OVERVIEW OF THE AVAILABILITY AND SUITABILITY OF SATELLITE-MOUNTED SENSORS FOR THE PROVISION OF INFORMATION APPLICABLE TO MARINE MANAGEMENT

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SUMMARY

Remote sensing can contribute to improved marine management for the future. It can save time, money and effort compared to in-situ monitoring practices. There are an increasing number of satellites with remote sensing capabilities, providing vast quantities of data. This report aims to provide an overview of some satellites and the tasks each can perform relevant to marine management. Although there are a large number of satellites available for marine management, a number of considerations are required when selecting which particular type of imagery to purchase and use for marine management applications.

A general background on remote sensing of the marine environment is available in *Applications of Satellite Remote Sensing to the Marine Environment in Western Australia* (Pearce & Pattiaratchi, 1997), *Methods of Satellite Oceanography* (Stewart, 1985) or *Evaluation of the Feasibility of Remote Sensing for Monitoring National State of the Environment Indicators* (Wallace & Campbell, 1998).

With respect to all sensors referred to in this report, further details may be obtained through the State's leading agency on remote sensing, DLA (Satellite Remote Sensing Services).

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1 GLOSSARY

Across-track Scanner: A sensor that uses a mirror system that moves from side to side, across the platform's direction of motion.

Active Sensing: Remote sensing methods that provide their own source of electromagnetic radiation. e.g. radar

Along-track (push-broom) Scanner: A sensor that scans along the flight direction achieved by the platform's direction of motion.

Backscatter: Portion of outgoing radar signal that the target redirects directly back towards the radar antenna.

Field of View: Area or solid angle which can be viewed through an optical instrument

Geosynchronous Orbit: Stays in a fixed position in relation to the surface of the Earth.

Ground Resolution: A measure of the resolving power of a sensor when expressed as cycles per unit length on the ground from a given altitude.

Hyperspectral Scanner: A form of electronic camera that can acquire images of the earth's surface in hundreds of contiguous colour bands across the visible and infra red spectral regions of the electromagnetic spectrum.

Hyperspectral Scanning: Imaging in up to several hundred discrete spectral bands simultaneously.

Microwave Band: Very short electromagnetic waves (between far infrared and radio frequencies on the spectrum).

Multispectral Scanner: Line scanning sensors that detect and quantify electromagnetic radiation simultaneously in several spectral bands.

Nadir: A single point, or locus of points on the Earth's surface directly below a sensor.

Panchromatic Imagery: Imagery using all wavelengths within the visible spectrum.

Passive Sensing: Remote sensing methods that detect/measure the radiation emitted or reflected by the target.

Pixel: Also called pixel element. Data element having both spatial and spectral aspects. The spatial variable defines the size of the resolution cell (area on ground represented by the data values) and the spectral variable defines the intensity of spectral response for that cell in a particular channel.

Polarisations (vertical and horizontal): Process of confining vibrations of magnetic (electrical field) vector of light or other radiation in one plane.

Radar Band: Electromagnetic wavelengths between the extreme visible (0.7μm) and shortest microwaves (100μm).

Radiometric Resolution: The expected spread of variation in each estimate of scene reflectivity as observed in an image. (Smaller is better).

Resolution: The ability of a sensor to distinguish two closely spaced objects or lines as two rather than one object or line. Alternatively, the smallest object or narrowest line a sensor can detect.

SAR (Synthetic Aperture Radar): Active radar system

Spatial Resolution: Measure of the smallest angular or linear separation between two objects usually expressed in radians or metres.

Spectral Band: An interval in the electromagnetic spectrum defined by two wavelengths, frequencies or wave numbers.

Spectral Resolution: The ability of a sensing system to resolve/differentiate electromagnetic radiations of different frequency.

Sun Synchronous Orbit: Earth satellite orbit where the orbital plane is near polar and the altitude is such that a satellite will always pass over a specific plane on Earth at the same local sun time and at fixed time intervals.

Swath: The width of the track covered by a sensing system

2 INTRODUCTION

Remote sensing from satellites or aircraft provides quality information which can assist in improving management of coastal areas. Historically, environmental problems in the coastal zone have resulted from unsustainable use and unrestricted development of coastal areas and resources (earth.esa.int). Remote sensing can be used to monitor and hopefully avoid these problems. It can provide data that allow accurate, long-term predictions to be made, so that resources can be used to plan for change, rather than react to it (eos-pm.gsfc.nasa.gov/science.html).

Hyperspectral sensing is a relatively new field of remote sensing technology that can be exploited for many applications. It is based on the interaction and reflectance of photons with molecular structures of surface materials (www.eoc.csiro.au). Specific chemicals and physical properties of surface materials can be measured remotely, without sample preparation and destruction, providing timely and accurate information to the user (www.eoc.csiro.au). Hyperspectral sensors are an improvement over existing sensors as they can detect many different wavelengths through a wide region of the electromagnetic spectrum (www.iocg.org). Hyperspectral sensing could prove to be an extremely useful tool, and in the future may become essential to marine management.

2.1 GENERAL BACKGROUND

The use of satellite mounted sensors is investigated in this report. To allow comparisons, some information on airborne sensors is also included. Basic information on satellites is provided in the following paragraphs so that the reader can appreciate the information presented in the body of the report.

The satellites examined in this report are polar orbiting; following an overhead path around the Earth so that they pass close to the North and South Poles (www.iocg.org). There are also geostationary satellites that travel in the same direction as the Earth is turning, continuously viewing the same portion of the Earth's surface (www.iocg.org).

Polar orbiting satellites usually operate at an altitude of around 800 kilometres, with a revisit time of one to three days (www.iocg.org). The sensors mounted on the satellites can be programmed to provide imagery of particular areas at certain times. Satellites with sensors capable of detecting wavelengths in the visible range of the spectrum between 400 and 700 nanometres are most useful to marine management (R.Stovold, personal communication, January 3, 2001).

Geostationary satellites could be extremely useful to marine management. For example, they could potentially provide data on the diurnal variation of phytoplankton abundance and productivity, aid in the determination of the effects of storms and tidal mixing on phytoplankton populations, monitor biotic and abiotic material in river plumes and tidal fronts, or track hazardous materials such as oil spills and algal blooms (www.iocg.org). There are currently no geostationary satellites in operation to aid marine management (www.iocg.org), but once developed will prove very helpful.

Hyperspectral sensing can obtain complex spectra, usually with a much finer resolution (www.eoc.csiro.au) than standard techniques. It means that remote sensing tasks which were previously impractical or impossible can now be accomplished. It must be remembered, however, that hyperspectral imaging is a passive technique, depending on the sun as an illumination source (www.iocg.org). Unfavourable weather conditions can influence the outcome of the desired images.

2.2 OBJECTIVES

This report aims to provide an overview of a number of satellites that are planned for the future or currently in operation. The sensors and their application to marine management are investigated as well as the availability of the data to management agencies, such as the Department of Conservation and Land Management (CALM). Hopefully, this will provide the basic information required to identify satellites that can supply valuable information to CALM for improved marine management.

2.3 METHODS

A computer-based web search was undertaken to provide information on the use of satellite mounted sensors for acquiring information useful to the management of the marine environment. This information was then compiled and summarised to facilitate an evaluation of the information useful in marine management that can be obtained from satellite imagery.

3 RESULTS

3.1 EROS

Satellite Information

EROS A has a polar, sun synchronous orbit at an altitude of 480km. The swath width is 12.5km. This satellite has a planned lifetime of at least 4 years.

EROS B will have a polar, sun synchronous orbit with an altitude of 600km and a swath width 16km. EROS B has an expected lifetime of at least 6 years.
Each satellite has a daily revisit capability.

Sensor Characteristics

Panchromatic, along-track scanners are installed on EROS A, with an image resolution of 1.8m.
The panchromatic sensors on EROS B will provide an image resolution of 0.82m, using along-track scanning.

Data Availability

EROS A was launched in December, 2000.
EROS B is planned for launch in the 2nd quarter of 2002.
Image Sat International have partners in archiving and distribution in Australia.
Imagery is available through the online catalogue, ImageNet.

Applications for Marine Management

EROS has similar capabilities to Landsat and SPOT (R.Stovold, personal communication, January 3, 2001).

Web Address for Further Information

http://www.imagesatintl.com

3.2 QUICKBIRD

Satellite Information

Quickbird 2 will have a polar, sun synchronous orbit and same time of day passes. The satellite will have a swath width of 22km, and will allow scheduling of consistent revisits.

Sensor Characteristics

Quickbird satellites have high resolution sensors operating in panchromatic and multispectral modes. They can provide imaging up to 45 degrees off nadir, with a 1m resolution up to 30 degrees off nadir.

The multispectral sensor will have a resolution and pixel size of 4m, and will operate in the blue region of the electromagnetic spectrum at a wavelength of 450 - 520nm, green at 520 - 600nm, red at 630 - 690nm and near infrared at 760 - 890nm.

Data Availability

Quickbird 1 failed on launch on November 20th 2000.

Quickbird 2 is a commercial satellite owned by Earthwatch, planned for launch within twelve months. Imagery is available through digitalglobe.com, an online imagery store providing high resoution panchromatic and multispectral imagery to commercial businesses and governments worldwide.

Applications for Marine Management

The wavelengths that this sensor will operate in will make it possible to measure chlorophyll and other pigments, turbidity, suspended sediments, red tides and oxygen absorption.

Web Address for Further Information

http://www.digitalglobe.com.shtml

3.3 ORBVIEW

Satellite Information

OrbView-2 has a wide swath of 2,800km. It provides routinely available ocean colour imagery.

Sensor Characteristics

The SeaWiFS sensor on board OrbView-2 is a multispectral scanner providing a low spatial resolution of 1.1km and 4km, and operating in eight spectral channels, six of which are in the visible range, and two in the near-infrared range. It has an effective revisit time of one day.

OrbView-3 should provide high resolution imagery with the OrbView sensor. This sensor has a multispectral scanner operating in four channels at a resolution of 3.2m, and a panchromatic sensor providing 1.5m resolution.

OrbView-4 will provide high resolution imagery. The OrbView-4 sensor has a multispectral scanner also operating in four channels, but with a 4m resolution. The panchromatic sensor will provide an improved resolution to that of the OrbView

sensor, at 1m resolution. An added hyperspectral sensor can operate in two hundred channels at 8m resolution.

Data Availability

Orbview-2 (Sea Star) was launched in August 1997. Data from this satellite is accessible via direct downlink or via the web.
Orbview-3 and Orbview-4 were expected for launch this year.
Data from these satellites is available through Orbimage online Data Stores (http://www.orbimage.com).

Applications for Marine Management

The Orbview satellites can be used for fishing, environmental monitoring, scientific research and naval operations. OrbView-2 is useful for monitoring plankton and sedimentation levels in oceans.

Web Address for Further Information

http://www.iocg.org/sensors/500m.html
http://www.orbimage.com

3.4 EARTH OBSERVING-1

Satellite Information

EO-1 will collect multispectral and hyperspectral scenes in coordination with ETM+ on Landsat 7, allowing comparisons. It has a 705km sun-synchronous orbit and is installed with three sensors.

Sensor Characteristics

The sensor on-board the satellite which is relevant for marine management is the Hyperion. It recognises 220 spectral bands with wavelengths ranging from 0.4 to 2.5µm at a 30m resolution, and a sixteen day revisit time. It can image a land area of 7.5km X 100km.

Data Availability

EO-1 was launched in November 2000 by NASA to ensure the continuity of future Landsat data.

Applications for Marine Management

The Hyperion can detect and measure the quantity of specific chemicals, minerals or sediments in water, or colour in plants.
Hyperion will be used to map mangroves and coral reefs in tropical QLD, and optical water quality in Moreton Bay and other areas.

Web Address for Further Information

http://eo1.gsfc.nasa.gov

3.5 MTI - MULTISPECTRAL THERMAL IMAGER

Satellite Information

MTI has a 360 mile, polar orbit and an expected mission life of three years.

Sensor Characteristics

The sensor operates in fifteen spectral bands, from the visible to infrared regions of the electromagnetic spectrum.

Data Availability

The MTI is sponsored by the US Department of Energy and was planned for launch this year (2001). It is mainly intended for use by military branches and civilian agencies for use in future systems for detecting and characterising facilities producing weapons of mass destruction.

Applications for Marine Management

This satellite measures surface temperatures, materials, water quality, vegetation health, and provides information on atmospheric water vapour, aerosol content and sub-visual cloud presence.

Web Address for Further Information

http://nis-www.lanl.gov/nis-projects/mti/

3.6 NOAA - NATIONAL OCEANOGRAPHIC AND ATMOSPHERIC ADMINISTRATION

Satellite Information

The NOAA satellites have polar, sun synchronous orbits and provide low resolution imagery.

NOAA 15 (NOAA-K) orbits at 833km altitude.

NOAA 14 orbits at an altitude of 850km and has a swath width of 3000km. The repeat cycle is 9 days at nadir.

Sensor Characteristics

NOAA satellites use the AVHRR (Advanced Very High Resolution Radiometer) sensor, which operates in five spectral channels, from wavelengths of 0.6µm to 13µm (Stovold, Wylie and Miller, 1990) at 1100m or 4000m resolution. This sensor has an effective revisit time of 0.25 days.

Data Availability

NOAA-N is planned for launch in 2003.
NOAA-M is planned for launch in 2001.
NOAA-L was planned for launch this year.
NOAA 15 was launched in May, 1998.
NOAA 14 was launched in December, 1994.
NOAA 12 continues transmitting HRPT (High Resolution Picture Transmission) data as a standby satellite.
Sea Surface Temperatures are available free of charge to government and academic agencies.

Applications for Marine Management

Some applications for NOAA satellite imagery include dynamic oceanography, hydrology, air and sea pollution monitoring and toxic algal bloom detection.
It can provide large-scale information on ocean current circulations, water temperature and algae concentrations.

Web Address for Further Information

http://www.eurimage.com
http://sgiot2.wwb.noaa.gov
http://psbgi1.nesdis.noaa.gov

3.7 ENVISAT-1

Satellite Information

No information readily available.

Sensor Characteristics

Envisat-1 holds a radar sensor (ASAR) and a multispectral sensor (MERIS). ASAR (Advanced Synthetic Aperture Radar) allows the selection of different swaths, providing a swath coverage over 400km wide. This means enhanced capability in terms of coverage, range of incidence angles, polarisation and modes of operation.

MERIS (Medium Resolution Imaging Spectrometer) covers a swath width of 1150km, and has a spatial resolution of 300m (at nadir). It uses along-track and cross-track scanning, and operates in the visible range of the spectrum, so illumination conditions need to be suitable. It detects fifteen spectral bands, ranging in wavelengths from

390nm to 1040nm, which can be selected by ground command and are programmable in width and location.

Data Availability

Envisat-1 will be launched in June, 2001 by ESA (European Space Agency). Imagery is available through ESA distributors and can be ordered online. Free data for scientific research will be available several months after the launch.
For more information on Envisat-1 contact envisat.help@esrin.esa.it.

Applications for Marine Management

The MERIS sensor can perform studies on the upper layers of the ocean. MERIS can measure the photosynthetic potential by detection of phytoplankton, and detect yellow substance (dissolved organic material) and suspended matter (e.g. re-suspended or river-borne sediments). Also, it is capable of detecting certain plankton blooms and water quality, monitoring of polluted areas and can provide topographic observations (coastal erosion).

Web Address for Further Information

http://www.iocg.org/sensors/500m.html
http://envisat.esa.int

3.8 ADEOS-II - ADVANCED EARTH OBSERVING SATELLITE-II

Satellite Information

ADEOS-II orbits at an altitude of 803km, provides a swath width of 1600km, and has 1km resolution imagery. ADEOS-II has a repeat capability of four days.

Sensor Characteristics

One of the sensors used on this satellite include the AMSR (Advanced Microwave Scanning Radiometer). The GLI (Global Imager) detects thirty-six spectral channels, of which fifteen are dedicated to ocean colour. Other sensors on the satellite include ILAS-II (Improved Limb Atmospheric Spectrometer), SeaWinds, and POLDER (Polarization and Directionality of the Earth's Reflectances).

Data Availability

Adeos-II was launched this year.

Applications for Marine Management

The sensors on ADEOS-II should aid in the understanding of the circulation of water and energy.

The AMI sensor seeks to collect data globally for investigating the circulation of water and energy. AMI measures water vapour content, precipitation, sea surface

temperature, sea surface wind, and sea ice measurements day and night, with or without clouds.

GLI is particularly useful for ocean colour observations. These measurements are important for determining global circulation of carbon, monitoring clouds, snow, ice and sea surface temperature, and investigating primary marine production. GLI provides water absorption bands to obtain vertical profiles of water vapour. Infrared radiation measures chlorophyll, dissolved organic matter, surface temperature, vegetation distribution, vegetation biomass, distribution and albedo of snow and ice.

Web Address for Further Information

http://www.iocg.org/sensors/500m.html
http://sharaku.eorc.nasda.go.jp/ADEOS2/

3.9 INDIAN REMOTE SENSING

Satellite Information

IRS-P4 has a polar, sun synchronous orbit at an altitude of 720km, a swath width of 1420km and a repeat cycle of two days. The mission is expected to last five years.

IRS-P3 has a polar, sun synchronous orbit at 817km altitude, and a five day revisit capability.

On IRS-1C, the panchromatic and LISS-3 sensor have a repeat cycle of twenty-four days and WiFS has a revisit time of five days.

Sensor Characteristics

IRS-P6 will hold two sensors: the LISS IV and the AwiFS sensors. LISS IV is a multispectral sensor operating in seven channels, with 6m or 23.5m resolution. AwiFS is also multispectral, with 3 channels, offered at 80m resolution.

IRS-P5 has a panchromatic sensor with a 2.5m resolution.

The Oceansat (IRS-P4) carries the multispectral OCM (Ocean Colour Monitor) and the MSMR (Multifrequency Scanning Microwave Radiometer). The OCM identifies eight narrow spectral bands (from 400 to 885nm) at 360m resolution and a sixteen day revisit time. The MSMR has a swath width of 1360km and uses four microwave frequencies.

IRS-P3 has three sensors: WiFS, MOS (Modular Optoelectronic Scanner) and X-Ray astronomy experiment. The MOS has a spatial resolution of 500m and a twenty-four day revisit time.

IRS-1D and IRS-1C contain a WiFS multispectral scanner which operates in two channels at the red and near infrared regions, at 188m resolution and a swath width of 774km. The multispectral scanner LISS III identifies three channels in the green (0.52-0.59μm), red (0.62-0.68μm) and near infrared (0.77-0.86μm) regions of the electromagnetic spectrum at 23m resolution, and one channel in the SWIR region (1.55-1.7μm) at 70m resolution. It has a swath width ranging from 70-141km. The

panchromatic sensor has a 5.8m resolution and swath widths ranging from 23 - 70.5km. IRS-1C is capable of off nadir viewing (+/- 26 degrees across track).

IRS-1B uses LISS-I, a multispectral scanner using four 4 channels at 72.5m resolution, and LISS-II, also a multispectral scanner using four channels at 36.25m resolution.

Data Availability

IRS-P6 is planned for launch in 2001.
IRS-P5 was launched in 1999.
IRS-P4 (Oceansat) was launched in 1999 and was primarily built for ocean applications.
IRS-P3 was launched in March 1996- 97/98
IRS-1D was launched in 1997.
IRS-1C was launched in 1995.
IRS-1B was launched in 1991.

ACRES does not directly downlink IRS data, but can supply it through Space Imaging, USA.
IRS-1C data is currently limited to the USA, Germany and India.
IRS-P3 is largely an experimental mission and information is generally only available to ISRO (Indian Space Research Organisation) and DLR (German Aerospace Research Establishment). However, access to other parties may be established depending on the success of the mission.
Data from the OCM on board IRS-P4 is available for scientific applications at copy cost.

Applications for Marine Management

The OCM on IRS-P4 can collect data on chlorophyll concentration, detect and monitor phytoplankton blooms, and obtain data on atmospheric aerosols and suspended sediments in the water. The MSMR sensor (also on IRS-P4) has the ability to collect data on sea surface temperature, wind speed, cloud water content and water vapour content in the atmosphere above the ocean.

The MOS on IRS-P3 can map water constituents (chlorophyll-a, yellow substance, sediments) in coastal zones. Oceanographic applications of the MOS include the mapping of different water constituents in open ocean and coastal zones. It can aid in the:

- Development of seasonal mapping of chlorophyll-a in open ocean and coastal zones,
- Estimation of primary production
- Regional and seasonal mapping of water constituents in coastal zones
- Derivation of anthropogenic pollution estimates, especially in coastal zones
- Study of land-ocean interaction in coastal zones
- Comparisons with other satellite sensors, and
- Estimation of sea roughness, using the SWIR channels of MOS and WiFS.

Web Address for Further Information

http://www.iocg.org/sensors/500m.html
http://www.auslig.gov.au
http://www.be.dlr.de/NE-WS/irs-p3.html
http://www.isro.org/irsp4.htm

3.10 SPIN-2

Satellite Information

No information given.

Sensor Characteristics

SPIN-2 has sensors for panchromatic photography called KVR-1000; providing 2m resolution and 1.56m pixel size, and TK-350; providing 10m resolution.

Data Availability

SPIN-2 was launched in 1999/2000. Imagery is commercially available through Aerial Images, Inc.

Applications for Marine Management

SPIN-2 imagery can be used as an alternative to aerial photography.

Web Address for Further Information

http://www.spin-2.com

3.11 RADARSAT

Satellite Information

Radarsat-2 can provide a resolution between 3m and 100m, and a swath width ranging from 10 to 527km. Radarsat-1 has a 798km circular, sun synchronous orbit, with a swath width ranging from 50km to 500km, and 8 - 100m resolution. Both satellites have a repeat cycle of twenty-four days.

Sensor Characteristics

The sensor on board Radarsat-1 is the Synthetic Aperture Radar (SAR). It has a spatial resolution of 10 – 100m and an effective revisit time from three to five days. The sensor can operate in 25 imaging modes, varying in respect to swath width, resolution, incidence angle and number of looks.

Data Availability

RADARSAT-2 is planned for launch in 2002.
RADARSAT-1 was launched in 1995.
For data contact ACRES or a Radarsat distributor.

Applications for Marine Management

Radarsat can be used for coastal zone monitoring. The sensor measures the amount of original signal returned back to it after loss due to scattering from the earth or water surface, and as such is suitable for discerning relatively 'rough' compared to relatively 'smooth' waters. It can also detect oil spills, ships, off-shore oil rigs. Radar penetrates cloud, fog and rain, so images can be guaranteed.

Web Address for Further Information

http://www.auslig.gov.au

3.12 AQUA

Satellite Information

Aqua will have a 705km polar, sun synchronous orbit and has a design life of six years.

Sensor Characteristics

There will be six instruments on board, of which AMSR/E E (Advanced Microwave Scanning Radiometer-EOS), MODIS (Moderate Resolution Imaging Spectrometer) and AIRS (Atmospheric Infrared Sounder) can be utilized for marine management. MODIS operates in thirty-six spectral bands, in wavelengths from 0.4 to 14μm. Bands 1-2 provide a spatial resolution of 250m, bands 3-7 provide 500m resolution and bands 8-36 can provide 1000m resolution. It achieves a 2330 km swath width and can view the entire Earth's surface every 1-2 days.

AIRS will measure simultaneously in more than 2,300 spectral channels in the ranges of 0.4 to 1.7μm and 3.4 to 15.4μm.

Data Availability

Aqua is planned for launch not earlier than July, 2001.

Applications for Marine Management

AMSR/E will measure cloud properties, radiative energy flux, precipitation, land surface wetness, sea ice, snow cover, sea surface temperature and sea surface wind fields. MODIS will measure ocean colour, which includes phytoplankton and dissolved organic matter. AIRS will measure atmospheric temperature and humidity, land and sea surface temperatures, cloud properties, radiative energy flux.

Web Address for Further Information

http://eos-pm.gsfc.nasa.gov/science.htmll

3.13 TERRA

Satellite Information

Terra has a near polar, sun synchronous orbit at an altitude of 705km. It has a swath width of 2300km across track, and 10km along track, at nadir. This satellite has a repeat cycle for this satellite is sixteen days. The satellite has an expected design life of six years.

Sensor Characteristics

The sensors on board Terra include ASTER (Advanced Spaceborne Thermal Emission and Reflection Radiometer); recognising fourteen spectral bands at 15, 30 and 90m resolution, MISR (Multi-angle Imaging Spectro-Radiometer), and MODIS (Moderate Resolution Imaging Spectrometer).

MISR determines the amount of sunlight scattered in different directions under natural conditions. It operates in four spectral bands (blue, green, red and NIR), at 275m resolution.

MODIS operates in thirty-six spectral bands, in wavelengths from 0.4 to 14μm. Bands 1-2 provide a spatial resolution of 250m, bands 3-7 provide 500m resolution and bands 8-36 can provide 1000m resolution. It can view the entire Earth's surface every 1-2 days. Parameters relevant to marine management are measured with bands 8 - 16, operating at wavelengths of approx 405 to 877nm. The revisit time is effectively two days.

Data Availability

Terra was launched by NASA in December 1999. The data stream from this satellite is free to air but requires reception from a suitable groundstation such as those operated by ACRES at Alice Springs and Hobart. New ocean and atmosphere data products will be available for research to the scientific community.

Applications for Marine Management

ASTER can be used to produce detailed maps of land surface temperature, emissivity, reflectance and elevation, and can aid hydrological studies.

MISR monitors monthly, seasonal and long term trends in the amount and type of atmospheric aerosol particles, the amount, types and heights of clouds, distribution of land surface cover.

MODIS can provide three categories of ocean products: ocean colour, sea surface temperature, and ocean primary production. These are used to investigate ocean circulation, ocean biology, and ocean chemistry. MODIS can measure chlorophyll fluorescence, which enables the mapping of phytoplankton distribution and health.

Web Address for Further Information

http://www.iocg.org/sensors/500m.html
http://asterweb.jpl.nasa.gov
http://terra.nasa.gov
http://modarch.gsfc.nasa.gov

3.14 ARIES - AUSTRALIAN RESOURCE INFORMATION AND ENVIRONMENT SATELLITE

Satellite Information

Orbiting sun synchronously at an altitude of 500km, ARIES has a swath width of 15km at nadir, and a revisit time of seven days.

Sensor Characteristics

The ARIES-1 hyperspectral remote sensing system operates with thirty-two contiguous bands in the visible and near infrared regions of the spectrum, from 400-1100nm, and thirty-two contiguous bands in the SWIR (Short Wave Infra Red) region, from 2000-2500nm. This system provides a spatial resolution of 30m at nadir. The panchromatic sensor has a resolution of 10m.

Data Availability

ARIES was planned for launch in 1999, and was operational by early 2000.
For further information email dpuniard@cossa.csiro.au

Applications for Marine Management

This satellite is useful for geological and resource mapping, finding variations in green and dry vegetation, and environmental monitoring.

Web Address for Further Information

http://www.eoc.csiro.au
http://www.auspace.com.au
http://www.syd.dem.csiro.au

3.15 NEMO - NAVAL EARTH MAP OBSERVER

Satellite Information

NEMO has a 605km, sun synchronous orbit with a swath width of 30km and a revisit time of seven days. The mission will last three years.

Sensor Characteristics

The sensors on board this satellite are COIS (Coastal Ocean Imaging Spectrometer) and PIC, a panchromatic sensor recognising wavelengths of 0.5 - 0.7μm, and with a 5m resolution.

COIS operates in 210 spectral bands over the range of 400 - 2500nm, with a 30m resolution. Sixty spectral bands make up the visible and near infrared regions of the spectrum, with wavelengths ranging from 400 - 1000nm, and the remaining 150 bands make up the SWIR regions, at wavelengths from 1000-2500nm.

Data Availability

This satellite was planned for launch in mid-2000 and is planned for use by the Office of Naval Research and Naval Research Laboratory in the United States.

Applications for Marine Management

NEMO is used for research activities in sensing and prediction, environmental science, and sea-based and littoral zone warfare, expeditionary, and special warfare. Areas of possible use include water clarity, bathymetry, underwater hazards, currents, oil slicks, bottom type, atmospheric visibility, tides, bioluminescence potential, beach characterization, atmospheric water vapour and subvisible cirrus.

Web Address for Further Information

http://nemo.nrl.navy.mil/public/science.html

3.16 SPOT

Satellite Information

For multispectral imagery, SPOT provides a ground sampling interval, or pixel size, of 20m X 20m. For panchromatic imagery the pixel size is 10m X 10m.
SPOT 5 provides a resolution of 10m for panchromatic imagery, and 20m for multispectral imagery. The swath width is 60km.

SPOT 4 has an 822km, near polar, sun synchronous orbit.

Sensor Characteristics

The sensor on board Spot satellites is the High-resolution visible and infrared instrument (HRV). It has a 20m spatial resolution and a twenty-six day revisit time, effectively four to five days with off-nadir viewing.

The multispectral sensor on SPOT 5 operates with three bands.

The HRV sensor on SPOT 4 recognises four bands: green, at 0.5-0.59μm, red at 0.61-0.68μm, near infrared at 0.79-0.89μm, and SWIR at1.58-1.75μm. It also has a monochramatic band operating in the visible region of 0.61-0.68μm. The VI (Vegetation Instrument) sensor has a 2250km swath width and uses the four bands at a 1km resolution. The HRV differs from the VI in that it has two 60km swath widths.

SPOT 2 has similar details to SPOT 4, except it houses the HRV sensor only, which operates at three spectral bands of green, red and near infrared, and it orbits at an altitude of 830km.

Data Availability

SPOT 5 is planned for launch in 2001.
SPOT 4 was launched in 1998.
SPOT 3 was launched in 1996 and is currently not available.
SPOT 2 was launched in 1990.

Enquiries and orders for SPOT data should be submitted to SPOT Imaging Services. Advanced programming is available through SPOT Imaging Services. Prices for Australian SPOT data can be found in the SPOT Price List.

Applications for Marine Management

SPOT can identify and map coastal features such as erosional and depositional features, coastal landforms, currents and wave patterns.

Web Address for Further Information

http://www.spotimage.com
http://www.auslig.gov.au

3.17 LANDSAT

Satellite Information

Landsat satellites have a near polar, sun synchronous orbit at 705km altitude, and a swath width of 185km. Landsat 1 - 5 provide an 80m resolution. The repeat cycle for all Landsat satellites is sixteen days.

Sensor Characteristics

The ETM+ (Enhanced Thematic Mapper Plus) and the ALI (Advanced Land Imager) are the sensors on board Landsat 7. The ALI has a 30m resolution and sixteen day revisit time. The ETM+ operates six multispectral bands at 30m resolution, one thermal band at 60m resolution, and one panchromatic band, at wavelengths from 0.52 to 0.9 μm (green to near infrared regions of the spectrum), and a resolution of 15m. Sensors on Landsat 5 include TM (Thematic Mappper) & MSS (Multispectral Scanner). TM has a resolution of 30m and uses seven bands in the visible, near, middle and thermal infrared regions. MSS uses four bands, except band 4 is turned off permanently, at an 80m resolution.

Data Availability

Landsat 7 was launched in April 1999.
Landsat 6 failed on launch
Landsat 5 was launched in 1984. Routine reception and ACRES acquisition of data ceased in December 1999. Future receptions depend on requests and information from Space Imaging, USA.
Landsat 4 was turned off in 1992, and kept in standby mode.
Landsat 1, 2 and 3 were decommissioned.

ACRES receives and processes data from the Landsat series of satellites. ACRES has archived nearly every pass over Australia and continues to receive and archive data from Landsat 7, generally on a daily basis. Enquiries about data availability or ordering of data should be directed to ACRES.

CALM may be eligible for discounted imagery from Landsat 5 TM and Landsat 7 ETM+ through membership to the Eurimage Research Club.

Applications for Marine Management

Landsat multispectral imagery can provide large-scale information on ocean current circulations, water temperature and algae concentrations. It can also be used for coastal water mapping.

Web Address for Further Information

http://geo.arc.nasa.gov/sge/landsat/17.html
http://www.auslig.gov.au

3.18 ERS - EARTH RESOURCE SATELLITE

Satellite Information

ERS 2 has a near polar, sun synchronous orbit at an altitude of 785km. This satellite has a 102.5km swath width, 30m resolution and a repeat cycle of thirty-five days.

Sensor Characteristics

The AMI (Active Microwave Instrument) is one of the sensors on board. It consists of the SAR (Synthetic Aperture Radar) which can operate in image or wave mode and the Wind Scatterometer. The SAR has a thirty-five day revisit time.

The image mode on SAR provides strips of high resolution (10 - 30m) imagery, 100km in width, but can only be used sparingly, as there are power and data storage limitations. Wave Mode detects changes in radar reflectivity of sea surface due to surface waves, and produces 5 X 5km images at intervals of 200km along track. The wind scatterometer has a 500km swath. It defines the relationship between backscatter, wind speed, wind direction and incidence angle.

Another sensor used on ERS-2 is the radar altimeter. It measures echoes from ocean and ice surfaces, and has a 10cm vertical resolution with a swath width of 1.3 degrees.

The ATSR (Along-Track Scanning Radiometer) is a four channel infrared radiometer with three channels operating, at 1.6, 10.8 and 12 μm. The ATSR provides a 1000m spatial resolution and has an effective three day revisit time.

The MWR (Microwave sounder) is attached to the ATSR, and provides measurements of total water content of the atmosphere within a 20km pixel. It is used to improve the accuracy of SSTs.

Data Availability

ERS-2 was launched in April 1995 by ESA. The measurements from its predecessor (ERS-1) were the most accurate measurements ever obtained from space, and have been enhanced for ERS-2. To order or enquire about data contact Eurimage. CALM may be eligible for discounted imagery from the ERS SAR data through membership to the Eurimage Research Club.

Applications for Marine Management

In the open ocean, ERS-2 can monitor ocean circulation, tides, currents and current fronts, the occurrence and propagation of internal waves, global wind/wave relationships, offshore exploration, ship routing, fish resource management, ship surveillance, design of ships and offshore equipment. The SAR can be used to determine evolution of swell wave systems, and the radar altimeter can study ocean currents, tides and the global geoid.

In the coastal zone, erosion studies and shallow-water bathymetry can be undertaken using SAR image data. Multispectral data-sets from ERS-2 reveal details of water clarity and can be used for pollution monitoring.

Web Address for Further Information

http://www.auslig.gov.au
http://earth.esa.int
http://www.eurimage.com

3.19 RESURS-01 #3

Satellite Information

This satellite has a 678km polar, sun synchronous orbit, with a wide swath width of 600km and a spatial resolution of 170m. RESURS-01#3 has a repeat capability of twenty-one days, with a potential repeat coverage of approximately four days at equator.

Sensor Characteristics

On board this satellite is the MSU-SK instrument. It uses four spectral bands; two visible and two near infrared, at wavelengths from 0.5 - 0.6, 0.6 - 0.7, 0.7 - 0.8, and 0.8 - 1.1µm. It provides a 160m pixel of medium resolution.

Data Availability

RESURS-01#3 was launched in November 1994. Information on this satellite is avalilable through ACRES.

Applications for Marine Management

RESURS-01#3 can be used for environmental monitoring and mapping the earth's natural resources. It can provide large-scale information on ocean current circulations, water temperature and algae concentrations.

Web Address for Further Information

http://www.auslig.gov.au

3.20 IKONOS

Satellite Information

IKONOS orbits at an altitude of 681km and has a swath width of 11km. It has a revisit interval of 2.9 days at 1m resolution, and 1.5 days at 1.5m resolution.

Sensor Characteristics

It uses panchromatic and multispectral sensors operating in the visible (blue, green and red) and visible near infrared regions of the electromagnetic spectrum. The panchromatic sensor provides a resolution of just 1m; the multispectral sensor provides a 4m resolution.

Data Availability

IKONOS was launched by Space Imaging in the United States, in September 1999. The distributor for IKONOS data is Iglass.

Applications for Marine Management

IKONOS has applications in cartography, defence, urban planning/industry, agriculture, forestry, and insurance.

Web Address for Further Information

http://www.eurimage.com

3.21 AIRBORNE SENSORS - AVIRIS

Satellite Information

Not Applicable

Sensor Characteristics

The AVIRIS (Airborne Visible Infrared Imaging Spectrometer) flies aboard a NASA ER-2 airplane, approximately 20km above sea level, at about 730km/hr. It recognises 224 contiguous spectral channels, each with a bandwidth of approximately 10nm, covering the range of wavelengths from 380 to 2500nm. For each scan, 614 pixels for the 224 detectors are used, with a pixel size of twenty square metres.

Data Availability

AVIRIS has imaged parts of the United States, Canada and Europe. For further information email av_tech@makalu.jpl.nasa.gov.

Applications for Marine Management

For coastal and inland waters, AVIRIS can measure chlorophyll, plankton, dissolved organics, sediment bottom composition, bathymetry, and detect environmental hazards. AVIRIS can be used to aid research in the areas of ecology, oceanography, geology, snow hydrology, cloud and atmospheric studies.

Web Address for Further Information

http://makalu.jpl.nasa.gov

3.22 AIRBORNE SENSORS - THEMAP

Satellite Information

Not Applicable

Sensor Characteristics

THEMAP system is a hyperspectral remote sensing measurement and mapping system. The equipment facilitating hyperspectral imagery is called CASI (Compact Airborne Spectrographic Imager). CASI data is gathered in three modes. In spatial mode it operates 19 bands, from 0.8m to 5m resolution. In spectral mode it operates 228 contiguous bands, and in enhanced spectral mode it can be used to acquire 72 spectral bands of 8.6nm width. It operates in the visible range from 400-1000nm (C.Ong, personal communication, January 3, 2001).

Data Availability

Images are available commercially (C.Ong, personal communication, January 3, 2001).

Applications for Marine Management

THEMAP system can be used to determine coastal benthic and water quality. It has been used for marine habitat mapping by CSIRO Land and Water at Hawkesbury River and Port Phillip Bay (C.Ong, personal communication, January 3, 2001).

Web Address for Further Information

www.themap.com.au

3.23 AIRBORNE SENSORS - HYMAP

Satellite Information

Not Applicable

Sensor Characteristics

HyMap operates 100 to 200 bands, each band having a width between 10 & 20nm. It can detect wavelengths between 450nm and 2500nm (C.Ong, personal communication, January 3, 2001). HyMap provides 2-10m spatial resolution and a sixty to seventy degree swath width.

Data Availability

The HyMap system has been introduced by Integrated Spectronics.

Applications for Marine Management

Hymap can be used for water quality monitoring, resource assessment and management, mineral exploration and geological mapping, wildfire monitoring, thermal surveys, defence and law enforcement, environmental audits, and urban planning.

Web Address for Further Information

http://www.intspec.com/hymap.html

3.24 ALLIANCE FOR MARINE REMOTE SENSING

The Alliance for Marine Remote Sensing (AMRS) Association publishes a magazine that focuses on marine observation. This magazine is titled Backscatter, and provides useful information on remote sensing of the marine environment. It provides practical information on remote sensing in the aquatic environment, and aims to present technologies that are relevant and practical to the maritime community.

Web Address for Further Information

http://www.amrs.org

4 DISCUSSION

There is a wealth of information that can be provided by the growing number of sensors on satellites. This report has reviewed a number of sensors that can be useful to marine management. The suitability of the sensors to particular projects can only be decided when considerations such as the quality and resolution of the imagery, revisit frequency, length of the mission and cost, among others, are taken into account.

This report found that of the satellites planned for launch this year, IRS-P6, Quickbird, Envisat-1 and Aqua can be most useful to marine management. Satellites already launched, and which have particularly useful applications to marine management, include Ikonos, ERS-2, ARIES, Terra, IRS-P4 Adeos-II, EO-1 and Orbview.

Other satellites also available for this purpose include Eros, Resurs-1, Landsat, SPOT and NOAA, although these satellites have a smaller range of wavelengths that can be detected. Radarsat could also be helpful depending on how the data it can provide would be used, as there is less detail provided. Airborne sensors could also be considered, particularly HyMap and Themap.

This report provides a very broad description of satellites, sensors and their functions. There was limited information online about the accuracy of the sensors and the specific parameters that they can measure. For more information, a more thorough search using a variety of sources, is required. In addition, the state's leading agency with expertise in remote sensing is DLA (Satellite Remote Sensing Services). Personnel from SRSS can provide further detail on the specifics of remote sensing instruments.

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