SHALLOW WATER BATHYMETRY

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A previous article in the SPC *Fisheries Newsletter* (# 117) described how ocean bottoms are largely unexplored, and that the available Pacific Ocean bathymetric maps are a mixture of localized oceanic surveys and satellite altimetry, with a resolution ranging from 30 seconds (~1 km at equator) to 5 minutes.

While these maps are quite useful for the management of pelagic fishes and seamounts, they are generally unsuitable for nearshore and reef fisheries management, for which, higher resolution maps are necessary. This article describes other sources of information for shallow water bathymetry, and how these can be used to produce bathymetric maps for coastal fisheries management purposes.

Nautical charts

Hydrographers and cartographers have produced nautical charts for the Pacific Islands region for centuries, and some of the charts available today are updated versions of 19th century original ones.

Nautical charts are generally available for the whole Pacific, but scale varies depending on the area. Because nautical charts have been created for navigational purposes, they emphasise hazards such as reefs, focusing on avoidance more than on the exact mapping of reefs. Nautical charts are generally quite detailed for approaches to harbours and passes, with additional detailed plans for these areas of interest.

Figure 1 shows that the bathymetry in the NZ945 chart for Penrhyn is much more detailed around Taruia Passage and Gudgeon Bay, than in the rest of the lagoon and the passage is even more detailed because of its importance for navigators.

Importation of nautical charts in a GIS

For use within geographic information system (GIS) software, charts can be scanned and geo-referenced (raster image), or they can be digitized (on screen or with a digitizing board) and stored as points, contour lines and polygons. Spatial queries are possible with digitized charts, while raster images are generally used as backdrop.

Nautical charts have been digitized on a large scale by US federal agencies such as the National Oceanic and Atmospheric Administration (NOAA), the National Geospatial-intelligence Agency (NGA), and the National Imagery and Mapping Agency (NIMA), but these products are generally not released to the public for copyright reasons, apart for US waters. Some private companies have also digitized charts to incorporate them in GPS plotters but these are generally encrypted and in a format incompatible with GIS software.

The projection and datum used to produce the chart must be known in order to geo-reference or digitize a chart, which is sometimes not the case for older charts for which adjustments for plotting GPS positions cannot be determined.

In conclusion, nautical charts are most often not readily available in vector format and often lack detailed bathymetry for reef areas and areas outside frequently used shipping lanes.

Hydrographic surveys of coastal waters

Depths between 30 m and 200 m are beyond remote sensing techniques (visible light is quickly absorbed and water is opaque to radar frequencies) and predicted bathymetry, using satellite altimetry, is not reliable for shallow water. Therefore, sonar and lead line remain the ways of measuring depths in the 30-200 m range.

A typical survey is done with a medium size boat equipped with a single-beam or multi-beam sonar that records depths regularly (every 20 m; see Fig. 2) along the boat path (parallel transects). Very shallow areas (e.g. patch reefs or flat reefs) are generally not covered because they cannot be safely explored by the survey boat; therefore, holes in the dataset often correspond to shallow reefs.

Hydrographic surveys provide very accurate depth information, and additional data can be collected with additional sensors at the same time (e.g. acoustic signatures can be used to map bottom types). These types of surveys are done routinely by the South Pacific Applied Geoscience Commission (SOPAC) for ACP countries, and NOAA's National Ocean Service for US territories.

An alternative method consists of digitizing individual soundings on nautical charts. This is a tedious process, but can make up for a lack of available sonar information for an area.

Use of hydrographic survey soundings

Each sounding point is stored as an XYZ position (geographic position and depth), and the dense set of sounding points is interpolated to produce a depth map (with isobaths at 5 m, 10 m, 20 m, 30 m), and determine the corresponding surfaces as in Figure 3.

It is noticeable on this figure that there are differences between what can be seen on the satellite image and with the isobaths, mostly due to the shallow areas excluded from the survey. The area circled in red for example is wrongly classified as a 20–30 m area while it is obviously much shallower. The actual error varies depending on the interpolation method and the pattern of data gaps.

It is possible to set a maximum distance between interpolated points and leave holes as unknown, or unclassified areas. Figure 4 correspond to the same location as Figure 3 but no interpolation has been done for data gaps (in white). As a result, the area for which depth can be retrieved is about 50% of the previous one, and the proportion of 10–20 m surface areas compared with deeper areas has changed dramatically because shallow reefs are mostly unclassified.

Because of these differences and depending on the processing of data, it is important when using isobaths or depth grids to determine how they have been produced (interpolation method and location of sounding points) and to compare the interpolated grid with available charts and satellite images.

Bathymetry of very shallow areas using remote sensing

Pacific reef fisheries focus on depths between 0 m and 20 m, for which detailed bathymetry is often out of the scope of sonar surveys (reef areas dangerous for navigation). Yet these very shallow waters are not totally opaque to visible light and both passive and active remote sensing can be used to determine bathymetry.

Light detection and ranging (LiDAR)

A LiDAR is an active remote sensing equipment that uses time delay between a laser pulse and its reflected signal by the target to determine the distance of the latter. The SHOALS-1000 (Scanning Hydrographic Operational Airborne LiDAR Survey) system in particular uses a blue-green laser and can measure depths up to 60 m over a 200 m swath width, a vertical accuracy of 15 cm and a distance of 8 m between sounding points (Wozencraft 2001). The SHOALS system is mounted on a Twin Otter aircraft and operated by the Joint Airborne Lidar Bathymetry Technical Center of Expertise (JALBTCX).

This technique is complementary to the traditional sonar surveys and can be used to map very shallow waters and surf zones. It can also map the topography of the nearshore (beaches and dunes). LiDAR data is currently freely available from the NOAA website for US coastlines.

Unfortunately, the cost of airborne operations restricts its use for specific areas, and it is very unlikely that LiDAR data will be available in the near future for remote islands. According to the JALBTCX website, SHOALS surveys will be conducted in Majuro, Kwajalein, Kosrae, Pohnpei, Chuuk and Yap in addition to US territories.

Multispectral and hyperspectral images

This method is based on the optical properties of the water column: light absorption is exponential with depth and varies with wavelength (wavelengths corresponding to red colour are absorbed twice as fast as blue ones, see Fig. 5). Compared with LiDAR, which uses laser pulses to illuminate the scene, passive remote sensing simply measures the sunlight reflected by the sea floor.

The difference between multi- and hyperspectral data is the number of sensors and their sensitivity a predefined range of wavelengths: Landsat and IKONOS satellites for example have four sensors (bands) for visible and near infrared spectrum, while the Compact Airborne Spectrographic Imager (CASI) can discriminate between 288 spectral bands.

The accuracy of depth as determined through passive remote sensing is far less than what can be achieved using sonar or LiDAR. The method often requires some kind of area specific calibration, using ground truth data and atmospheric correction to normalize the data. The advantage of this method is that it can use available images, and satellite images have a very large footprint compared witho airborne and ship surveys, which are more localized.

Passive remote sensing can be used for depths up to 30 m, depending on water turbidity and atmospheric conditions. Numerous papers have been published on the use of satellite images for shallow water bathymetry (Ishiguro et al. 2001; Stumpf and Holderied 2003; Provost et al. 2004) and it is still an active research topic as there is still room for improvement. The main problem being that not only the water column absorbs light but also the atmosphere, particles in suspension in water and the sea floor itself, depending on substrate type. The resultant signal contains the depth information, but is mixed with the other components.

Fortunately for fisheries management purposes, depth does not need to be known within a 15 cm accuracy. A rough mapping of depth classes (for example 0–5 m, 5–10 m, 10–15 m, 15–20 m, and 20 m+) is probably sufficient and can be obtained quite easily by using a ratio of blue and green bands if some soundings at various depths are available for the area and can be used to calibrate the image (Figure 6).

This method has been used to produce rough depth maps of Tonga's reefs, using available relatively cloud free Landsat images and sounding points from nautical charts.

Conclusion

Sonar surveys have limitations in term of coverage of very shallow waters and are well complemented by LiDAR surveys but the operational costs of these types of surveys limit their use to specific areas. Passive remote sensing can provide a cheaper alternative but at the expense of accuracy and more robust methods, and models are still sought by researchers for improvement of current mapping.

When using a bathymetric map for coastal waters it is important to know how it was produced, for which purpose, and its limitations in order to determine if the map is suitable for the particular intended use.

References

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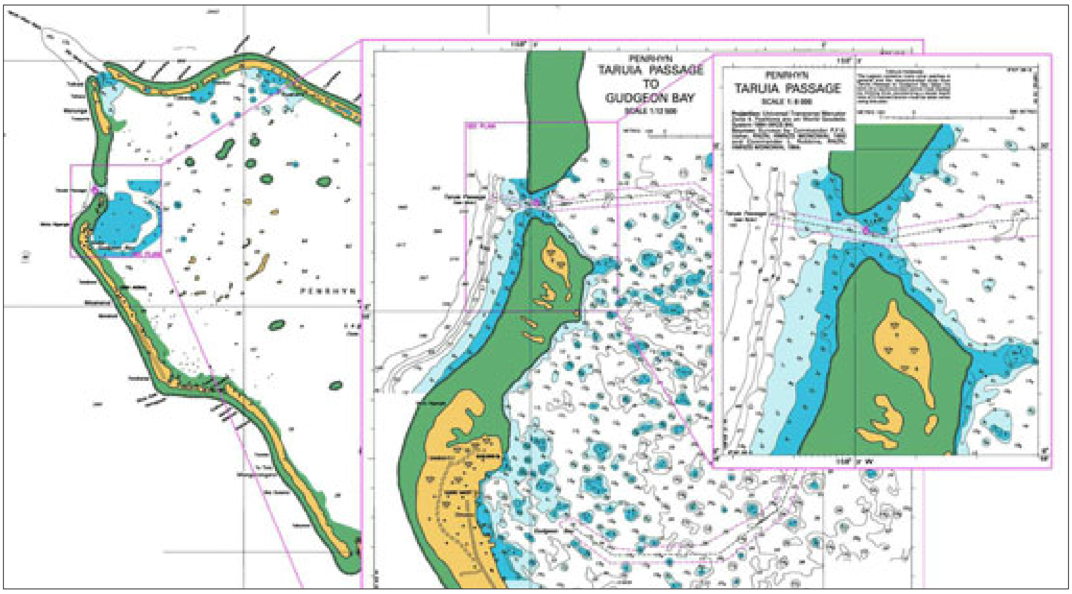


Figure 1: Increasing level of details around passes and harbours for navigational purposes (from NZ 945 chart)

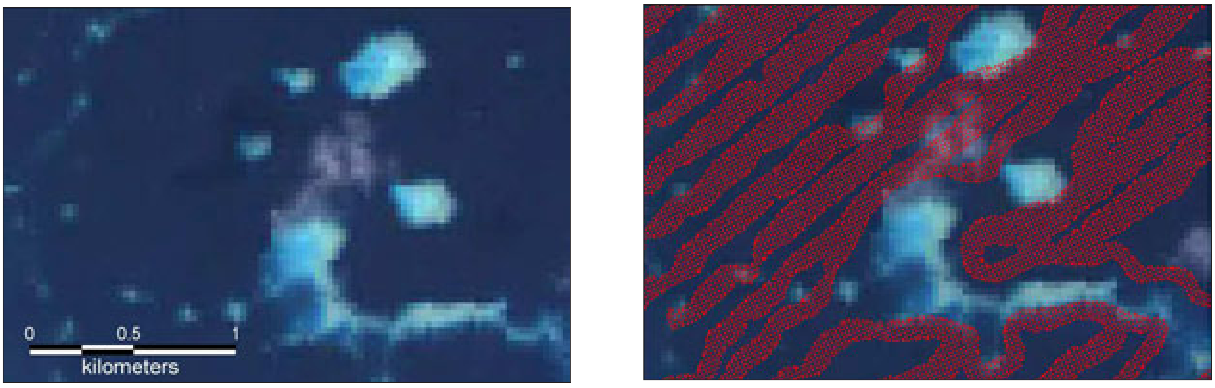
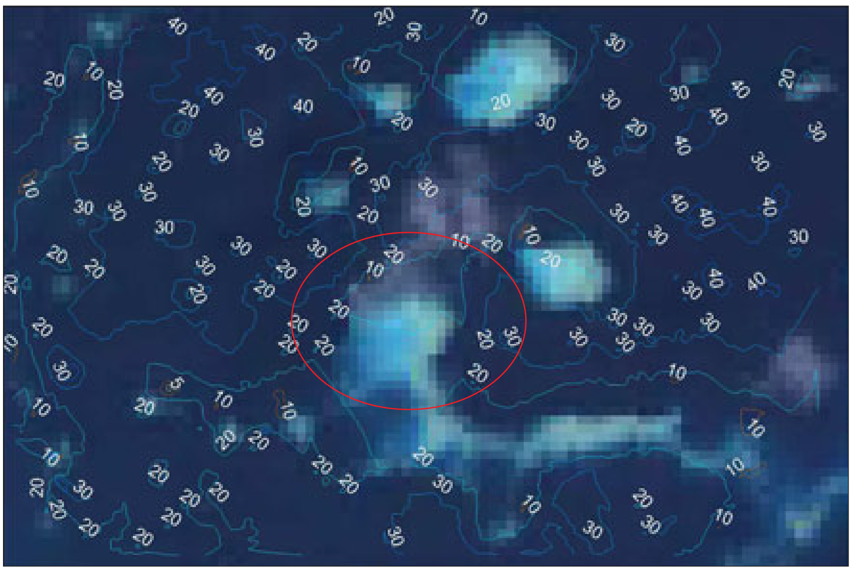
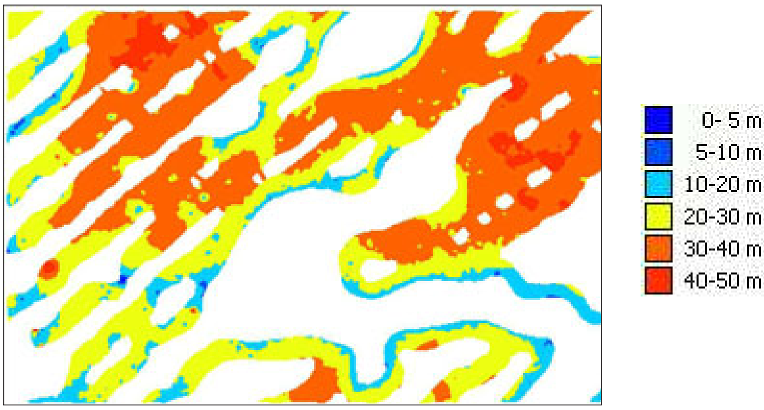


Figure 2: Sounding points of a typical sonar survey (in red) over a Landsat image



Depth (m)		Surface (km^2)
From	To	
0	5	0
5	10	0.016
10	20	1.193
20	30	1.992
30	40	1.732
40	50	0.108

Figure 3: Isobaths produced after interpolation of XYZ data (triangulation)



Depth (m)		Surface (km²)
From	To	
0	5	0
5	10	0.009
10	20	0.297
20	30	0.972
30	40	1.279
40	50	0.104

Figure 4: Depth classes with interpolation limited to a maximum distance of 50 m

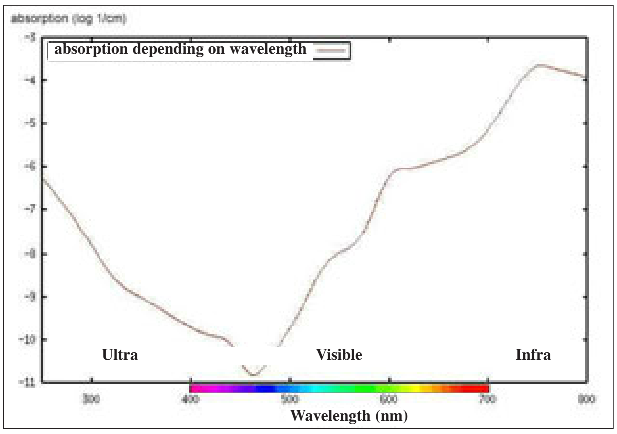


Figure 5 Absorption according to wavelength
(as per data from Shifrin 1988)

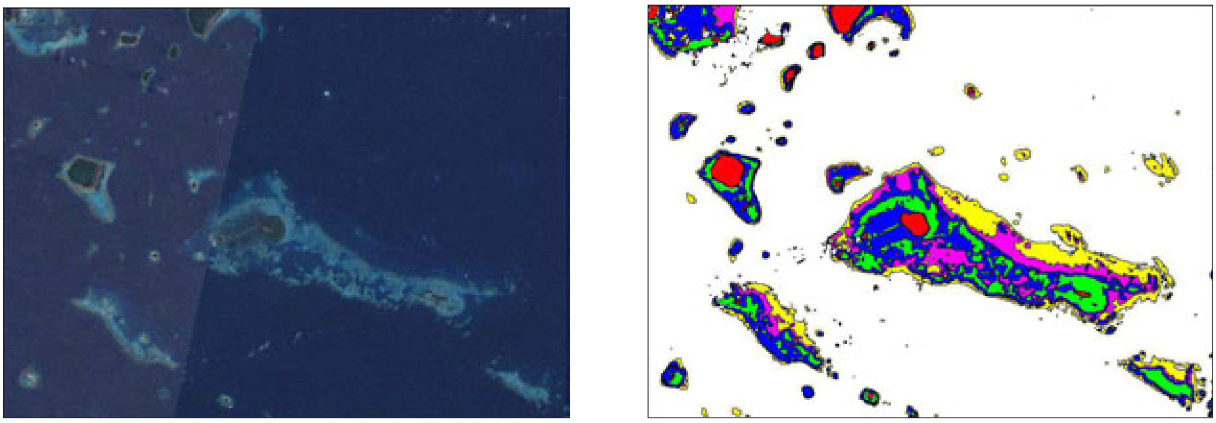


Figure 6: Satellite image (Landsat 7) and corresponding depth classes