COMPARITIVE MAPPING OF AERIAL AND SATELLITE SCALE RESOLUTIONS FOR MARINE NEAR-SHORE BATHYMETRY

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Principal Investigators Meeting.
European Space Agency, CHRIS/PROBA Workshop, ESRIN, Frascati, Italy.
21 -23 March 2005.

ABSTRACT

The simulation of CHRIS/PROBA hyperspectral data prior to the commencement of orbital acquisitions was trialled as a means of anticipating the likely successes and limitations of both reduced spectral and spatial resolutions in mapping near-shore bathymetry. HyMap airborne hyperspectral datasets were resampled to conform with CHRIS Mode 2 (Water) bandsets. A selection of hyperspectral tools were applied to both the HyMap imagery and the simulated-CHRIS data to provide an early comparison and preview of likely performance characteristics CHRIS data could provide to the mapping variable water depth in the marine environment. Simulated-CHRIS data adequately characterised bathymetric trends across the 0 – 12m water depth range, however the data could not readily resolve small scale topographic features in the wave zone due primarily to significantly "larger than feature" pixel sizes.

1. INTRODUCTION

In the last few years, both government and military emphasis in ship-borne oceanography has shifted from deep ocean investigations towards shallow water surveys (Sandidge and Holyer, 1998). The uses of standard depth determination techniques, such as sonar, are not suited to shallow & high energy "near-shore" environments. Therefore, alternate techniques are actively being sought. Remote sensing instruments with a high spectral, spatial, and temporal resolutions are providing one such solution.

Australian ongoing research into the application of CHRIS/PROBA imagery as multi-angular hyperspectral observations will be used in 2005 to determine bathymetric trends within the near-shore zone, defined as the area from the shoreline to the 15m bathymetric contour. Naval Hydrographic Charts at 1:75,000 in GEOTIFF format are routinely used for commercial, recreational, and military uses, but these existing datasets rarely match the accuracy of hyperspectral mapping methods and ground-truthed seafloor topography in the near-shore zone. This is particularly evident in the mapping of absolute depth and the alignment/orientation of bathymetric contours.

Research is in part designed to optimize naval military application use of hyperspectral data, a rapidly expanding sector that is adopting this technology to accurately map benthic topography in an operational setting. Study sites for this marine CHRIS/PROBA research are located along Sydney's Northern Beaches (NSW) and Duranbah Beach (QLD). Field, lab, airborne and satellite image data (HyMap & CHRIS) are being used to derive spectral signatures to effectively map bathymetric classes within the near-shore zone. Selected hyperspectral classification tools such as MNF and *n*-dimensional analysis will be optimized to further develop new and operationally efficient means for determining near-shore bathymetry. Emphasis is being placed on the complex 0 – 5m depth "wave zone" to map optical turbidity and wave aeration as a surrogate of masked underlying rip channels and irregular seafloor topography, linking ongoing shoreline-based spectral research (Boak, Turner, Merton, 2005). Additionally, research is also being directed to the

Proc. of the 3rd ESA CHRIS/Proba Workshop, 21–23 March, ESRIN, Frascati, Italy, (ESA SP-593, June 2005)

monitoring of sediment volume changes in this critical buffer/reservoir zone with important implications for sea level rise and the movement of the shoreline boundaries as a function of bathymetric changes.

This paper emphasizes the bathymetric mapping of the optically clearer 5 to 15m "near-shore" zone using hyperspectral imaging techniques. The aim of the research is to:

- determine the spectral properties across the near-shore zone from the shoreline to a depth of maximum water attenuation, and
- compare results obtained from mapping at higher spectral range and spatial resolution (HyMap) data for a comparison to simulated CHRIS data, and
- determine the performance and accuracy of the CHRIS data with varying water depth.

2. STUDY SITE AND DATA

2.1. Site

The study site is located on the Northern coastline of Sydney, Australia. Notable international surf beaches mapped in this study include: Manly Beach (*incl*. Freshwater Beach) and Dee Why Beach. The primary site, Manly Beach (Figure 2.1), is located at 33.7876°S 151.2878°E, whereas the Dee Why Beach is located 5.2km to the north. Both beaches are composed of medium grained, well sorted orange to brown sediments, consisting of predominantly iron stained quartz sediments and approximately 40% calcareous shell debris. These sands are utilized as "medium brightness sediments" in ongoing international ARGUS video imaging near-shore zone research (Boak, Turner, Merton, 2005). Sydney beaches are medium energy and are classified as meso-tidal, nominally ranging to 1.8m.

Figure 2.1. HyMap Image of Manly Beach Area.

2.2. Data

CHRIS/PROBA data at the time of writing had been requested for the Sydney Northern Beaches, but not acquired. Consequently, in order to carry out an early comparison of dataset scales (primarily spatially- and spectrally-driven), Mode 2 (Water) bandsets were selected for this comparison, providing optimal wavelength measurement of water related absorption/reflectance features. Additionally, the increased Gains in this mode permitted an improved likelihood of mapping bathymetric transitions into deep water low-return (dark target) areas.

Research is centred on the analysis of HyMap hyperspectral imagery of the Sydney Northern Beaches, flown along a N-S flightline orientation. The 126 spectral band imagery (0.4 -2.5μm) was flown at low altitude, achieving a high spatial resolution of 4.3m. The imagery was cross-track illumination corrected, georeferenced, and atmospherically corrected applying HYCORR with EFFORT refinement. The HyMap imagery was acquired near high tide, 1.3m above the nautical datum.

The HyMap data were used as the primary source for constructing a modelled "simulated-CHRIS" dataset prior to the acquisition of real CHRIS/PROBA imagery. A full adjustment was not feasible to be made for the highly variable FHWM values in CHRIS water mode bandset. Resampling comparatively uniform HyMap FWHM values to highly variable width CHRIS bands proved complex, especially without individual band distribution functions and an assumption of non-Gaussian asymmetry values. However, to approximate the simulated bandsets, ENVI BandMath was successfully utilised on a band by band basis to construct a robust 18 band simulated-CHRIS dataset.

Simple spatial transformation from 4.3m GSD for the HyMap dataset, rescaled to 18m in the simulated-CHRIS dataset was achieved via standard resampling techniques. However, although this study focuses on understanding spatio-spectral changes between datasets, the modelling, or simple addition of band noise into the simulated-CHRIS dataset would have been desirable. Noise addition, was however deemed to be beyond the scope of this research. Once CHRIS/PROBA satellite imagery has been acquired, and the noise across Mode 2 bands more fully understood, then a direct comparison will be made.

The latest 1:75,000 nautical bathymetric contour maps wer used to understand general benthic topographic trends. Digital versions of this map were not available, which necessitated scanning and georeferencing the data. Figure 2.2 & Figure 2.3 highlights the "known" topography and the extend of reef systems in the near-shore zone.

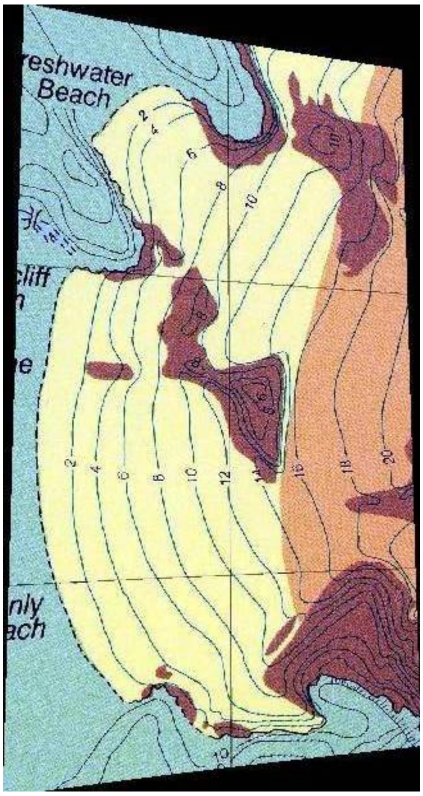

Figure 2.2. Bathymetric Contour Map of Manly.

Figure 2.3. Bathymetric Contour Map of Dee Why.

3. METHODS

In ongoing research, Manly image analysis is divided into three categories: bathymetric estimation, beach profile (*e.g.* bar, swash zone and channel) mapping and geological features (submerged and emerged rock reef, sand type) mapping. The primary analysis for these targets is via spectral-space projections (Figure 3.1).

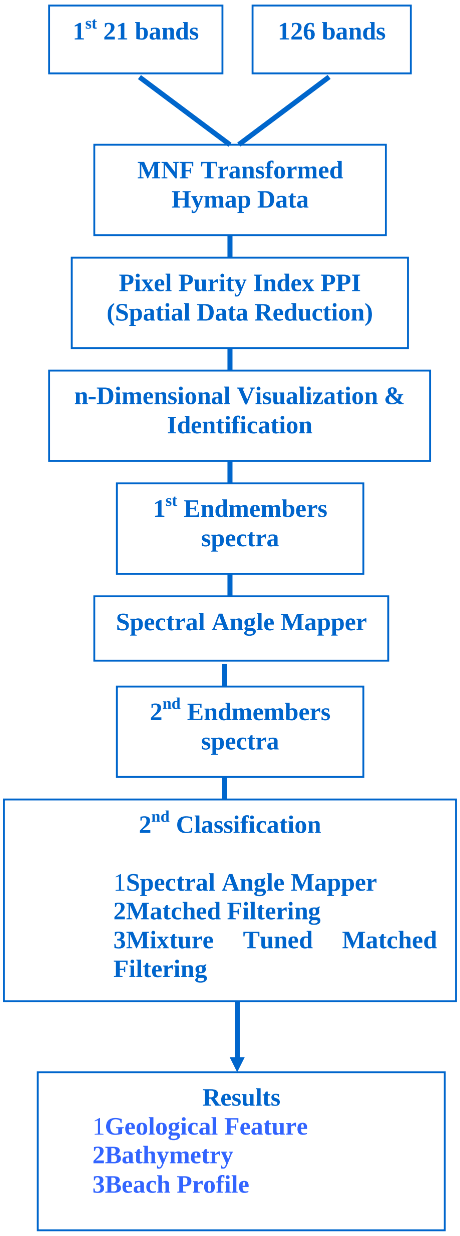

Figure 3.1. Analysis Flow Chart for 126 Band HyMap data & Simulated-CHRIS data.

4. RESULTS

4.1. MNF & *n*-Dimensional Analysis

Near-shore data projected in *n*-Dimensions can be visualized as a spiral form. The curving continuum represented significant simple trends within the data space. To determine and refine continuum classes, sections of the data where selected from one end to the other for assessment (Figure 4.1). The Minimum Noise Fractional processes spectrally separate the sand, rock reef, and especially water and submerged reefs (Figure 4.1). The location of submerged reefs is indicated in red circle. End- & edge-members of water were identified along the medial and outer spiral faces (Figure 4.1).

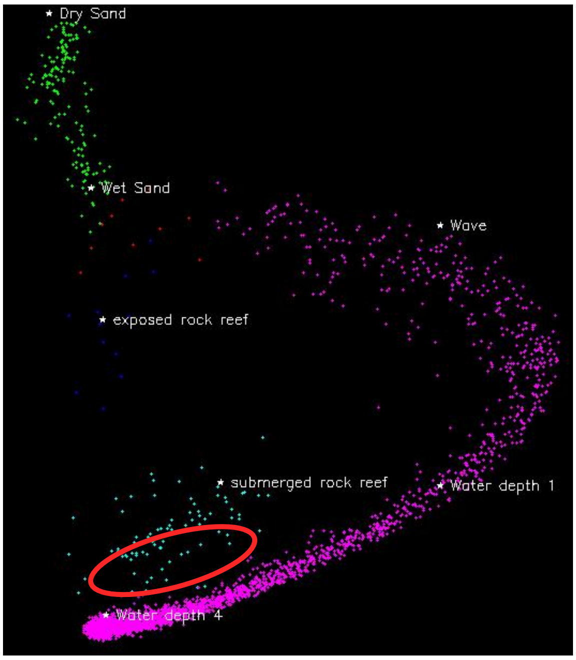

Figure 4.1. Distribution of Bathymetric Features in *n*-Dimensional Space.

Broad bathymetric *n*-D classes are displayed along the characteristic near-shore spiral form in Figure 4.2. A strong relationship within the data represents a continuum from "wet" (magenta) to "dry" (green) pixels, mapping a gradient from deep ocean to dry sand. Features along this trend were then assigned to match known field validated, spectral, and spatial trends in imagery, to facilitate initial near-shore zone bathymetric classification. Sections of this spiral form were further refined both across and along the simplex surface (edge members), and mapped to regular depth intervals (linear mixing) or "spectral bathymetric contours" (Figure 4.3).

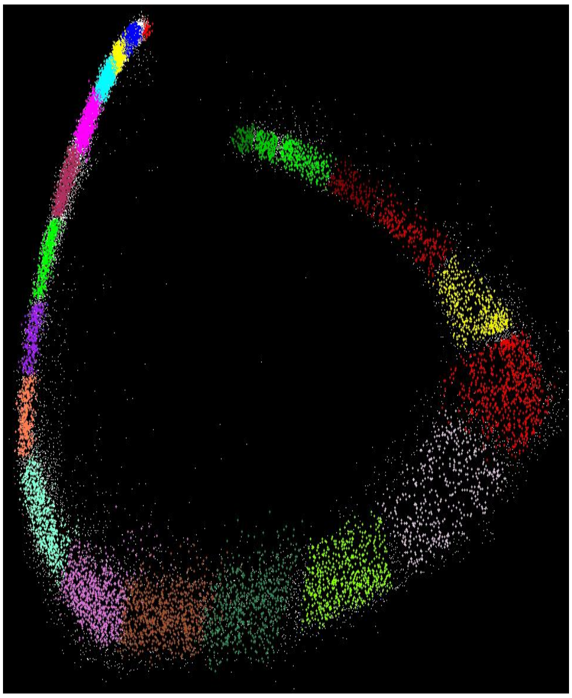

Figure 4.2 Dee Why *n*-D Bathymetric Classes.

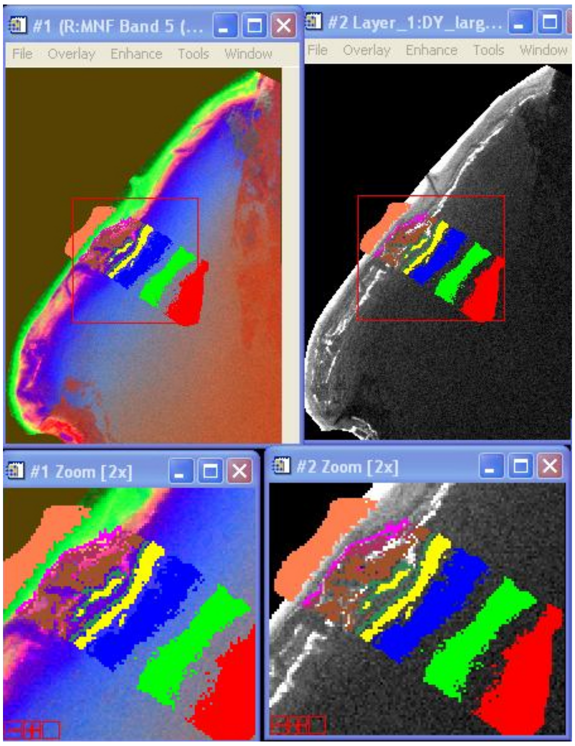

Figure 4.3 Bathymetric Contours at Dee Why Beach.

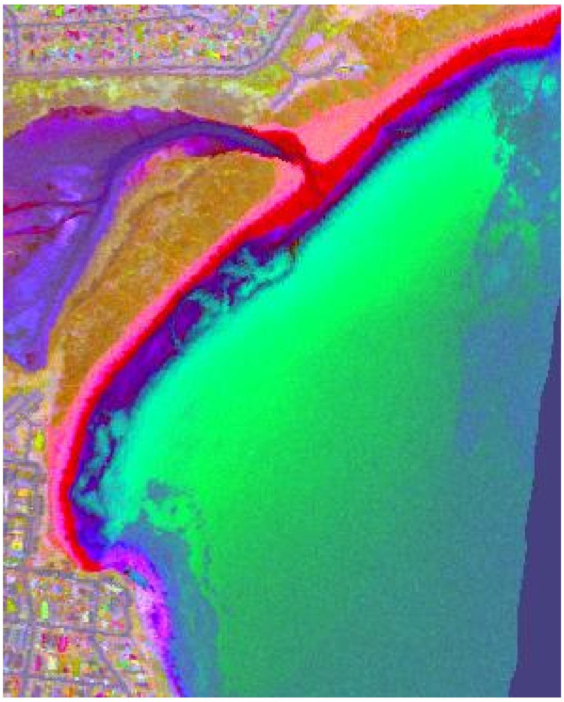

Figure 4.4 HyMap MNF Image of Dee Why Beach.

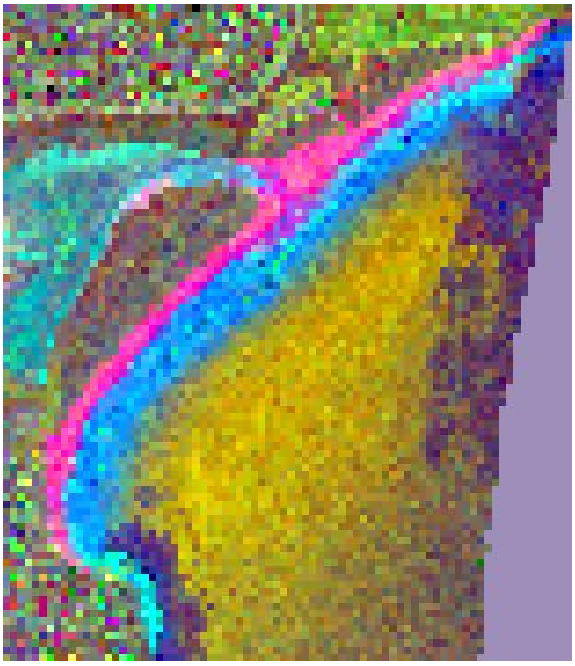

Figure 4.5 Simulated-CHRIS MNF Image of Dee Why Beach.

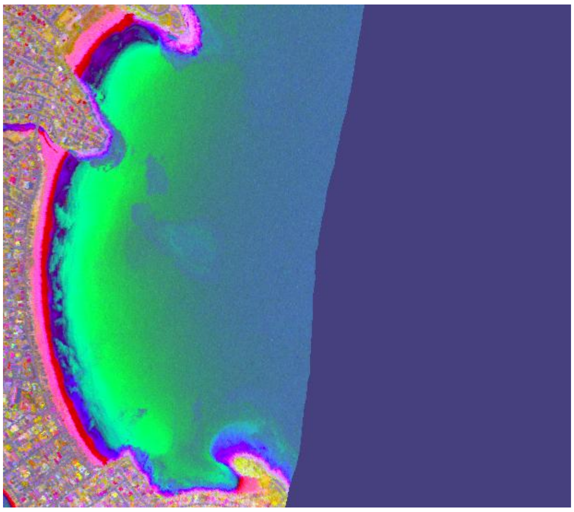

Figure 4.6 HyMap MNF Image of Manly Beach.

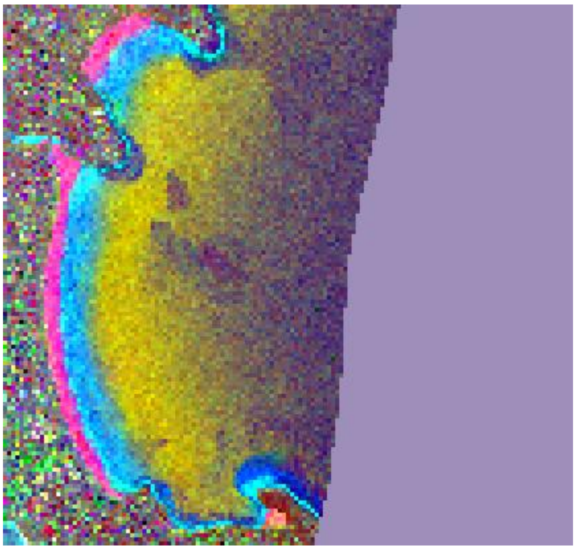

Figure 4.7 Simulated-CHRIS MNF Image of Manly Beach.

4.2. Bathymetric Vector Mapping

Both the Manly HyMap MNF image (Figure 4.7) and the vectorized output of this data (Figure 4.8) show that the bombora (submerged pinnacle reef) can be resolved at depths ranging from 3 – 14m, and is represented by a red complex vector line in centre of Figure 4.8. Furthermore, the bombora can be clearly identified as a split reef system with the bathymetry of the sand being continuously mapped between the two pinnacles (yellow and white arrows, Figure 4.8). As a function of water attenuation with depth, there is an absence of spectral information to determine bathymetric trends beyond the 14m depth contour.

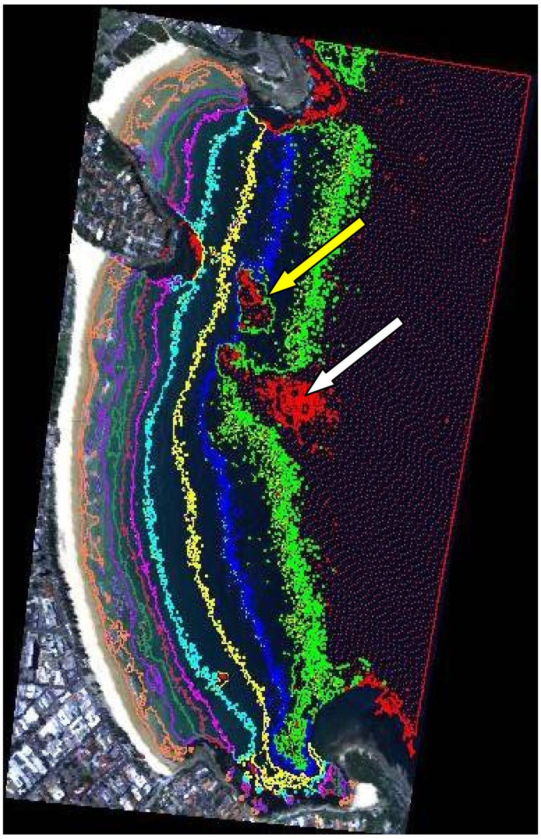

Figure 4.8 HyMap Marine Bathymetric Vector Map for Manly Beach.

Figure 4.9 displays the simulated-CHRIS data for the same area of Manly Beach. The lower spatial resolution produces a more pixelated appearance to the map, nevertheless a surprisingly similar bathymetric map can be derived from this product. The bombora, is clearly mapped in its shallower extent, but fails to be identified at depths exceeding ~12m (white arrow, Figure 4.9). A notable success is the ability of the simulated-CHRIS data to maintain mapping accuracy across the smaller bombora pinnacle (yellow arrow, Figure 4.9) .

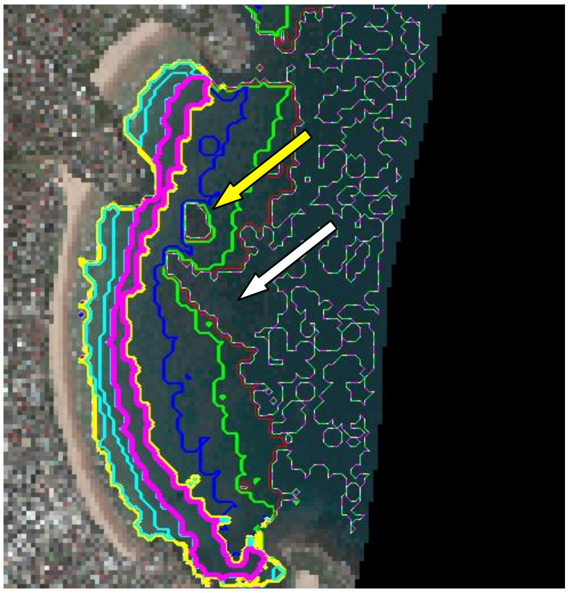

Figure 4.9 Simulated-CHRIS Marine Bathymetric Vector Map for Manly Beach.

The simulated-CHRIS imagery, although performing well in moderate to deep water environments, does not however show similar potential in the wave zone adjacent to the shoreline. For example, Figure 4.8 is derived from 4.3m GSD HyMap imagery, and very accurately delineates long-shore bars & troughs, and rip currents. Figure 4.9 is derived from 18m GSD simulated-CHRIS imagery, which does not retain these features. The primary explanation is that these geomorphic features have spatial dimensions that generally do not exceed ~20m along their narrowest axis, and any non-linear arrangements of these groups of pixels will be spatially resampled into adjacent "background" pixels.

5. CONCLUSIONS

The modelling of simulated CHRIS/PROBA hyperspectral satellite data via HyMap high spatial & high spectral resolution imagery, permitted an important understanding of CHRIS bathymetric mapping performance prior to acquisition. The simulated 18 band "water mode" performed sufficiently well to enable the mapping of coherent spectral trends in near-shore bathymetry along the optically clear Sydney Northern Beaches water column. Simulated-CHRIS bathymetric vector maps derived from the output of hyperspectral procedures (Figure 3.1) were used to create contour maps of water depth ranging from 0 – 12m. The use of statistical spline fitting methods is likely to assist in smoothing any erratic pixel vectorization shift errors.

The simulated CHRIS data however proved inadequate for the discrimination of small spatial scale features in the wave zone, especially narrow rip channels and long-shore bar-trough systems. It was determined that the lower spatial scale of the simulated-CHRIS imagery was more limiting to classification than the reduction in spectral dimensionality. Once orbital CHRIS/PROBA is acquired, onboard high spatial resolution HRC imagery will be used for image sharpening. However, the integration of non-coincident imagery in the dynamic near-shore coastal zone may limit its operational advantage.

Finally, it is important to note that the accuracy of simulated-CHRIS spectrally derived bathymetric maps matched, and in some areas exceeded, the detail presented by traditional 1:75,000 survey map products. This is especially evident in the delineation of reef boundaries, and the identification of sea floor bathymetric trends over sand surfaces in the near-shore zone.

6. REFERENCES

1. Boak, E., Turner, I., Merton, R. (2005) Laboratory Investigations of the Hyperspectral Reflectance of the Coastal Land-Water Boundary. Coasts and Ports, EERE Journal.
2. Sandidge, J. C. and Holyer, R. J. (1998) 'Coastal Bathymetry from Hyperspectral Observations of Water Radiance'. Remote Sensing of Environment. 65: 341-352

7. ACKNOWLEDGMENTS

We would like to thank the following agencies and their respective personnel: HyVista (Australia), SIRA, RAC, and ESA.