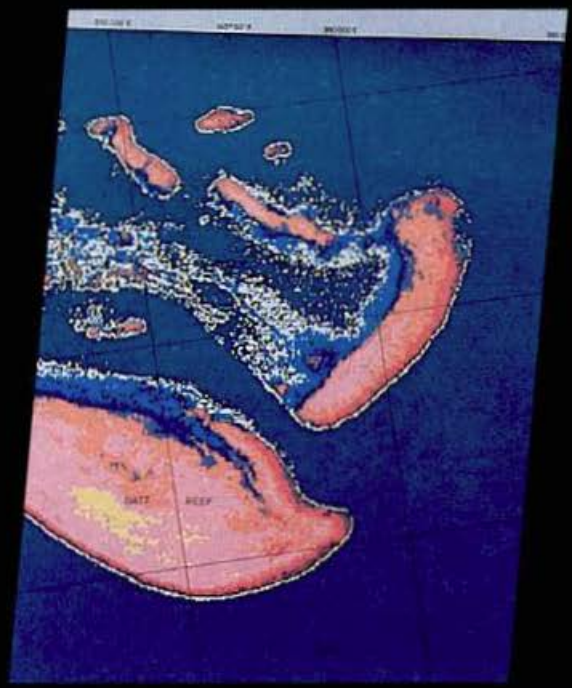
Satellite mapping of the Great Barrier Reef

A vast living treasure, the Great Barrier Reef covers 348 000 sq km and comprises some 2500 individual reefs. To protect this unique ecosystem, the Great Barrier Reef Marine Park Authority (GBRMPA) is progressively zoning sections of the Reef for scientific, commercial, and recreational uses.

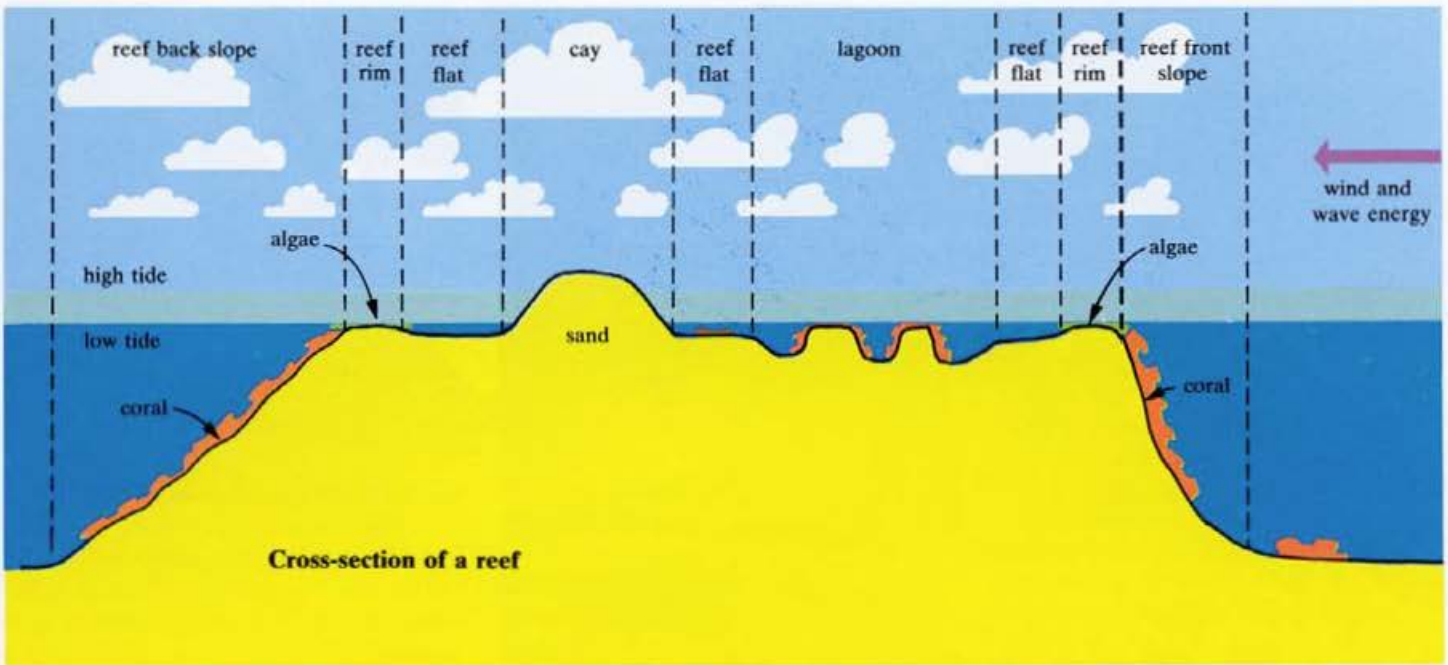
Tongue and Batt Reefs, near Cairns, as seen by Landsat. The image has been rectified: geometric distortions have been eliminated and map co-ordinates drawn in.

Variations in the depth to which Landsat's green, red, and infra-red bands could penetrate the water resulted in this map. It gives an approximate indication of water depth (water clarity also affects the depth of penetration).

Getting the computer to shadow the Reefs as if illuminated from the south-east gives this 'exposure image'. It provides a texture that indicates the Reefs' exposure to the south-east, from which prevailing winds come.



This map classifies Tongue and Batt Reefs into a number of significant zones. (The zones are portrayed in the diagram on the next page.)



Landsat sees three sorts of surface (sand, coral, and algae) through various amounts of water. The BRIAN system uses the spectral 'signature' of each to distinguish particular Reef zones.

Such an undertaking requires a comprehensive set of maps. Yet no satisfactory map of the Great Barrier Reef, at any scale, existed when GBRMPA was created in 1975.

To satisfy the urgent demand for an accurate map base on which research and planning could build, GBRMPA asked the CSIRO Division of Water and Land Resources whether Landsat pictures could be reliably used for mapping.

Between 1980 and 1984, Dr David Jupp and Divisional colleagues investigated the possibilities of transforming Landsat's digital images into effective tools for environmental planners and managers. Their work was supported by GBRMPA and the Australian Marine Sciences and Technologies Advisory Council (AMSTAC),

Interpreting Landsat's pixels

The mapping effort has utilized not only Landsat's spatial resolution — limited by the 80 m × 80 m size of each pixel — but also the fact that each Landsat image comes in four different wavelength bands, two in the visible band and two in the infra-red.

Landsat's spectral bands were not designed for water mapping and reef work, but the BRIAN system carefully analyses and enhances the colour information contained in the scenes (each wavelength band appears as one of 64 shades) to bring out essential features of the reef environment.

The diagram shows a cross-section of a typical reef, and all its different zones that can be discerned using the BRIAN system. Significantly, most of the reef cover classes are under water except at very low (spring) tides. For example, of the 1150 pixels that cover Green Island reef, only 50 cover the cay itself. (Incidentally, a standard Landsat scene contains 7·6 million pixels.)

Since the water properties and depth vary from scene to scene, the effect of water weakening the signal is significant. The ability of Landsat to see through the water is limited to about 20 m under ideal conditions, and considerably less under turbid ones.

Considerable care must be taken to separate out the various effects of turbidity, water depth, actual bottom reflectance, and haze in the atmosphere. Several images of the same area are required to achieve this.

Unfortunately, Landsat only gets a good view of the Reef on relatively few occasions. The most important factors are a low water cover (low tide) and little cloud. Yet in summer, when the sun is most directly overhead (giving better light penetration into the water), only about 1 overpass in 20 coincides with less than three-eighths cloud cover and a tide height of not more than 1·5 m. So, given that Landsat returns to the same position every 18 days, it takes about 2 years to get one good summer scene.

In winter, cloud cover is much less, and Landsat is then likely to get two good images during a single season, but the signal returning from beneath the water is weaker.

Given good images, BRIAN sets to work to identify the 'signature' of each biologically significant reef cover. This is easier said than done; the task is described in some detail in *Ecos* 31.

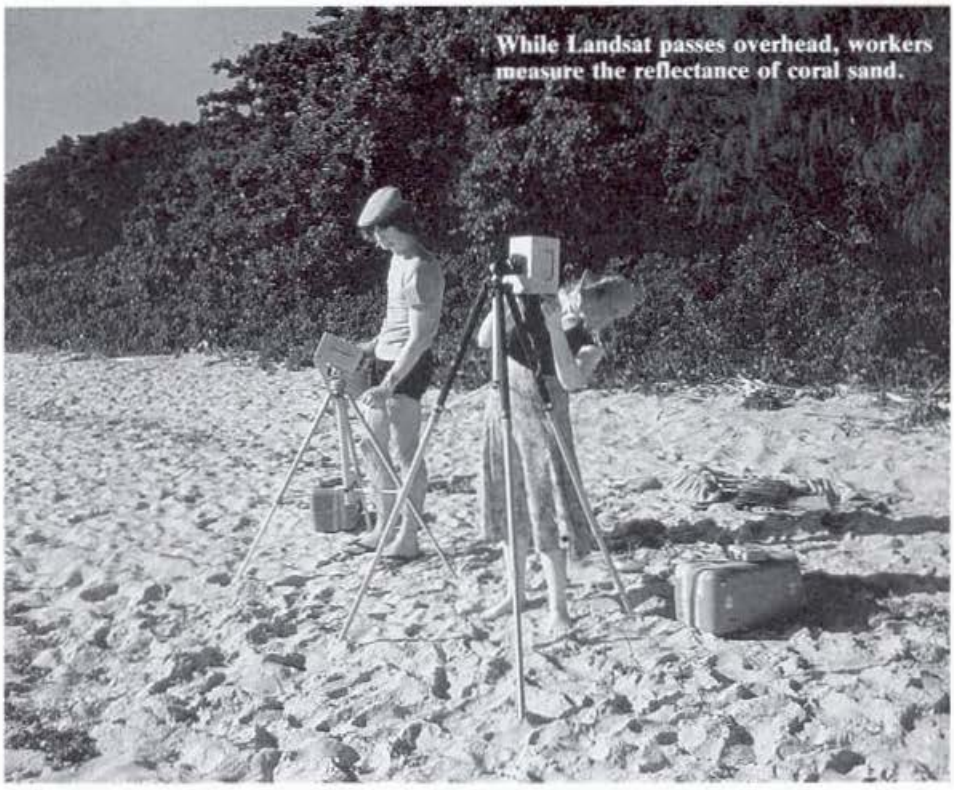
The success of the method can be judged by its results, and the images of Tongue and Batt Reefs, reproduced on the facing page, give an idea of how much information can be extracted from the raw Landsat data.

The 'depth of penetration' image uses the strengths of the green, red, and infra-red signals to give an idea of water depth at any point. The clarity of the water also affects the signal strength.

The 'exposure' image provides a good indication of reef structure and exposure to the south-east, which is the direction prevailing winds come from. Effectively, the three-dimensional structure of the reef is 'shadowed' as if illuminated from the south-east. This map makes it relatively easy to interpret where particular types of coral will be found, since certain types (brain coral, for example) can withstand exposure to wind and waves on the reef front; others (like branching corals) generally prefer a sheltered spot at the back of the reef.

The 'classified' image relies on a complex analysis of all the wavelength bands. It takes regions labelled in terms of coral and sand cover (based on the physics of light reflection and transmission) and develops them into a detailed description meaningful to a reef scientist.

Taken together, the three images provide a good working description of a reef's physical make-up.



While Landsat passes overhead, workers measure the reflectance of coral sand.

and involved close collaboration with the Australian Survey Office. Some of the work was done in collaboration with the James Cook University of North Queensland at Townsville.

Dr Jupp's Remote Sensing group has shown that it can be done. They have demonstrated that 24 Landsat scenes, each containing 7·6 million picture elements (pixels), can be processed by computer into maps of the entire Reef. At a scale of 1:250 000 the maps satisfy the stringent National Map Accuracy Standard: 90% of ground reference points deviate by less than 0·5 mm from their correct grid co-ordinates.

Effectively, that means an error on the ground of about 64 m — not bad when you consider that each Landsat pixel covers an area 80 m square. The new maps are of far better standard than any existing maps, some of which were found to contain errors as large as 1 km.

The new maps are far better than any existing ones.

In addition to standard maps indicating position, the CSIRO researchers have distilled the raw Landsat data into three other types of map indicating important reef features.

One type shows approximate water depth; another classifies the reef into various sorts of reef flats, reef rims, lagoons, and reef slopes. The shaded texture of the third allows ready inference of the profile of a reef, from which a reef worker can interpret where various coral types and ecological habitats are likely to be encountered.

The computer programs and techniques developed by CSIRO — collectively called

From pixels to plotter

Converting a digital Landsat image into a map isn't as easy as it appears at first sight.

The major problem is distortion: when a raw Landsat image, built up from to-and-fro scanning of the earth's surface, is displayed on a screen, it differs markedly from a true projection of that surface. Most of the distortion comes from the way the satellite observes a spherical earth from an oblique angle. However, other contributions come from the satellite's orbital movement, the earth's rotation, optical and instrumental errors in the scanning system, and several other minor effects.

Trying to take account of all these factors is called 'rectifying' the image, and can take a considerable amount of computer time.

The resulting image has a typical error of 200–500 m. This is satisfactory for many applications, but if you want to attach co-ordinates, or monitor physical changes at some particular point, then you need a lot more work. First you need to identify certain pixels with known features on the ground (man-made structures are often good for this). This gives you a number of 'ground control points' that have known map co-ordinates.

Once these pixels have been put in register with the ground control points, the job is to try to fit all the other pixels into register in a uniform way. The fit is never perfect, because of jitter and other fleeting irregularities in the scanning system. The best possible fit (using some mathematical relation) will minimize the degree of mismatch between known and inferred co-ordinates.

When all goes well, you find that the residual effective error can be less than a pixel's width (80 m). Unfortunately, ground control points don't always occur where they are needed for making good fits. In the Great Barrier Reef region, you often find that the ground control points are on the coast, while the reef to be mapped lies 80 or 100 km off shore. Extrapolating that far is bound to give errors, and accuracy of no better than a couple of hundred metres can be claimed.

An additional problem arises for those images where ground control points are themselves unreliable. Dr Jupp has discovered systematic errors in existing charts of up to 550 m. For example, the marked position of the coast near Innisfail can vary by 170 m from the true position depending on what map you consult, and the positions of reefs nearby can differ by more than 500 m.

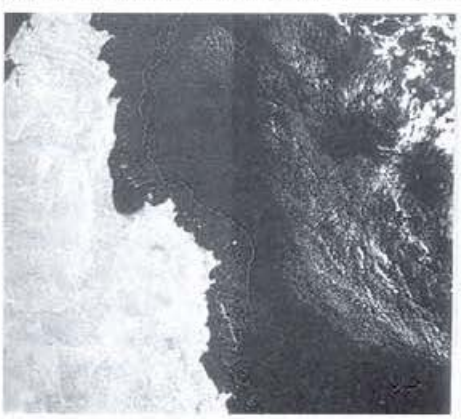
The point to remember is that Landsat can produce maps rapidly, but these can be no more accurate than the co-ordinates assigned to ground control points. The Australian Survey Office and the Queensland Department of Mapping and Surveying have recognized this, and they are providing very accurately surveyed selected groups of reefs for careful registration of the Landsat imagery.

The Landsat maps produced to date have been individually made by computer-controlled ink-jet plotters — a relatively cheap, quick, and repeatable production method. The scale of the map can be easily changed to suit the purpose at hand. Standard contour maps (at the same scale) can be conveniently overprinted by this method.

Landsat maps at a 1:25 000 scale (a 10-times enlargement of the base maps), and laminated with plastic, have been taken into the field by GBRMPA personnel, who have found them extremely useful.

The Fitzroy River, near Rockhampton, disperses into the ocean. Landsat picks out how the river loses its suspended sediment.

'BRIAN', the Barrier Reef Image ANalysis system — have been transferred to the Australian Survey Office (A.S.O.). The staff of A.S.O. can now produce a map of



A satellite view of the Great Barrier Reef. This image comes not from Landsat, but from Nimbus–7, which has a much broader view.

any reef to order and, together with the Queensland Department of Mapping and Surveying and the GBRMPA, the body is considering the production of a complete Atlas of the Barrier Reef.

At the same time, A.S.O. and the Queensland Department of Mapping and Surveying are continuing with conventional cartography of the Reef, a time-consuming and expensive business that requires survey crews to visit and chart each component reef one by one. But it's necessary so that eventually maps with the precision of the best land surface maps will be available for those reefs that may need intensive management. Meanwhile, for many purposes the Landsat-based maps will serve the needs of reef planners well.

Landsat for microcomputers

GBRMPA is delighted with the Landsat maps. Its Chairman, Mr Graeme Kelleher, estimates that the complete map set has cost the Authority $250 000, whereas production of charts using conventional techniques might cost $21 million, and 10 years' work.

In addition, the BRIAN system has been developed into a software package that can be run on a microcomputer. This means that reef scientists and planners can take the raw Landsat image, stored on disc, and manipulate it themselves to bring out features of particular interest. (The basics of how BRIAN processes Landsat data were described in *Ecos* 31.)

The wider potential of this 'micro-BRIAN' system has been recognized by an Australian computer company, Microprocessor Applications Pty Ltd. The company has mounted micro-BRIAN on image-processing equipment that, together with software, should sell for about $25 000. For this sum, many Pacific and ASEAN nations can acquire a complete system for analysis of Landsat data.

A successful pilot project has already been completed in Papua New Guinea, and interest has been shown by government authorities in Indonesia, the Philippines, Malaysia, Thailand, the Republic of the Maldives, Fiji, and the Solomon Islands. These countries possess a considerable quantity of poorly charted or uncharted reefs and islands, and Landsat could quickly fill a recognized gap. The same image-analysis system could also be used for monitoring land use, such as the development of rice crops.

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More about the topic

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Landsat based interpretation of the Cairns section of the Great Barrier Reef Marine Park. D.L.B. Jupp, K.K. Mayo, D.A. Kuchler, S.J. Heggen, S.W. Kendall, B.M. Radke, and T. Ayling. *CSIRO Division of Water and Land Resources, Natural Resources Series* No.4, 1985.

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