4. EXISTING DATA OPPORTUNITIES

Within the scope of the useful and feasible types of remotely sensed data which may be applied to the research and management needs within the GBR system there already exists a significant base of largely unexploited data.

4.1 Aerial photography and sunglint

Existing aerial photography of reefs contains interesting information on micro-flows of water around and over reefs. Where sunglint occurs within the frame, extensive slick and shear patterns can be seen (cf Stilwell, 1969). Cox and Munk (1954, 1956) have also used the glint area to infer wind speeds and spectra near the sea surface. At spacecraft altitudes, the areas of extensive calm within the sunglint can be mapped and related to frontal areas in the wind and current systems (McClain and Strong, 1969). Even simple hand-held panchromatic photography could be gleaned for important wave information, such as dominant wave length, wave direction and refraction around shallow reef areas. However, the lack of quantitative multispectral information in a photograph generally limits the use of this opportunity.

4.2 Landsat data

Landsat combines good spatial resolution with a large area mapping capability (80 metre resolution element - or pixel, and a 180 Km swath width). This enables it to detect broad scale ocean and shelf circulation and suspended sediment flow patterns throughout the GBR system on an opportunistic basis dependent on the 18 day repeat cycle and the degree of cloud cover. Such data have been successfully used (Thomson and Carpenter, 1981; Wolanski et al., 1984a, 1984b) in oceanographic applications to investigate the large area context of current mixing and island wakes and thereby to optimize the data from expensive ship based survey.

Oceanic and near coast fronts occur between water masses with quite different dynamics (such as tidal currents) or properties (such as river outflows). The fronts are the areas where material or energy exchanges are occurring and represent highly significant features in GBR studies. Klemas (1980) has shown how frontal systems, which can be delineated in Landsat imagery, are highly significant in pollution dynamics as oil and even fish eggs are entrapped by the fronts. Such oceanic fronts are some of the most dynamic areas of the ocean and growth of phytoplankton is often associated with them (Pingree et al., 1979). The Landsat image base provides one means for locating and investigating persistent frontal systems in the GBR region.

Landsat images sense different water masses and associated fronts since the different masses hold different amounts of suspended particles. This difference is also associated with different temperatures, salinities and chlorophyll contents (Mueller and LaViolette, 1981).

Alfoldi has applied algorithms developed in Canada (Alfoldi and Munday, 1978; Amos and Alfoldi, 1979; Munday et al., 1979; Alfoldi, 1982) to map suspended sediment concentration for selected rivers of the Queensland coast. The technique, called the 'Chromaticity' method, uses colour ratios of Landsat bands and a method for standardizing between different dates to obtain quantitative estimates of suspended solids concentration. With more ground data for calibration the chromaticity method could be applied to the complete historical set of images available and help research the dynamics of the plumes of terrigenous sediment which move along the Queensland coast. (cf Lindell, 1983 for applications in Sweden). The chromaticity technique has also been applied to mapping, on an opportunistic basis, oil slicks which it is able to separate from sediment plumes.

Landsat does not, however, have sufficient spectral resolution to separate inorganic and organic suspended solids and also lacks the time resolution (a repeat time, assuming no cloud, of 18 days) to

investigate shelf circulation, suspended sediment plumes and pollutants on any more than an opportunistic basis (Klemas and Philpot, 1981). It is feasible (for example) that, due to the effective time resolution of the Landsat MSS, if an oil-spill occurred in the GBR region it might never be imaged, even if cloud free Landsat scenes were available, since the oil could be spilled and disperse between overpasses.

4.3 Coastal Zone Color Scanner (CZCS)

An instrument with much better spectral and time properties - but having low space resolution - is the CZCS which has been imaging the oceans from the NIMBUS-7 satellite platform since 1978 (Hovis et al, 1980; see also Carpenter, 1982)

CZCS has a range of sensors for spectral bands in the blue (443 nm), the green (520 nm and 550 nm) and the red (670 nm) regions of the spectrum as well as one on the boundary between the red and near infrared (700 to 800 nm) and one in the thermal infrared region (10.5 to 12.5 microns). These sensors were designed with high sensitivity and optimized for water property mapping. The CZCS bands are about 60 times as sensitive as the corresponding Landsat bands. CZCS is a large area mapping tool with a pixel size of 800 meters and a swath width of some 1000 Km. CZCS has a 6 day repeat coverage of any area - assuming cloud free days - with consecutive day overlap to improve the chance of attaining its basic period.

CZCS is designed to assess marine biomass (Hovis et al., 1980; Gordon et al., 1980) by detecting variations in concentrations of phytoplankton pigments. It has been shown that optical measurements using well placed spectral bands in the blue (high chlorophyll absorption) and green (low chlorophyll absorption) regions can give quantitative estimates of chlorophyll and related pigments concentration (Gordon and Clark, 1980; Smith and Baker, 1982; Gordon et al., 1983) in ocean regions where organic suspensions dominate.

Considerable data of opportunity exist over the GBR in the CZCS archive. The thermal channel senses Sea Surface Temperature (SST) to the same spatial resolution and is co-registered with the optical bands. These data represent a prime source for opportunistic mapping of GBR biological dynamics - including general communications between reefs and the estuaries of the Queensland coast (cf Smith and Eppley, 1982).

4.4 Advanced Very High Resolution Radiometer (AVHRR)

The energy distibution in the sea which is displayed by thermal gradients comes from absorption of the sun's energy and through the tidal forces of the sun and moon. The turbulent mixing in the ocean expesses the interaction of these physical forces through the energy balance and can be sensed as temperature differences in the upper layers of the ocean.

To the extent that the temperature of the sea surface (SST) mirrors temperature of the upper layers, the AVHRR instrument carried on the NOAA 6 and 7 satellites represents another large area data opportunity (Kidwell, 1981; Bernstein, 1982) for detecting frontal systems in the waters of the GBR and the Coral Sea.

The AVHRR has five spectral bands (one visible, one near infra-red and three thermal bands). The most important bands for SST studies are two thermal infra-red bands in the 8 to 14 micron atmospheric window. The use of this pair allows measurement of absolute SST to within 1.0 degree Celsius. With two satellites in operation up to four images may be obtained in a day (one morning, one afternoon and two at night) giving this instrument excellent time resolution.

The sensor transmitts data in two modes, a high resolution mode (HRPT or High Resolution Picture Transmission) and a lower resolution mode (APT or Automatic Picture Transmission). HRPT data has a pixel size of about 1.1 Km and APT data a pixel size of about 4 Km. APT data for the whole earth is able to be collected by NOAA but HRPT data, because of the volume of data generated, has only been collected for specific areas by NOAA or by local receiving stations.

Unfortunately, few high resolution images of the GBR exist, and historical data are limited to low resolution SST data (based on AVHRR-APT data). As AVHRR-HRPT data becomes routinely recorded in East Australia by local receiving stations (Carroll, 1982; Nilsson, 1982) these data will be significant in GBR very large area research. It is worth investigating the establishment of a local receiving station for this purpose as a station so located would effectively cover the Coral Sea and Northern Australia in a way not available through currently planned receivers in Southern Australia.

Of particular value will be the application of these data in fisheries research and applications (cf Borstad et al, 1982) where the rapid availability of data will enable many of the large area factors in fish population dynamics to be investigated.

4.5 Depth of penetration

While optical and thermal sensors provide significant data from the ocean and coastal region, it must be borne in mind that the information contained in the data concerns the uppermost layers of water.

The depth of penetration by optical sensors such as the first four CZCS bands is maximum in the blue for clear water at about 20 to 40 metres with the peak of penetration shifting to the green and red accompanied by rapidly decreasing depth as suspended particle concentrations increase. There is no water penetration in the thermal band and the AVHRR measures only the temperature of the surface skin of the water mass. The relationship between this surface temperature and optical depth penetration is also complex as the optical depth defines the extent to which the sun's radiation reaches different depths.

This has two implications. The first is that different bands provide information on different sections of the water column and should be used in conjunction to assess the homogeneity of the column. Mixing, for example, may be visible in one band and not in others. It is

especially important also, when using sea surface temperature, to assess the homogeneity of the water mass beneath the surface. The blue and green bands can do this.

The second implication is that supplementary data, taken at the sea surface and from the water column, are necessary to interpret and fully utilize remotely sensed data. A balanced integration of ship, aircraft and satellite borne measurements is therefore necessary to fully study the GBR water mass.

Remote sensing provides an ideal frame in which to embed traditional survey data and conversely, the ground truth provided by traditional survey and a variety of measuring tools is essential to obtain full value from remotely sensed data. However, existing (historical) data lacks the ability to integrate with other data in this way and the greatest benefits from future remote sensing will come when the remotely sensed and field based data types are combined in a well planned design.

5. FUTURE REMOTE SENSING OF GBR DYNAMICS

In the future, the flow of data from satellites, aircraft and sensors mounted on ships and buoys will increase dramatically.

5.1 Meteorological satellites

The fundamental role of the ocean temperature and the ocean climate in weather prediction and monitoring means that global coverage by meteorological satellites will continue and grow.

This provides an opportunity for GBR studies as satellites such as the NOAA series with the AVHRR sensors provide extremely valuable oceanographic data.

Future plans indicate that an AVHRR with a smaller pixel size (possibly as low as 100 metres or less than 400 metres) may be developed which would provide data of great value for research into dynamic inter-reef flows.

To assure data availability it could well be the time to assess this opportunity and construct a facility to access this and similar data for the GBR region from Townsville, or some other convenient location in Northern Australia.

5.2 High resolution satellite data

Satellites carrying higher resolution instruments like Landsat-5 with the TM (Thematic Mapper) instrument (which has a 30 metre spatial resolution and 7 bands) and the French SPOT satellite (20 metre spatial resolution for 3 bands and 10 metre for the single panchromatic band) offer the prospect of significant data opportunities to help map and survey the GBR. However, their spectral and time resolutions and extents are generally not ideal for fine scale dynamic water property mapping.

It is expected that within 10 years there will be a large number of high resolution optical scanning satellites in orbit, including the commercial successor to the NASA Landsat experiment. These satellites will almost certainly address the needs of the oceanic marketplace. For a discussion of future plans in this area see ALCORSS (1982).

5.3 Multispectral scanners

Multispectral scanners and imaging spectrometers on aircraft platforms sensing natural radiation provide a new dimension in flexible assessment of the properties of the waters in and around reefs. Although they are not new in remote sensing of water properties (Clarke et al., 1970; Arvesen et al., 1973; Hovis and Lueng, 1977), instrumentation and recording technology have developed considerably in recent years. (cf Hoge and Swift, 1981a; Edel et al., 1982).

It is important to note that despite advances in data analysis such as the development of algorithms for chlorophyll and suspended sediment mapping from passive multispectral data (Zwick et al., 1981), the actual limits and abilities of multispectral data to resolve significant water parameters are not fully established. Any actual data collection by multispectral instruments over GBR waters needs to be made initially in a research framework, be based on careful planning and utilize in-water measurements (cf Anderson, 1976; Smith et al., 1979).

Scanner data is becoming more common in Australia as commercial groups offer scanner data as an (expensive) option. As sensors and data logging develop and more companies provide scanners these costs can only decrease.

5.4 Active scanners

Active scanners carried on aircraft platforms can also map at spatial scales relevant to reef lagoon dynamics and local variations in phytoplankton populations. The laser fluorosensor (Campbell and Thomas, 1981) is among the most discriminating of the instruments available for deployment and such instruments are becoming available for research or commercial applications in the USA and Canada (EPA, 1981).

As with any aircraft flown instruments, the time resolution is poor and they lack the ability to make routine biological measurements with depth. Therefore, collateral data from moored buoys or ships are needed to fully utilize the remotely sensed data. The use of fluorescence to construct a biological analogue of the current meter, and provide such collateral data, is described by Whitledge and Wirick (1982).

5.5 Camera systems

The presence of camera systems as opportunities in Table 1 should not be neglected. Camera systems lead to film products which have good rectification and which are easily accommodated within existing survey systems.

A camera system is a basic complement to any aircraft based remote sensing system. It provides a record of the flight and data collection and may range from a hand held 35mm camera to a battery of fixed and free cameras with a variety of formats, films and filters.

Modern filters and films can provide narrow band data and multispectral cameras may be used to separate the bands during flight. Even at spacecraft altitudes, the high resolution, large format metric camera deployed on space shuttle by NOAA-NOS provides a data opportunity of great value for GBR mapping and inventory.

The main limitation to film is that the data are not radiometric, cannot be directly analysed by computer and its dynamic range (maximum measurable contrast) is poor. In water this problem is significant although film digitizing, in which the photogaphy is converted into digital form, with subsequent computer enhancement may improve matters (Munday and Zubkoff, 1981). The effectiveness of film digitizing and computer enhancement in this context should be researched as a significant means of providing future remotely sensed data for the GBR.

5.6 Radars

In the next 10 years there will be a dramatic increase in the number of radars flown by satellites. Following the (brief) success of SEASAT, radars (mainly SAR) will be flown on the Japanese Marine Observation Satellite (MOS-1), the Canadian RADARSAT and the European Space Agency's Earth Resources Satellite (ERS-1).

The USA plans to launch a satellite with an accurate altimeter called TOPEX and this, as well as those listed above, will provide data of great value for oceanographic and near reef current studies.

The main impetus for operational radar sensors on satellite platforms has been the benefits of their use for mapping and monitoring sea ice. Oceanography generally, however, will benefit from their data.