3. REMOTE SENSING OPPORTUNITIES FOR THE GBR

The remote sensing opportunities for the GBR depend on a match being made between the needs of management and research and the available methods and technology which comprize remote sensing.

3.1 Platform and sensor coverage

Figure 2 plots, on the same axes as Figure 1, the space and time resolution of the main existing remote sensing platforms. Together, satellites, aircraft, ships and buoys cover most of the range depicted in Figure 1 (Esaias, 1981). There are some gaps, but a sampling scheme like that recommended by the OCS Working Group (1982) in which an ocean colour scanner similar to the Coastal Zone Color Scanner (CZCS) carried on the NIMBUS-7 satellite (see section 4.3) is combined with ship cruises and moored and floating buoys would seem to effectively cover the space and time structure of (i), (ii) and (iii) above.

Each of the platforms has advantages and disadvantages as vehicles for covering the range of space and time scales involved.

Ships provide the distinct advantage of supplying detailed and fully controlled data using complex equipment measuring over a wide range of depths at every location. However, considerable time (and therefore money) is needed to cover areas with any extent and at reasonable resolution. It has been quoted (Simpson, 1981) that one day of ship time is needed to survey a 40 Km square at 5 Km resolution. For larger area surveys significant evolution of environmental parameters will have occurred and results cannot be treated on the same time basis.

Aircraft can cover much greater areas in less time but cannot carry the complexity of equipment nor manage the data flow to the extent possible on board ship. Also, the data are remote and generally no data from within the water column nor water samples can be taken. Nevertheless, aircraft provide the most flexible of the available platforms for obtaining remotely sensed data.

The main limitations for both ships and aircraft are defined by ship or flying time. In a given time (or cost range) the platforms may either concentrate the area of study to get good space and time resolution or extend the area at the cost of time resolution.

Satellite system design, on the other hand, is limited mainly by the technical limits to recording, transmitting and processing digital data. Large area synoptic survey with a rapid repeat time is usually matched with large pixels (low space resolution). Satellites with high

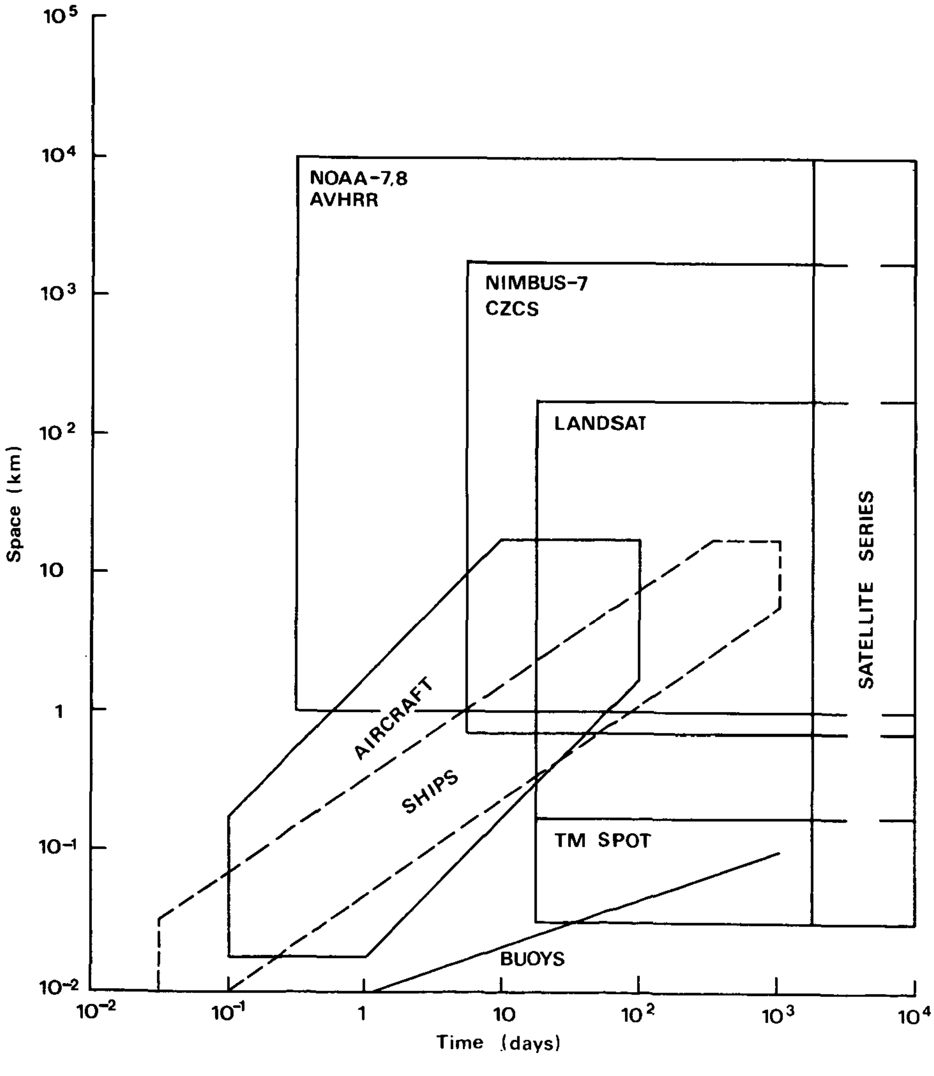

Figure 2. Resolution and extent of data platforms in time and space dimensions.

space resolution (small pixel size) generally cover smaller regions and visit them less frequently (see Figure 2) which reduces their effective time resolution. This different form of trade-off, in which the cost effectiveness of satellite systems increases as their operational lifetime, allows satellites to provide another degree of freedom in the design covering the full space and time range of the phenomena of interest in the GBR.

However, the total value of a sensor deployed on any of these platforms depends on its spectral resolution and extent and the intrinsic ability of spectral data to define the physical parameters of interest.

Spectral resolution refers to the width of the spectral region over which an observation is integrated and spectral extent to the range of wavelengths involved. Useful remotely sensed data come from many spectral bands ranging from the Ultra-violet to radio frequencies. Individual sensors, however, can only handle a limited combination of spectral resolution and extent.

3.2 The instruments available

Table 1 lists the most important of the instruments available at the present time and some of their proven applications. These instruments can be carried as sensors by a number of platforms, including satellites, aircraft, ships and even buoys. Moreover, matching sensors from Table 1 with platforms from Figure 2 may form a basis for designing a set of remote sensing applications to cover the phenomena plotted in Figure 1.

Some of the wide ranging uses to which these sensors have been put in oceanic and water quality measurement can be found in the Cited References and Additional Reading lists of this report and in Middleton (1983).

3.2.1 Optical remote sensing

Optical remote sensing sounds the Euphotic (or photo-productive) zone. In the GBR this may be the first 20 metres depth near the reefs and much less near the coast.

Generally speaking, the optical properties (or 'colour') of water depend on the underlying appearance of pure water (blue) modified by dissolved substances, inorganic and organic suspended particles as well as water depth and the nature of the sea floor. It is still not established whether an analysis of multispectral data can resolve all of these effects at a single point. However, it is well established that in restricted circumstances multispectral data can be used to resolve some of them, and that instruments may be flown from spacecraft to do it (Gower (Ed), 1981).

TABLE 1

Instrument	Description	Applications
Ocean Colour Instrument (OCI)	Selected visible and thermal bands or chlorophyll mapping	Primary production shelf processes. Chlorophyll and suspended sediment
Multispectral Scanner (MSS)	Wide set of bands for general applic- ations. Flexible spectral extent.	Coastal zone(incl wetlands) mapping and shallow water applications
Imaging Spectrometer (ISS)	Like MSS but using solid state tech- nology.	As for MSS but having better rectification
Camera System (AC,MSC, LFC)	Film based, possibly Multispectral (MSC) or Large format (LFC). recording, but low sensitivity.	Similar to MSS better rectification, cheaper data
Infra-red Radiometer (IR)	Thermal emission from sea surface.	Sea surface Temp, upwelling, fronts water masses.

Laser Fluorosensor (LIDAR)	Single wavelength laser to induce fluorescence. Emission measured over many bands.	Chlorophyll A and pigments. light attenuation, oil type.
Laser Depth Sounder (LIDAR)	Multi-wavelength laser profiler to measure time delay between sea floor and surface.	Bathymetry Turbidity
Microwave Radiometer (MR)	Microwave emission from sea surface.	Sea surface Temp and salinity. Oil slick thickness.

Instrument	Description	Applications
Altimeter (ALT)	Very precise nadir radar sensing height of satellite.	Surface current velocities, shear convergence and divergence.
Scatterometer (SCAT)	Off nadir back scattered radar.	Wind driven zones of convergence and divergence.
Synthetic Aperture Radar (SAR)	Off nadir radar with high (processed) resolution.	sea surface effects (eg swell, internal waves), bathymetry and surveillance.

In shallow waters, when suspended particles are not disturbing the signal, and water depths are of the order of 25 metres and less, then multispectral instruments can map bathymetry with fair accuracy (Bukata et al., 1981; Jain et al., 1981; Shiver, 1981).

For deep waters where organic suspended particles form the main factor modifying colour, Morel and Prieur (1977), Austin and Petzold (1981) and Clark (1981) have derived algorithms which measure ocean chlorophyll from spectral bands with specific resolution and extent. When the data are sensed from space, successful application of their methods also depends on careful correction for atmospheric and sea surface effects.

More generally, Moore (1980) and Johnson and Harriss (1980) describe how aircraft and spacecraft flown multispectral data can resolve a variety of ocean parameters more or less quantitatively depending on the complexity of the situation.

The relationship between fluorescence and chlorophyll A concentration has been used to measure phytoplankton for many years (Yentsch and Menzel, 1963; Strickland and Parsons, 1968; Kiefer, 1973a). With highly sensitive instruments, the natural fluorescence of chlorophyll may be used to infer phytoplankton abundance from airborne imaging systems (Neville and Gower, 1977; Gower, 1980; Gower and Borstad, 1981). This fluorescence may also be usefully induced with a laser as described below.

3.2.2 Thermal remote sensing

Optical remote sensing records the light which is scattered and reflected by the water column, the sea floor and any other components of the image. The signal is modified by the selective absorption of light by the different scene components to give them their characteristic signatures.

As well as reflecting and absorbing incident radiation, materials also emit radiation in various wavebands to balance the absorption and other energy inputs. The most important of these is thermal emission which occurs from every material above absolute zero temperature. The higher the temperature the shorter the wavelength of the maximum radiant energy so that the sun emitts most strongly in the visible region and the earth re-radiates most strongly in the infra-red region (3 microns to 1 mm) and weakly in the microwave (radio wave) region.

Reflected radiance is insignificant above about 4 microns and the atmosphere is reasonably transparent to radiation emitted in the 'windows' bounded by 3 to 5 and 8 to 14 microns. Therefore, remote sensing of this emitted radiation allows the temperature of the earth or sea surface to be sensed, even at satellite altitudes.

The temperature of the sea has great biological and physical significance. Temperature and salinity provide an oceanic index for different water masses and thermal gradients in the sea are both an indicator and mechanism for mixing and energy exchange between masses. Cool upwelling waters with high nutrient contents are often associated with highly productive areas (Walsh et al, 1977), and the 'warm core rings' of the Gulf Stream - as well as the East Australia Current - can form cells which transport biota over great distances.

Detectors for the major thermal emission band for the sea surface (8 to 14 microns) are well developed for all of the platforms used for remote sensing (Bernstein, 1982), and (unlike optical sensing) data may be taken at night as well as during the day. With multi-channel data, temperature and emissivity variations may be separated - with some significance for pollution mapping where emissivity variations represent significant components in the observed data.

Emission in the microwave region may also be used in conjunction with infra-red sensors (Thomann, 1975) to measure sea surface temperature and salinity (see also Blume et al., 1981).

3.2.3 Active lidars and radars

The previous instruments provide what is termed 'passive' remotely sensed data. That is, the source of energy is the sun and (in the case of thermal sensing) natural dynamic processes. When the source of energy is supplied by the instrument the method is said to be 'active'. Laser pulses and radar are the most widely used active energy sources used to date.

Active systems have the great advantage of being able to operate with cloud cover and during day or night - both significant advantages in the difficult GBR environment. It could be argued that for natural resources management in an area like the GBR a program based on remote sensing would be incomplete without the inclusion of some active remote sensing systems.

The LADS (Laser Airborne Depth Sounder, Calder and Penny, 1981) system is an active system which will, within 10 years, play a significant role in mapping GBR bathymetry. This system sounds depth by measuring the time difference between signals reflected from the surface and the sea floor providing an airborne replacement for the traditional echo sounder. The backscatter parameter is an additional measurement available from the data which can be used to measure turbidity (see Gordon, 1982; Phillips and Koerber, 1984; Phillips et al., 1984).

Laser induced fluorescence (emission) with a peak emission wavelength at 685 nm can be directly attributed to chlorophyll concentration (Bristow et al., 1979; O'Neil et al., 1980; Hoge and Swift, 1981a, 1983). This effect can be maximized by pumping with a laser beam in the blue region (440 nm) where chlorophyll A exhibits strong absorption. The developments outlined by Bristow et al (1981) have made this tool operational with high quality and reliability. Water has a natural fluorescence peak (Raman Fluorescence) defined by the input energy wavelength. Chlorophyll concentrations may be measured even in the presence of turbidity by using the Raman peak to normalize the measurement (Bristow et al., 1981).

By altering the frequency of the laser pulse a similar instrument may be used to unambiguously identify oil type in oil spills (O'Neil et al., 1981), and oil slick thickness (Hoge and Swift, 1983). Again, the Raman fluorescence is used to normalize the measurement. In this case the results are more reliable than chlorophyll concentration as oil has none of the feed-back mechanisms which living organisms use to avoid laser excitation (see Kiefer, 1973a and 1973b).

Sea state and wave spectra can be measured with Laser profilers, as well as the concentration of tracer dyes (Hoge and Swift, 1981b) and the location of estuarine fronts (Hoge and Swift, 1982).

Radar altimeters and Synthetic Aperture Radar (SAR) have applications for mapping surface winds, wave structure, internal waves and upwelling (Ross et al., 1970; Paniker, 1974) through an analysis of the energy backscattered from the rough sea surface. SAR is also a possible tool for general surveillance and detection of oil spills which may be separated from the general sea signal through the smoothing effect of the oil on the water.

The Seasat satellite's global coverage demonstrated how satellite borne radar, especially SAR, could measure sea surface topography, wave spectra, surface currents and even (indirectly) sense bathymetry (Born et al., 1979). The SIR-A experiment (Ford et al., 1983) confirmed this potential, and the SIR-B experiment (to be run in late 1984) may cover areas of the GBR - in which case more direct assessments of the potential of SAR may be available.

It would be very expensive, however, to monitor wave climates (for example) in the GBR region using radar based remote sensing. Such data would be occasional, but very useful, additions to data from a strategically located system of moored buoys.

Among the types of radar which might be considered for operational work is shore-based radar (Dexter et al., 1982) which could play a similar role to moored buoys in an integrated data system.