a good approximation of depth. It can be improved using a more complex model that uses the three visible bands and is fitted using the available sonar and reef crest data. For that purpose, we used a multi-layer perceptron (artificial neural network) to model the depth from colour: the available soundings and corresponding colours were initially used to train the neural network, and then the model was applied to the whole image to predict the depth of the whole lagoon.

After training, the artificial neural network was able to predict depth with an average error of less than 1 m on the training data set (a fraction of the data is actually used for training and the rest used to test the result). The model was also able to spot some errors in the sonar data (due to multi-reflections of the sonar signal), which were subsequently removed from the training data. Once applied on the whole image, it was possible to obtain a bathymetric map for the lagoon (Figure 6), on which emerged areas and thick clouds have been masked and coloured in purple.

Conclusion

The availability of both a high-resolution satellite image and sonar data for various depths and substrate made it possible to produce a detailed bathymetric map for Aitutaki Lagoon. This map will be used in the near future by SOPAC to build a hydrographic model of the lagoon.

The same methodology can be used for other shallow lagoons for which satellite imagery and shallow water soundings for various depths and substrates are available.

References

Philpot W.D. 1989. Bathymetric mapping with passive multi-spectral imagery. Applied Optics 28:1569–1578.

Shifrin K.S. 1988. Physical optics of ocean water. American Institute of Physics, New York.

Stumpf R.P. and Holderied K. 2003. Determination of water depth with high-resolution satellite imagery over variable bottom types. Limnological Oceanography 48:7–556.

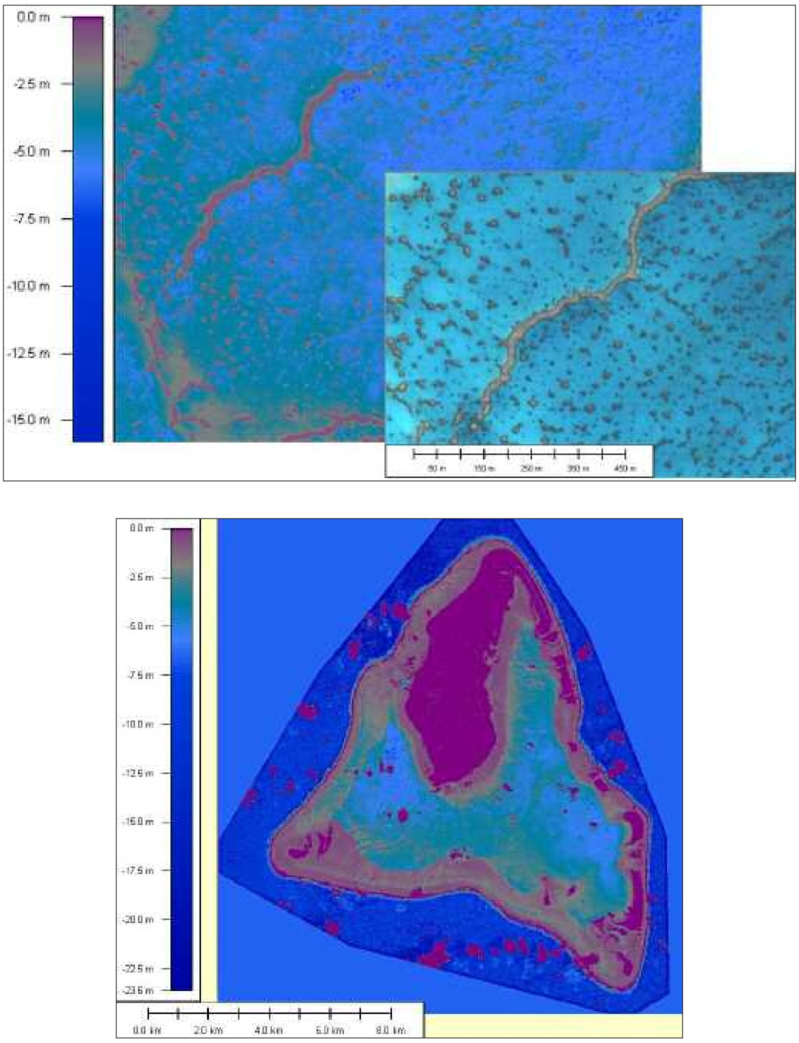


Figure 6. Predicted depth of Aitutaki Lagoon.