Remote Sensing for Coastal Resource Managers:

An Overview

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l Oceanic and Atmospheric Administration
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ORCA Organization

The Office of Ocean Resources Conservation and Assessment (ORCA) is one of four line offices of the National Oceanic and Atmospheric Administration's (NOAA) National Ocean Service (NOS). ORCA provides data, information, and knowledge for decisions that affect the quality of natural resources along the nation's coasts and in its estuaries and coastal waters. It also manages most of NOAA's marine pollution programs. ORCA consists of three divisions and a center: the Strategic Environmental Assessments (SEA) Division; the Coastal Monitoring and Bioeffects Assessment Division (CMBAD); the Hazardous Materials Response and Assessment Division (HAZMAT); and the Damage Assessment Center (DAC), a part of NOAA's Damage Assessment and Restoration Program.

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On the Cover

A high-resolution satellite image of Florida Bay (December 1995) using KVR-1000 instrument. Captain Key is located at bottom left; the Manatee Keys are at upper right. The above-water land is clearly outlined, while the submerged coral, sand and mud areas appear much lighter. Darker shades of blue indicate deeper waters and/or dark-colored vegetation (terrestrial or submerged). Average resolution is 2 meters per pixel (note 300 m scale bar).

Remote Sensing for Coastal Resource Managers: An Overview

1 Introduction

This report presents an overview of satellite-based remote sensing technologies, and discusses their potential as tools for assessing, managing, and protecting coastal resources. While remote sensing has proven useful in open ocean applications, it is an under utilized, yet very promising, technology for use in coastal regions. This overview focuses on the available systems, capabilities, and limitations of satellite-based technologies because they can be cost-effective methods for collecting environmental data. Once in service, satellites are usually a continuous source of information for many years, providing decade-scale monitoring of natural and man-made changes in ecosystems. This document is intended to provide coastal managers with sufficient detail to evaluate whether or not remote sensing can provide useful and usable information concerning their specific coastal issues.

In addition, this overview is intended to be a ready reference for coastal resource managers and their assistants who have heard or read that remote sensing is ***the*** answer. Many resource managers have not had time to stay abreast of the rapidly developing technologies involved in remote sensing. Yet, they find themselves in the position of needing to resolve specific environmental problems in regions which are: difficult to gain physical access to; do not lend themselves well to conventional manual sampling regimes; so large they cannot be plausibly studied within time constraints; or are in need of a change analysis with no previous on-site sampling having been conducted.

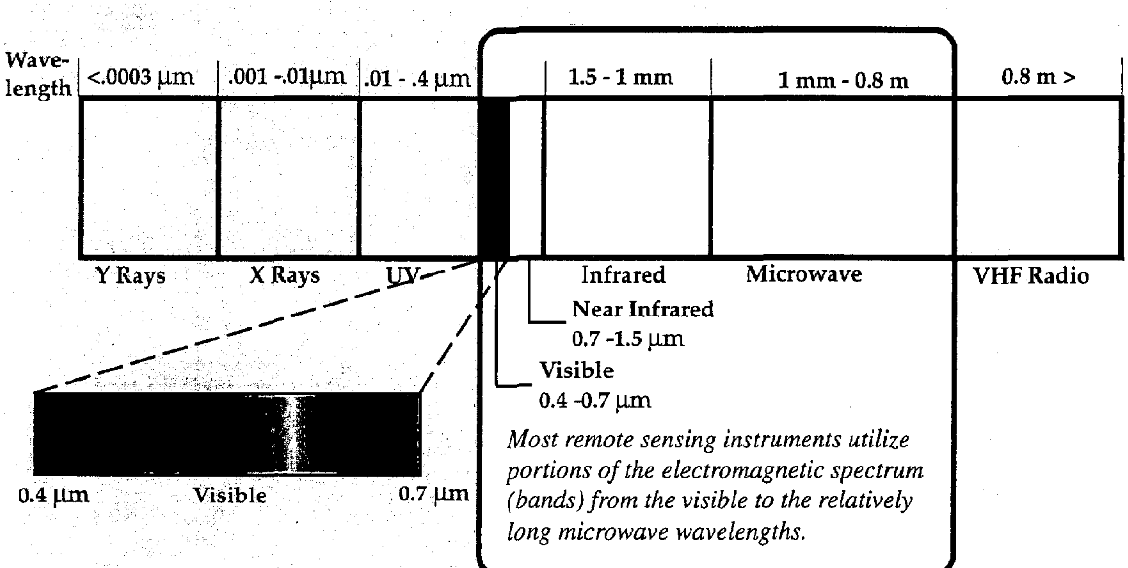
The different classes of instruments employed in a variety of satellite systems are discussed in the context of their application. Since most of these space-based sensors were not developed specifically to replace traditional manual coastal environmental assessment techniques, they have design and physical limitations for near shore applications. Additional limitations (such as whether or not they will be useful on a cloudy day) are also discussed. The realities of obtaining and utilizing remotely sensed data are reviewed. Since remote sensing and space science are highly technical arenas, they have generated their own lexicon of acronyms, which are explained in the Glossary. Five appendices provide tabular summaries of past, present, and proposed future space-borne environmental sensor systems.

The coasts are used by many individuals and industries for many different purposes, thus, the term ***coastal*** has many different meanings depending upon the intended use. For the purposes of this document, the term coastal will be confined to include the waters adjacent to the coastline (mean high water mark) out to where the open ocean processes dominate (usually the 200 meter isopleth). This definition of ***coastal*** is meant to include estuaries, harbors, inlets, embayments, lakes, and swamps; but exclude areas along the shoreline which are above the mean high water line.

Electromagnetic spectrum used for remote sensing

Generally, active and passive detectors in satellite-mounted instruments are sensitive to the optical (0.4 - 0.7 µm), near-infrared (0.7 - 0.9 µm), infrared (0.9 - 12 µm), and microwave (0.3 - 30 cm) portions of the electromagnetic spectrum. Within this range of the spectrum, data from the sensors are used to ***detect*** four basic properties of the ocean: color, temperature, height, and roughness. Many applications have been derived from the quantitative detection of these properties.

The images shown on the cover and in Figures 2-4 and 7-9 were produced from satellites with visible and thermal infrared optical sensors. Other remote sensing instruments provide information from parts of the electromagnetic spectrum beyond the visible and thermal regions. Microwave instruments, such as Synthetic Aperture Radar (SAR), can be used to map oceanographic features including ice fields, internal waves, fronts, eddies, and coastal habitats (Figure 9) in all weather conditions. The high-resolution SAR instrument has been used to detect oil spills, locate ships, monitor the topography in the ocean surface to detect changes in the coast, and map the bottom topography of shallow water. When data from multiple sensors is integrated, the product (Figure 3) can provide additional environmental detail, such as when sea heights (from altimetry) and temperatures (from infrared detectors) are ***fused*** to study circulation dynamics.



Most remote sensing instruments utilize portions of the electromagnetic spectrum (bands) from the visible to the relatively long microwave wavelengths.

2 What is remote sensing?

Remote sensing is the science of gathering information from a distance. Eyes and ears are remote sensing instruments. Vision is a form of optical remote sensing; listening is a form of acoustical remote sensing. Remote sensing makes use of a wide variety of media and technologies: radar is a type of radio energy remote sensing, and X-ray photography is a form of high-energy remote sensing.

In the case of eyes and ears as remote sensing instruments they are passive detectors and rely upon other phenomena to supply the energy (room light or a car horn). In contrast, radar and sonar actively broadcast their own energy source and derive information from its reflection and scattering. Information is produced by processing and interpreting the data arriving at the instruments.

Satellite remote sensing is used to obtain information about, and to take measurements of a place or phenomenon without direct physical sampling. The desired end product of photogrammetry* and remote sensing is scientifically valid, quantitative analyses derived from the data. A few of the environmental products derived from satellite remote sensing include: descriptions of current weather conditions; the status of wetlands habitat; coastal erosion processes; the location of oil spills; and the extent of algal blooms.

Satellite imagery can be valuable for observing large expanses and/or inaccessible areas. Ocean features such as large-scale circulation, currents, river outflow and water quality; can be visualized by highlighting variations in water color and/or temperature. These observations can then be used for such activities as ship routing, environmental monitoring of sensitive coastal zones, hazards assessment, and management of fishing fleets. High-resolution coastal images can be used to analyze and map sediment transport, bathymetry, erosion, and aquaculture applications; however, several of these are possible only when the skies are clear.

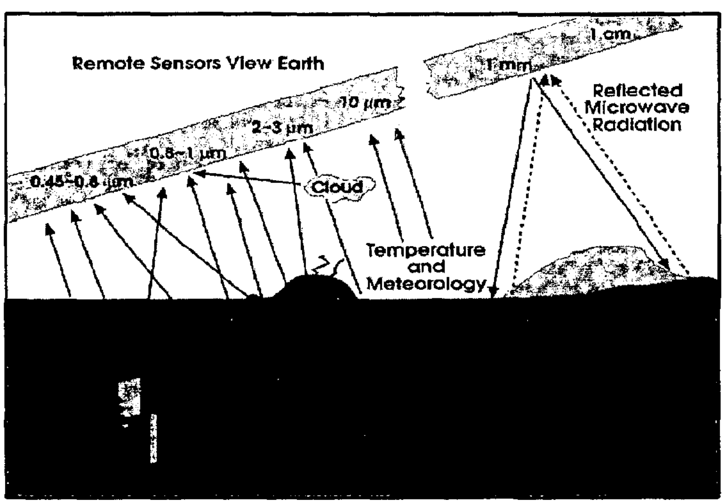


Figure 1. Depiction of how remote sensors view the Earth. Courtesy of the U.S. Office of Technology Assessment.

Applications of remote sensing to coastal management activities include infrared imagery to monitor changes in vegetative habitat; data on water temperature and color to better understand fish and invertebrate distributions; and real-time atmospheric data for weather forecasting. Remote sensing techniques are becoming increasingly cost-effective, given the rapid pace of innovation in computer technology, information networks, and improvements in sensing systems for satellites.

* the science of making reliable measurements by the use of photographs and especially aerial photographs.

Some Remote Sensing Terms

Resolution:

- **Spatial** is the parameter which describes the correspondence between the size of the spot on the ground viewed by each individual picture element (pixel) in the sensor on-board the spacecraft and is a function of altitude, lens geometry, construction of the sensing array, etc. (a 1 km pixel may be useful for observing the location of the Gulf Stream, but would be of no use in distinguishing among the different physical habitats in a 2-4 km wide estuary).

- **Temporal** defines the number of repeat passes an imaging system may provide over the same location (a satellite which provides repeat coverage of every other day may be sufficient to follow processes which have time scales of days but will be of limited use in observing change events which occur over only a few hours or during a tidal cycle).

- **Radiometric** is the number of data bits used to represent the intensity of the signal arriving at the sensor (a 4 bit representation or 16 levels of the full range from full brightness to full darkness is much less than that in an 8 bit or 256 levels radiometric resolution instrument).

- **Spectral** is the description of the instrument in terms of the number of different wavelengths each separate channel can detect and the width of each one of these (an 8 channel instrument with very wide channels is much less useful than an instrument with many, very narrow channels).

Geostationary vs. Polar Orbiting: The concepts explained above are not independent of one another. Observing satellites in orbit around the earth are generally placed into either of two different types of orbits. The traditional weather satellites as seen on TV are placed into an orbit such that, when viewed from the ground looking up, they appear to be stationed above one place on the surface as a consequence of their velocity through space matching that of the rotation of the earth. Thus, these are called geostationary satellites and have the advantage of being able to view one side of the planet continuously from their 39,000 km altitude. Geostationary satellites have very high temporal resolution and very wide viewing swath (one complete scan of one side of the planet every few minutes) but their spatial resolution is very low by virtue of being so high above the planet and their spectral and radiometric resolution are usually quite low to ensure rapid data transmission sufficient to identify rapidly moving storm fronts.

The other common orbital configuration for observing satellites is that referred to as Low Earth Orbiting (LEO) and is most commonly employed in near-polar orbits (canted to pass just to the East or West of the poles of the planet). While near-polar orbiting LEOs can view only a narrow swath as they speed by (low temporal resolution), they are able to collect imagery from the entire planet by virtue of the earth rotating underneath while the satellite collects non-repetitive imagery on succeeding passes. Near-polar orbiters, being much closer to the earth (800 km altitude) than geostationary satellites, also tend to collect much higher spatial resolution imagery.

Ocean Color (instruments sensing the visible portion of the spectrum)

The colors of ocean and coastal waters provide information as to their contents, and thus, their recent history and possible present productivity. Clear waters do not contain much suspended material, such as algae or silt; opaque, muddy waters indicate high concentrations of suspended sediment; and bright green waters normally indicate dense concentrations of algae, typically phytoplankton. These microscopic plants are important because they constitute one of the lowest trophic levels of the marine food web, and are involved in many geochemical processes including fixation of carbon and nitrogen.

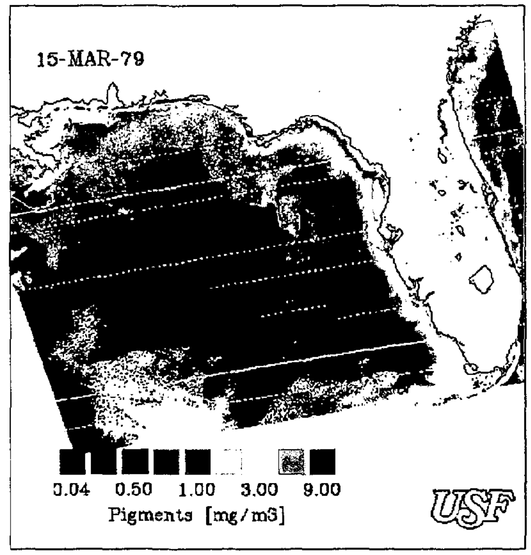


Figure 2. *Ocean color image, Eastern Gulf of Mexico, Nimbus-7 (CZCS)/Univ. of South Florida, March 1979.*

The observed color of water results from many phenomena: among them, the reflection and absorption of sunlight off of phytoplankton, suspended minerals, organic complexes, and dissolved organic and inorganic materials. The narrow, visible portion of the electromagnetic spectrum is used to record ocean color (Figure 2), which can be measured only during daylight hours in cloud-free conditions. The atmosphere between the water and the sensor also affects the quality and quantity of light detected at the sensor. To ensure accurate calibration of the numbers from the remote sensor, it is necessary to obtain frequent, *in situ* measurements of the waters being remotely ***measured***.

Typical coastal applications of ocean color monitoring include quantitative estimates of riverine input into estuaries, coastal erosion (the magnitude and direction of sediment transport), and the location and extent of human impacts on the marine environment. However, the geographic scale of coastal events is often so small that the spatial resolution and/or radiometric sensitivity of current space-based sensors are of minimal utility to coastal resource managers. In the near future, sensors such as SeaWiFS on SEASTAR, MOS on PRIRODA, and OCTS and POLDER on ADEOS should provide sufficiently fine detail to permit the location of algal blooms, including toxic red tides, fish stocks (because many planktivorous fish aggregate near the food sources), and ocean fronts and eddies (see Table 1 for sensors and applications).

Coastal Regions

Coastlines (ocean, lake, river) vary widely in their geomorphology, biota, and hydrology and thus, the precise definition of ***coastal*** depends upon the phenomena under evaluation and the region of observation. Applications of coastal remote sensing are discussed throughout this document and the resolution of various sensing systems is rated relative to its applicability for specific tasks. For example, 4 km spatial resolution remote sensing system can be adequate for imaging storms moving across the middle of North America, but are of little use in discerning details of the Florida Keys (most of which are less than 1 km wide). The need to locate a 500 m long oil spill requires finer resolution imaging systems than ones following meanders of the Gulf Stream (found off the East Coast of North America).

Sea Surface Temperatures (infrared, microwave)

The surface temperature of ocean and coastal waters may provide information as to the waters' origins and recent history. Waters upwelled from great depths are cold, nutrient-rich, and clearer than the surrounding water. Many of the world's major surface currents are warmer than the adjacent water masses.

In coastal areas, sea surface temperature (SST) measurements can locate coastal upwellings, fronts, river outflows, and intrusions of water masses. Regional SST measurements are useful for identifying the location and areal extent of major currents (e.g., Gulf Stream, Labrador Current) and their associated eddies and meanders, and major upwelling events (e.g., Peruvian upwelling during non-El Niño years).

The very narrow infrared portion of the electromagnetic spectrum is typically used for high-resolution temperature observations, which can be made any time of day but only under cloud-free conditions. Thermal infrared energy from the sun reflected off the water's surface can lead to daytime interpretation problems. Passive microwave sensors can measure water surface temperatures through clouds, although with a significant decrease in thermal accuracy and spatial resolution. To ensure accurate calibration of the ***temperature*** numbers from the remote sensor, frequent, *in situ* measurements are required.

Remote sensing systems can ***view*** only the top few millimeters to centimeters of the water and thus, cannot provide information on subsurface temperatures. Making use of temperature remote sensing techniques for coastal waters requires high resolution data because of the small spatial scale of the land and its adjoining water masses. Many coastal areas are so calm that the water surface maintains a constant temperature for months at a time, rendering thermal imagery of little use. Due to their low spatial resolution, the current SST-sensing satellites are of minimal utility for coastal applications. Currently, AVHRR on TIROS and ATSR on ERS provide the data that is used predominantly for regional and ocean-basin SST determinations (Figure 3). The ATSR provides a more accurate measurement, while the wider viewing swath of the AVHRR (2,580 km) provides more coverage. Sensors such as OCTS on ADEOS (12 channels, 700 m resolution) and the soon to be deployed MODIS on EOS (36 channels at 250 m resolution) should improve available spatial and spectral resolution significantly.

Figure 3. Sea surface temperature (14 km analysis), Gulf of California, NOAA-14/NOAA/NESDIS, June 1996.

Circulation (altimeters)

There are several physical reasons for the movement of water from one place to another, such as wind stress, tides, and density discontinuity. Intense and/or lengthy windstorms crossing the surface of a regional body of water can push large quantities of water away from one area and pile it up onto another, such as a shore or embayment. In coastal areas—particularly in regions where the bottom shallows over a very short distance and/or the entrance to an embayment narrows abruptly—the daily ebb and flow of the tides can produce substantial changes in the elevation of the water across a short distance.

Several phenomena can cause water masses to have differing elevations from those around them. One of the most consistent and significant is the gravitational attraction of seafloor mountains and canyons. Undulations of local mass of the earth, and therefore differences in this gravitational pull, are referred to as the earth's geoid. The more massive mountains attract more water above them; canyons attract proportionately less.

Altimeters in orbit provide high-precision (3 cm) information on the height of various water masses and the earth's geoid. The location and motion of large-scale water masses, such as Gulf Stream eddies or the Gulf of Mexico Loop Current, can be visualized using satellite-borne altimeters (Figure 4). On a coastal scale, knowledge of the velocity and direction of parcels of water known to contain toxic red tide algal blooms or hazardous materials (e.g., spilled oil, industrial waste) is essential to planning an appropriate response. Additionally, data on ocean circulation is a significant component of global climate programs.

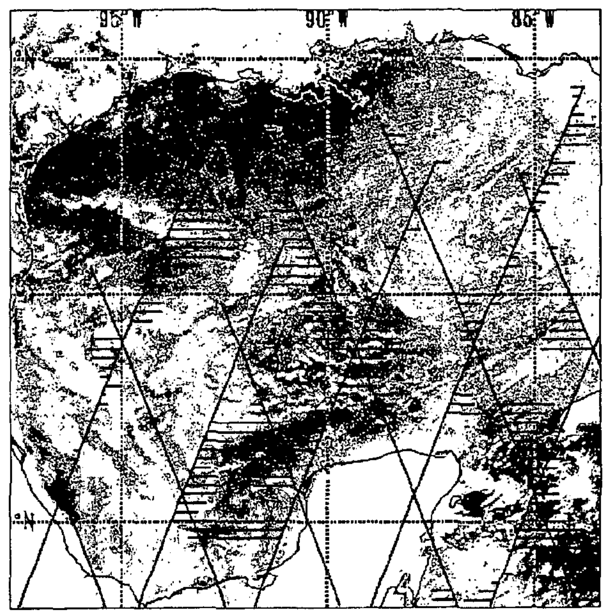


Figure 4. Sea level height differences as determined from Topex altimeter data superimposed over AVHRR temperature image. Relative heights above and below mean are represented by line lengths proportional to the magnitude of the water surface elevation (to the right of satellite track) or depression (to the left of satellite track), Gulf of Mexico, Topex/NOAA/NOS, December 1993.

Since they are active microwave instruments, which calculate the round trip time of a pulse transmitted from a satellite in space, altimeters are usable in all weather conditions. With the development of higher spatial resolution altimeters (presently one measurement every 25 km) and/or deployment of a larger constellation of instruments, remote sensing could be used to study coastal processes for resource assessments such as beach erosion, salt-marsh subsidence, and barrier island expansion.

Wave Height and Spectrum (altimeters and SAR)

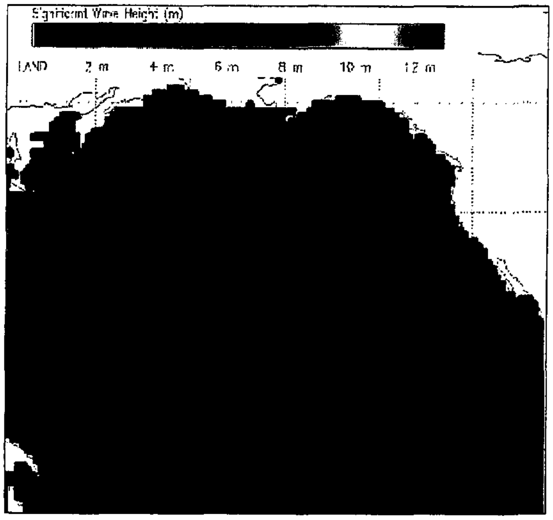


Figure 5. Wave height, North Pacific Ocean, Wave Model/ FNMOC, March 1996.

Wave height is dependent on the velocity of the wind, the distance over which the wind blows (fetch), and the length of time it blows. Wave direction, average wave height and wave spectrum data are very useful, both as inputs to predictive weather forecast models and for real-time information about sea conditions. Sea state is an important consideration when planning any at-sea operations such as search-and-rescue, response to hazardous material releases, ship routing, oil drilling, and dredging. Satellite altimeters provide only limited wave height information (Figure 5) due to poor spatial resolution (25 km). These active microwave instruments derive wave information from the shape of the reflected microwave pulse transmitted from satellite to the water. Thus, they will function in all weather.

Sea Surface Winds (scatterometers)

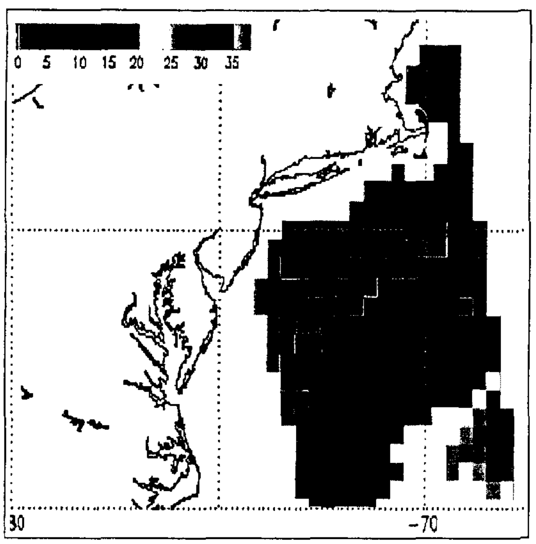


Figure 6. Wind speed, U.S. Northeast coast, ERS-1/ NOAA/NESDIS, June 1996.

Information about the velocity of coastal and ocean winds is important in resource management. This is especially true during response efforts to hazardous materials releases, since disasters seldom happen in ideal weather. It is also useful in weather forecasting, ship routing, and air-sea flux studies (Figure 6).

Winds transfer some energy to the surface layer of the sea, causing ripples. The ripples can develop into wavelets and waves in proportion to the direction and magnitude of the wind. Scatterometers compare a microwave pulse transmitted from a satellite with the waveform of the reflected pulse to extrapolate a wind speed. They lack sufficient spatial resolution (7-50 km) to be of direct use in near shore coastal processes, but they can provide warnings of surface wind conditions that may be headed toward shore. Previous generations of scatterometers were limited by a single-side field of view. With the launch of ADEOS, this wind direction limitation should be minimized due to its dual-sided viewing NSCAT instrument.

Sea Ice (optical, infrared, microwave)

Nearly 12% of the world's ocean is covered by sea ice, the properties of which can differ greatly from both the land and the liquid water. Sea ice may be distinguished from the surrounding water by virtue of its being more reflective, lower in temperature, and different in texture and salt content. Using these properties, optical, thermal and especially microwave (because microwaves pass through clouds or fog for all weather capabilities) remote sensing is employed for ice investigations.

The location, formation, melting, movement, and thickness of ice in coastal waters are important to organizations conducting ocean or lake surface activities (disaster mitigation, transportation, fishing). The principal concerns in ice observations are ice concentration, thickness, and the locations of the edge, polynya (areas of open water), and open leads (channels) (Figure 7). The areal extent of ice coverage is used for input to climate models.

Visible and infrared observing satellites (TIROS, ASTR, GOES) can be used for moderate resolution (1-4 km) data, but only under cloud-free conditions. Passive (SSM/I) and active (SAR) microwave imagers can produce ice imagery products in all weather, but are currently limited by poor resolution (12-25 km) and narrow swath widths, respectively.

Figure 7. Sea ice (near infrared), Larsen Ice Shelf, Antarctica, AVHRR/NSIDC, March 1995.

Coastal Land Cover and Wetland Mapping (optical, infrared, microwave)

Habitat mapping and classification by means of remote sensing are performed by correlating a cluster of numerical pixel values with verified features, such as vegetative cover, open water, tidal flats, inland marshes, forested wetlands, or bare soil type. Multispectral sensors such as Landsat's Thematic Mapper (TM) and SPOT have been the traditional instruments of choice for these types of mapping projects over relatively large areas (Figure 8) (e.g., estuarine sediment/dumping plumes, shallow-water bathymetry) because of the relatively high spatial (20-30 m) and radiometric resolution (eight bits), and because the visible spectral bands are co-registered with the infrared channels. These passive optical instruments are unable to produce land/water imagery during cloudy weather.

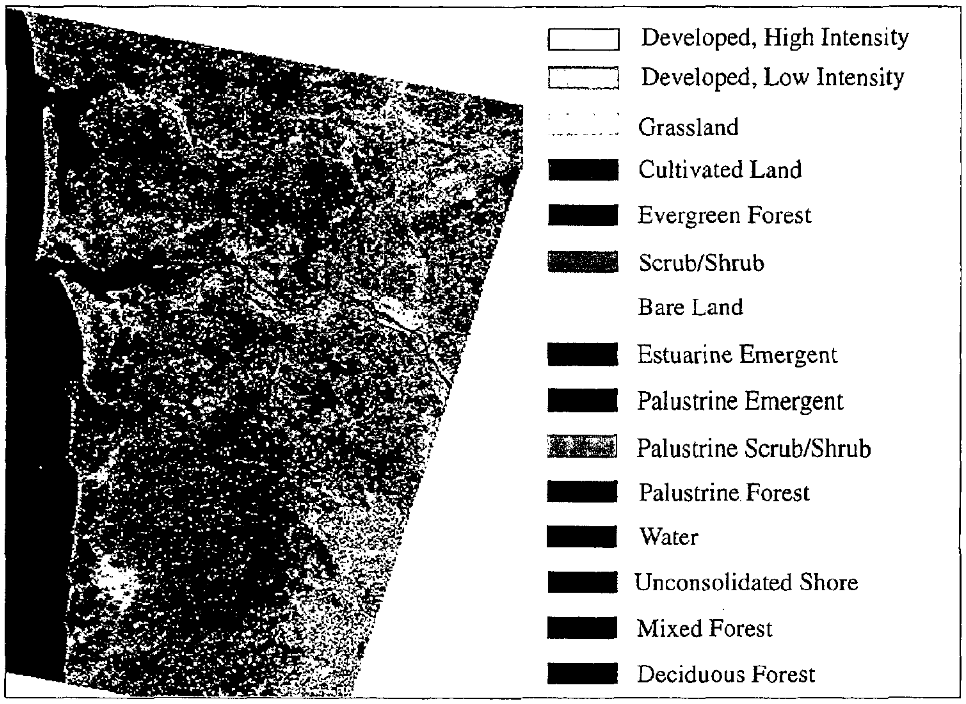


Figure 8. Land Cover, Washington State, Landsat TM/NOAA/CSC, September 1992.

The Synthetic Aperture Radar (SAR) instruments on ERS-1, JERS-1 and RADARSAT also show promise in providing higher spatial resolution (10-30 m) data for wetland mapping and classification for fine scale coastal regions (Figure 9). These instruments rely on reflected microwave energy from the earth to provide an image. Land and water boundaries appear in sharp contrast in SAR imagery because the water tends to reflect energy away from the sensors while rough textured land scatters transmitted signals. Soil moisture and plant type produce differential (gray shade) absorptions of the microwave energy providing coastal surface habitat information in all weather conditions.

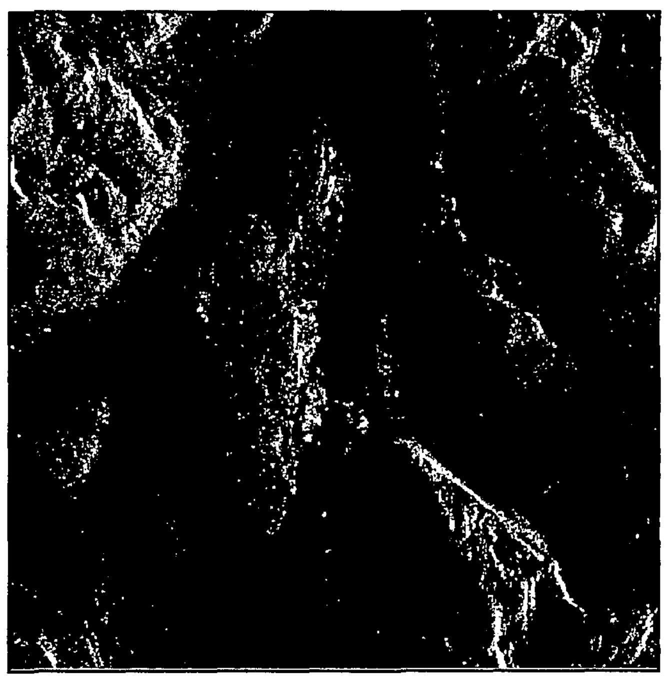


Figure 9. Coastal SAR Image, Tromso Norway, January 1996. RADARSAT data Canadian Space Agency 1996. Data received by the Canada Centre for Remote Sensing. Processed and distributed by RADARSAT International.

Table 1. Selected platform/sensors and traditional coastal and ocean applications

Period	Platform	Sensor	Ocean Color	Sea Surface Temperature	Circulation	Wave Heights	Surface Winds	Sea Ice	Land Cover/ Wetlands
			Application						
Prior 1995	ERS-1 & 2	AMI-SCATT, RA			●		●	●	
		RA				●	●		
		ATSR		●				●	
		SAR			●			●	●
	GMS 4 & 5	VISSR		●					
	INSAT	VHRR		●					
	GOES 7	VAS		●					
		VISSR		●					
	JERS-1	OPS						●	
		SAR			●			●	
	LANDSAT 4 & 5	TM		●				●	●
	METEOSAT 3-7	MVIRI		●					
	MOS-1b	MESSR	●					●	●
		VTIR		●					
	NOAA 9-14	AVHRR		●				●	
		HIRS		●					
	OKEAN-01	RLSBO			●	●		●	
		RM-0.8					●	●	
	RESOURCE-01 N2 & N3	MSU-E						●	
		MSU-SK						●	
	SPOT 1-3	HRV						●	
	TOPEX/POSEIDON	ALT			●				
		SSALT				●	●		
1995	ERS-2	ATSR-2						●	
	GOES 9 K-M	IMAGER		●					
	PRIRODA	IKAR-N, R-400					●		
		IKARD, R-400		●					
		MOS	●						
		MSU-SK						●	
		SAR							
	RADARSAT	SAR			●			●	●
	SEASTAR	SEAWIFS	●						
	SICH-1	MSU-M						●	
		MSU-S						●	
		RLSBO			●	●		●	
		RM-0.8					●	●	
1996	ADEOS	AVNIR						●	
		NSCAT					●	●	
		OCTS	●	●				●	
		POLDER	●						
	NOAA K-M	AMSU B						●	

Table 1 (cont.). *Selected platform/sensors and traditional coastal and ocean applications*

Year	Platform	Sensor	Application: Ocean Color	Sea Surface Temperature	Circulation	Wave Heights	Surface Winds	Sea Ice	Land Cover/ Wetlands
1996	NOAA K-N	AMSU A						●	
		AVHRR/3		●				●	
		HIRS/3		●					
	OKEAN-0	MSU-M						●	
		MSU-S						●	
		MSU-SK						●	
		MSU-V						●	
		RLSBO			●	●		●	
	FY-2	VIS & IR		●					
1997	SICH-2	RLSBO			○	●	○	●	
		SAR			○			●	
	SICH-3	Smr		●					
	SPOT 4	HRVIR						●	○
		VEG							○
1998	ENVISAT-1	AATSR		●				●	
		ASAR				●		●	
		DORIS			○				
		MERIS	○					●	
		RA-2			○	●	○	●	
	EOS-AM1	ASTER						●	
		MODIS	○	●					
	EOS-COLOR	OCEAN COLOR	○						
	FY-1C	VIS & IR		●					
	LANDSAT 7	ETM+		●				●	○
1999	ADEOS II	AMSR		●			○	●	
		GLI	○	●				●	
		POLDER	○						
		SEA WINDS					○		
	EOS-ALT	DORIS			○				
		SSALT			○		○	●	
2000	FY-1D	MS VIS & IR		●					
	MSG	SEVIRI		●					
2001	EOS-PM	AIRS		●					
		AMSU						●	
		MIMR		●			○	●	
		MODIS	●	●					
	SPOT 5	HRG						●	○
		VEG							○

3

Relationship to Coastal Resource Management

This section describes existing and potential relationships between remote sensing and five representative examples of issues facing coastal managers: (1) environmental monitoring; (2) resource inventory and mapping; (3) damage assessment; (4) protected area management; and (5) coastal hazards. It includes a discussion of limitations of current remote sensing systems as well as key, soon-to-be-launched satellites which should provide a plethora of datasets with spectral, spatial, and radiometric resolutions to be of direct value to the coastal resource manager.

Environmental Monitoring

Coastal environmental monitoring includes a wide variety of activities directed toward understanding the status and trends of environmental quality. Examples of measured properties include: water temperature, salinity, sediment loading, rainfall, water quality, and the presence/absence/ health of plants and animals. Monitoring is conducted in many different ways depending, in part, on the parameter(s) being measured, the monitoring objective, and the resources available to conduct the work.

Remote sensing can, under certain conditions, contribute to environmental monitoring by allowing managers to obtain repetitive, nonintrusive, synoptic data for some parameters across broad spatial and temporal domains. With respect to water quality, certain sensors can provide managers with data on water temperature, clarity, circulation, depth, and productivity. Multi-spectral sensors on satellites such as Landsat-MSS, Landsat-TM, SPOT-HRV, and ADEOS-OCTS are already providing quantitative information on water color that can be applied to investigations of sediment plumes and transport, algal blooms, and point sources of pollution.

Point sources of pollution are typically detected by recognizing characteristic surface patterns within the water body rather than by a simple analysis for anomalous spectral properties. Pollution detection is more difficult if it has had time to disperse over a large area, or when it does not emanate from a concentrated point source. In such cases, remote sensing can be used to quantitatively compare spectral properties of similar, unpolluted water from elsewhere, or to evaluate images of the same area that predate the pollution event(s). Both methods are constrained by the high natural variability of the coastal environment. Thermal sensor bands, such as AVHRR on the TIROS satellite series can provide data on water temperature that can help track large (greater than 5 km) coastal upwellings, river outflow, and major coastal currents. Presently, there are substantial limitations in the availability of high spatial resolution, multi-spectral and thermal satellite image data. With the near-term expectation for the launch of high resolution satellites including Earlybird/Quickbird (3-15 m, due in 1997-98), Lewis/Clark (3-30 m due in 1997), and EROS (1.8-11.5 m due in 1997) many of these problems should be overcome.

Coastal Management In the U.S.

The U.S. has extensive coastal boundaries with the Atlantic, Pacific, and Arctic Oceans, the Gulf of Mexico, and the Great Lakes. The majority of the population is located either directly along these coastlines or within the associated waterways, embayments, and estuaries which presents the potential for widespread environmental stress to these regions. Since the enactment of the Coastal Zone Management Act in 1972, the U.S. has expended increasing resources to manage these regions and understand how they are changing under our stewardship.

Coastal management includes a broad range of activities that typically occur among and across Federal, state, county, and municipal levels of government. These include the promotion and regulation of recreation, land development, and transportation as well as the protection of property and life against natural hazards both on the land bordering coastal waters as well as in and on the water itself. The goal of coastal management is to achieve a balance between conservation of resources and sensible development in order to ensure the optimal and most sustainable use of these unique regions for current and future generations. As priorities and technologies change, this is an ongoing, dynamic process that requires constant evaluation and revision.

Resource Inventory and Mapping

Environmental inventory and mapping is performed to establish a baseline description of resource spatial distribution and abundance, from which to determine trends, and identify priorities for management. Coastal resources that are often inventoried and/or mapped include wetlands, harvestable resources such as timber and oil, birds, finfish, and shellfish. Inventories are typically conducted using a combination of extensive field work (e.g. species collection from specific sampling sites), data cataloging, and mapping.

Inventory of living marine resources by space-borne sensors has had variable degrees of success. Large pelagic species of fish which form large schools near the surface can be readily imaged by satellites, but many near-shore fish schools are relatively small compared to the spatial resolution of current satellite imaging systems (30-1000 m). However, satellites can identify a number of environmental variables associated with habitat that are potential ***indicators*** of distribution and abundance such as water temperature, water clarity, circulation, the location of ***fronts*** and ***eddies***, and the presence of coastal vegetated habitat such as wetlands and sea grasses.

Sub-surface habitats such as corals, shellfish beds, and sea grasses are more difficult to quantify by satellite than those above the water line because the space-borne sensors can image only that electromagnetic energy which makes it up through the water column. Thus, turbid waters present significant limitations in the ability of remote sensing systems to quantify bottom features. Mapping wetlands with satellite imagery provides a number of advantages over conventional ground surveys or aerial photography including: timeliness, synopticity, frequency of repeated observations and significantly reduced costs.

Damage Assessment

Environmental damage assessment typically involves evaluating impacts on coastal natural resources resulting from natural events as well as from human activities. These include: long-term exposures to pollutants, cumulative changes caused by certain land use practices, and episodic events such as oil spills, ship groundings, flooding, and hurricanes.

Satellite remote sensing derived inventories of existing resources can be crucial in establishing the ***before*** and ***after*** status of a region to quantify the extent of damage. Such baseline studies are also useful for identifying areas that may be particularly susceptible to damage such as a sensitive habitat located close to shipping lanes, or densely populated areas that are subject to storm surge inundation. This information can improve the effectiveness of management decisions with respect to preparedness and response.

Remote sensing can be of value to managers in tracking the movement of air or water-borne hazardous materials releases. Large surface oil slicks are routinely imaged by TIROS/AVHRR, Landsat, SPOT, ERS-1/SAR, RADARSAT/SAR satellites, but oil type, age, slick thickness, sea state, and the satellite's viewing angle can limit remote sensing's ability to quantify or locate oil spills. For a meaningful response to hazardous materials spills, managers need timely access to data on its size, position and trajectory.

Protected Area Management

Sanctuary areas managed by various Federal, state, local, and private institutions have been set aside for special use and protection because of their environmental, recreational and/or historical value. These include parks, recreation areas, wildlife reservations, and marine sanctuaries. Managers of these areas are typically required to balance the needs of public access and use with natural resource conservation and protection. The goal is to ensure that these areas and their associated natural resources are protected and, where possible, enhanced for future use.

Several remote sensing applications for protected area management are described above (e.g. Environmental Monitoring, Resource Inventory and Mapping, and Damage Assessment). Additional applications include monitoring public use, particularly in expansive marine areas where access is difficult or impossible to restrict, assessing the status of protected area resources with respect to adjacent areas that are not similarly protected, and evaluating the effectiveness of various management strategies. Such information can provide critical ***early warning*** information regarding the possible need for additional protective measures.

Direct monitoring of public use in coastal areas through remote sensing is usually restricted to identifying the presence/absence of boats in open water. This type of monitoring is possible only with extremely high resolution media such as aerial photography or classified satellite imagery. Some countries (including the U.S.) use this technique to assist with the enforcement of fishery regulations. Such monitoring may become a routine resource for coastal managers with the anticipated launch of several high resolution commercial satellites (see Environmental Monitoring) and the potential availability of at least some of the imagery from previously classified space-borne sensors.

Coastal Hazards

Coastal hazards are natural phenomena that have the potential to impact natural resources, property, and the quality of human life. These include coastal erosion, flooding, storms, and salt water intrusion. The proximity of population centers to the coasts accentuates the perceived effects and real costs of coastal hazards. Imagery products are often invaluable in determining response priorities during emergency situations. Because of their synoptic coverage, satellites are also quantitative tools for post mortem damage assessments to property and resources.

The primary application for remote sensing to coastal hazards is the forecasting and analysis of local and regional wind and rain events. Landsat and SPOT satellites currently provide synoptic, regional imagery that can help managers identify natural resources and property at risk. A time series of such imagery may help identify local patterns of shoreline erosion and/or accretion, or plant community successional events. Understanding these patterns may be particularly important in some regions since coastal wetlands such as salt marshes and mangroves can mitigate the severity of coastal hazards from waves and flooding.

Coastal Nutrient Enrichment

Coastal regions are not only delicately balanced ecosystems, but are a primary location for introduction of nutrient-laden or toxic materials such as domestic sewerage, agricultural runoff, and industrial waste. Supplementing the concentrations of nutrients (which would otherwise be limiting factors for growth, such as phosphorous, nitrogen, or silicon) or poisoning key species in any stable or metastable environment generally produces biological imbalances.

Left unchecked, these conditions can produce massive die-offs of many of the native organisms and alter the local geochemistry (pH, Eh, alkalinity). This may lead to oscillations in species composition and even the habitat's suitability to sustain long-term, stable populations. Accelerated erosion of the underlying substrate is a common outcome of loss of biological stability and diversity, resulting in permanent loss of habitat.

While it is presently not possible to measure nitrate, phosphate, or silicate concentrations (much less pH, Eh, or alkalinity) from an aircraft or satellite-borne system, the effects of changes in their values on the biota are frequently easily observed by visible spectrum (and fluorescence spectroscopy) remote sensing techniques. Red tide and green algal blooms are readily detected, located, and quantified by ocean color sensing systems (see section on Ocean Color). Algal blooms which correlated with cholera outbreaks have been identified by use of ocean color sensors.

4

Realities of Acquiring and Processing Data

Although the remote sensing systems mentioned above and described in Appendices A through D rely upon very different phenomena to provide information about the coastal environment, they have several issues in common with regard to getting from a number sent by the sensor in space to a usable product for the analyst or resource manager. This section describes the processing steps required before remotely sensed data can be utilized by the analyst or resource manager. General processing considerations are briefly outlined below, followed by a typical 6-step processing scenario. Ten to 32 weeks is a realistic time frame for implementing such a project (Figure 10). This time frame largely depends on an organization's experience and/or the number of steps that have been provided by others (e.g., data providers, software programs).

Processing of photogrammetry and remote sensing information is composed of several related components: hardware; software; personnel; and data. As with most things, the more that is desired and the quicker it is needed constitute the principal cost drivers. Thus, if the data has been preprocessed (irreversible mathematical transformation) to a high level by the data providers (high cost), then entry level personnel (low cost) can use fully developed software (high cost) running on a moderately powerful hardware system (low cost) to produce ***standard*** (defined by the software manufacturer) products.

Data Realities

- **Incoming data:** Each data provider typically has several levels of processed products, so that ***data*** must be carefully defined. The timeliness and convenience of directly receiving data has, historically, been offset by the cost of establishing and maintaining a large, complex receiving station. With the rapid development of hardware and software ingest systems, it is now cost-effective, in some instances, to purchase a complete download station and data license (if required), rather than to submit data orders and await delivery.

- **Data Processing/Display:** The appeal of ***raw*** data is the ability to apply one's own calibration/navigation formulae to it, in contrast to using ***standard*** algorithms from some data provider (often full of errors). It is virtually impossible to return to the original data quality once it has been ***processed*** (think of a food processor!). The disadvantage of this approach is that the user must possess the hardware, software, and personnel resources to perform these steps before the data is usable.

Nevertheless, the costs of hardware, maintenance, and personnel can be relatively fixed once guidelines have been established for data access, volumes, processing and desired end products. The cost of developing application-specific software can be high, but may be rather stable when compared against the licensing costs added to ***by-the-hour*** consultant charges for customized modifications of commercial software products. Presently, there exist several hundred ***standard*** data formats for remotely sensed data, and there are multiple international efforts to create a single standard format to describe them.

- **Calibration:** Calibration of the sensor systems is a critical part of remote sensing. The instrument manufacturers carefully determine the relationship between known radiances and detector counts prior to deployment in space (launch). Monitoring the sensor system's calibration after deployment is more difficult, but at least as important because electronic systems age in unpredictable ways. Since the ultimate objective of remote sensing is to accurately relate the numbers returned from the remote system to the physical state of the object(s) being sensed, it is imperative to maintain a rigorous *in-situ* validation (ground truth) program for known reference points which are relevant to the specific concerns of the user.

- **Atmospheric considerations:** Remote determination of temperature can be accomplished with either infrared film (photogrammetry) or electronic detectors that are sensitive to low-energy infrared photons (imagery). Remote detection of temperatures in marine environments by use of a single remote sensing system is subject to serious, changeable errors in calibration accuracy. This is due to variations in the local relative humidity, because water vapor absorbs infrared radiation very strongly and is not uniformly distributed. Thus, multiple, simultaneous measurements are required if high-precision thermal measurements are to be made remotely. This is commonly performed with a multichannel instrument which permits calculation of a moisture content ***correction*** for each pixel in the scene.

- **Navigation considerations:** Another crucial aspect of remote sensing is knowing precisely where, on the face of the earth, the numbers being returned from the satellite originated. With on-board telemetry information, the location of the platform and its attitude (pitch, roll, yaw) are known. With this information, the location of each pixel within the scene can be calculated (often performed by the data provider - with varying accuracy).

Cautionary Note

The tools of remote sensing can provide many useful products for the coastal manager, but, as with most tools, some knowledge is required to obtain the desired end result. An ocean color image can be equally used for mapping estuarine eutrophication as it could be used for directing fishing efforts to the total depletion of a fishery.

Acquiring and Processing

There are generally six steps involved in processing photogrammetric and remotely sensed data: acquire, ingest, geo-reference, calibrate, display, process/analyze. These steps are not necessarily independent of one another. The amount of development effort required to get from the first step to the last can vary substantially depending upon many factors, not the least of which is the developers' experience with the data and its idiosyncrasies (Figure 10).

1. The first step is to identify and **acquire** the correct information. This involves identifying a source for an appropriate type, location and date of photo or image, determining the most effective method for obtaining it, and making the necessary arrangements to acquire it. This can involve anything from a quick phone call to international negotiations with foreign governments, and from a simple network file transfer to complex archival exhumations. Because of the complex nature of international negotiations, this can often be the most time-consuming step. (Appendix D contains many useful contact names, addresses, and phone numbers to simplify this task.)

2. The second step is to **ingest** the data. Hard-copy imagery must be digitally scanned. Digital imagery can be made available at any of the stages through which it passes from the initial observation/direct download stage to data that a vendor has recorded in predetermined formats on standard media (e.g., tape, disc, CD-ROM). Data cannot be viewed, mapped, calibrated, or used until it can be accessed and decoded by computers and transformed into its constituent components (scan lines, channels, etc.), which are then converted into individual pixels (numerical picture element values).

3. Once picture/image data has been ingested, it needs to be ***geo-referenced.*** This is normally performed as a series of mathematical calculations, which permits the pixels to be located with respect to the surface of the earth and the desired viewing projection. Usually, this step also provides geometric corrections to each pixel for viewing angle anomalies. This is often the second most complex operation because there is such a plethora of similar but totally incompatible map projections (cf: Mercator, Lambert, Polar 90, etc.). Typically, data suppliers have limited subsets of projections available and thus, users must be very specific in their requirements.

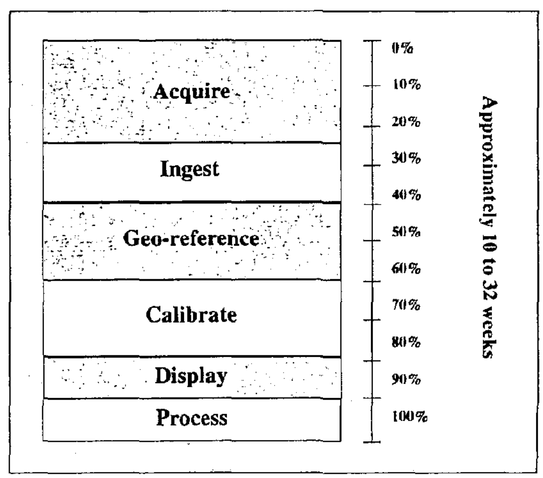


Figure 10. Remote sensing imagery processing scenario (percentage of effort).

4. After the data pixels are geo-referenced so that they will fit properly onto the desired digital map, they are **calibrated.** Sensor values are converted into geophysical parameters by means of known conversion algorithms and constants for each sensor (e.g., a temperature of two degrees has twice the numerical value of a temperature of one degree). Different instrument channels have differing sensitivity to various parts of the electromagnetic spectrum, and to the physical environment between the sensor and the objects being sensed. Subsequent to the derivation of calibration equations and coefficients, an accuracy assessment should be performed. Independent estimates of the error associated with each processed pixel measurement should be performed using data from a series of both *in situ* measurements and remote sensing data which have been collected independent of the data used in the derivation of the calibration algorithms. There are several levels of calibration precision and thus, users must balance their specific requirements against the amount of effort (cost) required to achieve it.

5. Properly geo-referenced and calibrated imagery is normally graphically **displayed** to ensure that the preceding calculations have had the desired effect, and that the resulting image product approximates reality. Common image display/manipulation systems include ArcView, MIPS, PCI, ERDAS, IDL, SEIs, etc. Depending on the knowledge base of the user's support personnel, this can be the shortest step.

6. Image **processing and analysis** are usually necessary to derive useful analytical products from the geo-referenced, calibrated imagery. This is accomplished by manipulating individual pixels to add information to the image (e.g., atmospheric moisture corrections) and produce a derived image product (e.g., calculating temperatures or chlorophyll concentrations using multiple channels). Additional data may also be integrated from a variety of other sensors (e.g., ship and buoy data), coastal geography files, and time series.

Image data and/or their derived products may be imported as information layer(s) into a geographic information system (GIS). Image processors also normally provide the ability to zoom, roam, pan, modify enhancement curves, annotate, export analyses, etc. This step results in the creation of products that coastal resource managers can use (e.g., analyses of habitat change, locations of oil spills, intensity of algal blooms, upwelling events), as illustrated on the cover of this document and in Figures 2 through 9.

5 Concluding Thoughts

Large-scale changes of the earth's surface have been occurring at a rapid pace, particularly in coastal regions. Remote sensing from space-borne satellites is perhaps the only data-acquisition system capable of recording many of these changes at the required spatial and temporal resolution, given the size of the areas affected and the rate at which these changes are taking place. Remote sensing systems maximize information and areal coverage in a timely fashion and at minimal cost.

Current Requirements

The space and time domains for observing various coastal phenomena are diagrammed in Figure 11 (reproduced from Klemas et al. 1995). Note that the spatial/temporal resolution provided by weather satellites appears by itself in the upper left of the diagram, while the spatial resolution required for following coastal processes (pollution, upwelling, plankton dynamics, wetland biomass studies, marsh habitat mapping) occupies the 10-100 m spatial resolution range, and the temporal requirements for repeat coverage over the same area span the range from hours to hundreds of days.

None of the present satellite systems were specifically designed to examine coastal processes. While maximum resolution (spatial, temporal, spectral, radiometric) is desirable, it would not be practical to create any single system to meet all of these needs. Each portion of the electromagnetic spectrum—the physical parameter quantified in remote sensing—offers specific advantages (e.g., all-weather, high-resolution) and contains inherent limitations (e.g., unusable in cloudy weather, narrow viewing swath) for determining variables in the coastal environment. It is important to note, however, that systems now being developed will make use of advances in sensor and computational technologies to provide more capable instruments, probably within the next eight years.

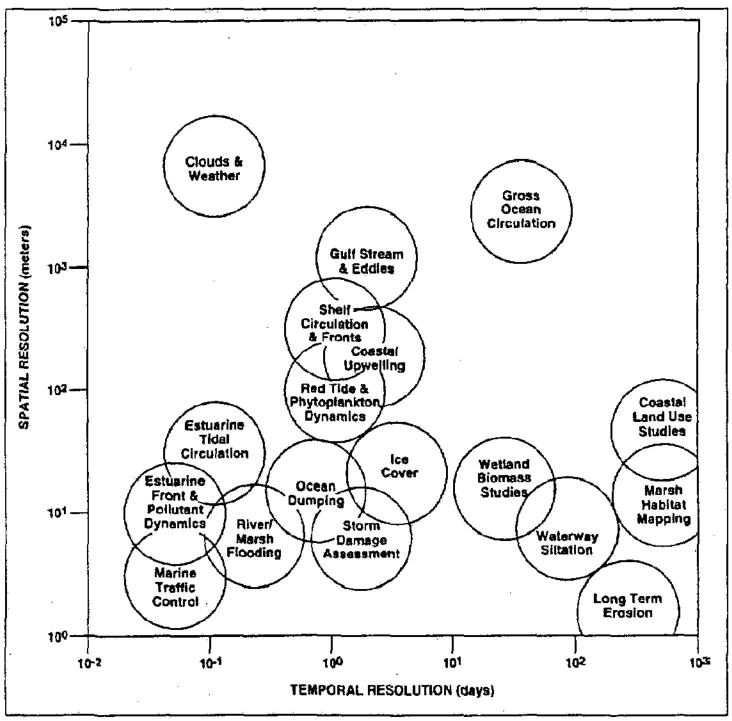


Figure 11. Spatial and Temporal Resolution Requirements for Coastal Studies, Univ. of Delaware.

A Look Toward the Future

Remote sensing is a technology whose ***time is coming*** as an important tool for coastal resource managers. Strengthening the connections between coastal management issues and the contributions that remote sensing technology can make toward resolving them will require addressing of important issues. Remote sensing engineers and coastal managers must increase their efforts to communicate and collaborate. Coastal managers need to become more familiar with the capabilities of remote sensing systems, and designers of remote sensing systems need to focus on the requirements of these relatively new customers. Another effort is to develop better and cheaper remote sensing instruments—sensors that are designed to detect specific coastal changes at a relatively fine level of resolution (high-resolution imagery can be sub-sampled if less detail is required, but coarse-resolution imagery cannot be substantially ***reprocessed*** to improve its inherent limitations).

The image on the cover of this document is representative of commercially available 2 m panchromatic (black and white) products from Sovinformsputnik (Russia). At the time of this printing, the Japanese ADEOS satellite has been successfully placed into orbit (on schedule) and has begun collection of imagery from its 12 channel Ocean Color and Temperature Sensor (OCTS). The follow-on ADEOS II system (scheduled for launch in 1999) will have 34 channels digitized to 12 bits radiometric resolution. Several governmental and commercial organizations have undertaken significant initiatives (Appendices C through D) to begin supplying very high quality (high spectral, spatial, radiometric resolution) imagery to all customers. The constellation of planned active and passive microwave and optical satellite sensors will provide the coastal manager the means to perform coastal surveillance within a single synoptic view. The fusion of multiple, complementary image data sources (differing spatial, spectral, temporal, radiometric resolutions) and existing GIS databases into single products for the analyst continues to accelerate due to the growth in capabilities of small, inexpensive computers. As the products from these systems become readily available in a timely manner, the remote sensing problem of the coastal resource manager will become one of making educated decisions on which of the plethora of alternatives will best address the issues currently on the table. For additional information see references in Section 6.

6 Additional Reading

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7 Glossary

AATSR	Advanced Along Track Scanning Radiometer to be flown on ESA's ENVISAT
ADEOS	NASDA'S Advanced Earth Observing Satellite
AIRS	Atmospheric InfraRed Sounder to be flown on NASA's EOS-PM
ALADIN	Atmospheric laser Doppler Instrument on ESA satellite
ALMAZ	Russian satellite series
ALOS	Japanese satellite scheduled to be launched in 2000
ALT	Altimeter
altim	Altimeter
AMI	Active Microwave Instrument, 3 modes on ERS satellite
AMMS	Airborne Multispectral Measurement System
AMR	Scanning Microwave Radiometer on NSAU SICH satellite
AMSR	Advanced Microwave Scanning Radiometer on ADEOS II satellite
AMSU	Advanced Microwave Scanning Unit on NOAA k-n satellites
ASAR	Advanced Synthetic Aperture Radar on ESA's ENVISAT
ASCAT	Advanced Scatterometer to be flown on future ESA missions
ASTER	Advanced Spaceborne Thermal Emission and Reflection to be on NASA's EOS-AM platform
ATSR	Along Track Scanning Radiometer flown by ESA on ERS satellite
AVHRR	Advanced Very High Resolution Radiometer flown by NOAA on TIROS
AVNIR	Advanced Visible and Near-Infrared Radiometer flown by NASDA on ADEOS
BTVK	Scanning television radiometer on Russian Electro-GOMS satellite
BUFS	Backscattering UV spectrometer on Russian METEOR satellite
CAST	Chinese Academy of Space Technology
CBERS	China-Brazil Earth Resources Satellite
CCD	Charge-Coupled Device
CLARK	Joint NASA and CTA Systems satellite
CONAE	Comision Nacional de Actividades Espaciales (Argentina)
CSA	Canadian Space Agency
CZCS	Coastal Zone Color Scanner flown by NASA on NIMBUS-7
DARA	Deutsch Agentur Fur Raumfahrtangelenheiten GmbH (Germany)
DCP	Data Collection Platform
DCT	Data Collection and Transmission system
DCS	Data Collection System
DELTA	Multispectral microwave scanner on board the NSAU Okean satellite
DMSP	United States Defense Meteorological Satellite Program
DORIS	Doppler Orbitography and Radio positioning Integrated by Satellite to be flown on ESA's Envisat,TOPEX/POSEIDON, and NASA's EOS-ALT EARLY BIRD An EarthWatch, Inc satellite

Eh	Oxidizing potential in millivolts
ELECTRO-GOMS	Geostationary satellite flown by Russia ENVISAT environmental Satellite to be flown by ESA
EOS	Earth Observing System platforms to be flown by NASA
ERS	European Remote Sensing Satellite flown by ESA
EROS-1	Israel's satellite carring high resolution VIS/IR instruments
EROS	Earth Resources Observation Systems of the U.S. Geological Survey of the U.S. Department of the Interior
ESA	European Space Agency
ETM	Enhanced Thematic Mapper to be flown on LANDSAT 7
FY	Feng Yeng (cloud wind) satellite series flown by The People's Republic of China
GDE	GDE Systems, Inc. and the name of their satellite
GEOSAT	Geodynamic Experimental Ocean Satellite flown by the U.S. Navy
GLAS	Geoscience laser Altimeter System to be flown on NASA's EOS-ALT
GLI	Global Imager to be flown on the Japanese NASDA's ADEOS II
GMS	Geostationary Meteorological Satellite flown by NASDA
GOES	Geosynchronous Operational Environmental Satellite flown by NOAA
GOME	Nadir looking double spectrometer flown on ESA's ERS-2
HIRS	High resolution InfraRed Sounder flown on NOAA's TIROS satellites
HRC	High Resolution CCD
HRG	Enhanced High Resolution plus vegetation flown on CNES SPOT 5
HRV	High Resolution Visible flown by CNES on SPOT
HRVIR	High Resolution Visible and Infra-Red flown on CNES SPOT 4
HSI	HyperSpectral Imager flown on NASA's and TRW's Lewis satellite
IASI	Infra-red Atmospheric Sounding Interferometer flown on EUMETSAT METOP satellite
IMAGER	Visible and IR radiometer flown on NOAA's GOES INE Instituto de Pesquisas Espaciais (Brazil)
INSAT	Indian Satellite in geostationary orbit
IKAR	Multispectral microwave scanner flown on Russia's PRIRODA
IKAR-D	Multispectral microwave scanner flown on Russia's PRIRODA
IR	Infrared
IRMSS	Infrared Multispectral Scanner flown on CBERS
IRS	Indian Remote Sensing Satellite
ISRO	Indian Space Research Organization
JERS	Japanese Earth Resources Satellite
KARI	Korean Aerospace Research Institute
KFA	Photographic camera flown on Russia's Resource satellites
KLIMAT	Scanning IR radiometer flown on Russia's METEOR satellite
KOMSAT	Korean Mapping Satellite, operated by KARI
KVR	Photographic camera flown on Russia's and Lambda Tech's satellite
LANDSAT	Land Remote Sensing Satellite flown by NASA, then NOAA then EOSAT
LEISA	Linear Etalon Imaging Spectral Array flown on NASA's and TRW's Lewis
LEWIS	Polar orbiting satellite co-operated by NASA and TRW.
LFC	Large Format Camera flown on NASA's Space Shuttle

Continued on next page

Glossary (cont.)

LISS	Linear Imaging Self Scanning sensor flown on ISRO's IRS
MECB	Brazilian satellite operated by INPE
MERIS	Medium-Resolution Imaging Spectrometer flown on ESA's ENVISAT
MESSR	Multispectral Electronic Self-Scanning Radiometer flown on NASDA's MOS satellite series
METEOR	Satellite platforms flown by Russia
METEOSAT	Geostationary satellite series flown by EUMETSAT
METOP	Meteorological Operational Satellite flown by EUMETSAT
MIMR	Multifrequency Imaging Microwave Radiometer to be flown on NASA's EOS-PM
MISR	Multi-angle Imaging Spectro-Radiometer to be flown on NASA's EOS-AM
MITI	Japan's Ministry of International Trade and Industry
MIVZA	Experimental mivrowave radiometer flown on Russia's METEOR
MK	Multispectral photographic camera flown on Russia's Resource
MODIS	Moderate-Resolution Imaging Spectroradiometer to be flown on NASA's EOS-AM platform
MOMS	Modular Opto-electronic Multi-spectral Scanner to be flown on Russia's PRIRODA
MOS	Marine Observation Satellite flown by NASDA
MOS	Modular Optoelectronic Scanner flown on Russia's PRIRODA
MSR	Microwave Scanning Radiometer flown on NASDA's MOS
MSS	MultiSpectral Scanner flown on LANDSAT
MSG	Geostationary satellite series flown by EUMETSAT
MSU	Medium Resolution Scanner flown on Russia's RESOURCE
MTZA	Scanning microwave radiometer flown on Russia's METEOR
MVIRI	METEOSAT Visible and Infra-Red Imager operated by EUMETSAT
MWR	Microwave Radiometer flown on ESA's ENVISAT
MZOAS	Scanning microwave radiometer flown on Russia's METEOR satellites
NAPP	National Aerial Photography Program archived by the USGS
NASA	U.S. National Aeronautics and Space Administration
NASDA	National Space Development Agency of Japan
NHAPP	National High Altitude Photography Program archived by the USGS
NIMBUS	NASA's satellite series first launched in 1964
NOAA	U.S. National Oceanic and Atmospheric Administration
NRSA	India's National Remote Sensing Agency
NSAU	National Space Agency of the Ukraine
NSCAT	NASA Scatterometer flown on NASDA's ADEOS
OCEAN-01	N7 of the OKEAN-01 satellite series launched by Russia
OCEAN COLOR	NASA instrument to fly on EOS-COLOR satellite
OCTS	Ocean Color and Temperature Scanner flown on NASDA's ADEOS
OKEAN	Soviet Union satellite series, now with NSAU
OLS	Operational Line Scanner flown on the U.S. DMSP
OPS	Optical sensors flown on NASDA's JERS-1 satellite
OSC	Orbital Sciences Corporation

ORBVIEW	Visible and infrared instrument flown on ORBVIEW satellite by OSC
PAN	Panchromatic mode of an instrument sensitive to a wide visible band
pH	Hydrogen ion concentration
POLDER	Polarization and Directionality of the Earth's Reflectances flown on NASDA's ADEOS
PRIRODA	Russian space station type platform
QUICKBIRD	EarthWatch, Inc. satellite
R	Single channel microwave radiometer flown on NSAU OKEAN series
RA	Radar Altimeter flown on ESA's ERS satellite
RADAR	Radio Detection and Ranging
RADARSAT	Canadian Radar Satellite
RESOURCE	Russian successor to the RESURS satellite series
RESOURCE21	Name of Vis/IR sensor and satellite platform flown by RESOURCE21 Company.
RLSBO	Side looking microwave radar flown on NSAU OKEAN satellite
RM	Scanning microwave radiometer flown on Russian OCEAN satellite
RSA	Russian Space Agency
SAC	Argentine satellite
SAR	Synthetic Aperture Radar flown on many satellites (SEASAT, ERS, JERS, SIR)
SCARAB	Scanner for Earth's Radiation Budget flown on Russia's METEOR and on ESA's ENVISAT
scene	A view or "picture" of landscape or image
SCIAMACHY	Scanning Imaging Absorption Spectrometer for Atmospheric Cartography to be flown on ESA's ENVISAT
SCR	Scanning Microwave Radiometer
SEASAT	NASA satellite launched in 1978
SEASTAR	NASA and Orbital Sciences Corporation's (OSC) satellite SEAWINDS NASA Scatterometer to be flown on NASDA's ADEOS II
SeaWIFS	Sea-viewing Wide Field-of-View Sensor to be flown on NASA's and OSC's SEASTAR
SEVIRI	Spinning Enhanced Visible and Infra-Red Imager flown on EUMETSAT's MSG
SICH	NSAU's successor to the Soviet Union's OKEAN satellite series
SILVA	Optical Equipment for Stereography to fly on Russian ALMAZ
SLAR	Side Looking Airborne Radar
SLFMR	Scanning Low-Frequency Microwave Radiometer
SMMR	Scanning Multichannel Microwave Radiometer flown on NASA's SEASAT
SMR	Scanning microwave radiometer flown on NSAU's SICH satellite SPACE IMAGING name of the instrument, satellite and company
SPOT	System Probatoire d'Observation de la Terre flown by CNES
SROSM	Spectroradiometer for ocean monitoring flown on Russia's ALMAZ
SRMR	SpectroRadiometer medium Resolution flown on NSAU's SICH
SSALT	Solid State Altimeter to be flown on NASA's EOS-ALT
SSM/I	Special Sensor Microwave Imager flown on the U.S. DMSP
SSM/T	Special Sensor Microwave Temperature flown on the U.S. DMSP
SSR	Camera flown on INPE's MECB
SSU	Stratospheric Sounding Unit flown on NOAA's TIROS
SWIR	Short Wave Infra Red flown on NASA's EOS-AM

Continued on next page

Glossary (cont.)

TIR	Thermal Infra Red
TIROS	Television InfraRed Observation Satellite series referred to as NOAA polar orbiter series
TK	Photographic camera flown on Russia's and Lambda Tech's satellite
TM	Thematic Mapper instrument flown LANDSAT satellite
TMR	TOPEX Microwave Radiometer flown on NASA's and CNES's TOPEX/ POSEIDON and follow on platforms such as NASA's EOS-ALT TOMS Total Ozone Mapping Spectrometer flown on NUMBUS satellite
TOPEX	NASA/CNES ocean topography experiment satellite
TRASSER	Microwave spectroradiometer flown on NSAU OKEAN
TRMM	NASA satellite scheduled to be launched in 1997
TSR	Thermal Spectroradiometer flown on NSAU's SICH
UV	Ultra-violet portion of the electromagnetic spectrum
VAS	VISSR Atmospheric Sounder flown on NOAA's GOES
VEG	Vegetation instrument to be flown on CNES's SPOT satellite
VHRR	Very High Resolution Radiometer flown on ISRO's INSAT and early NOAA satellites and on NASA's NIMBUS
VIRR	Visible and Infrared Radiometer flown on NASA's SEASAT
VIRS	Visual Infra-Red Scanner to be flown on NASA's TRMM
VIS	Visible portion of the electromagnetic spectrum
VISSR	Visible and Infrared Spin-Scan Radiometer flown on NOAA's GOES and NASDA's GMS
VNIR	Visible and Near Infrared Radiometer flown on many platforms, CONAE's SAC, NASA'S EOS-AM, KARI's KOMSAT, OSC's ORBVIEW
VSAR	Synthetic aperture radar instrument to be flown on NASDA's ALOS
VTIR	Visible and Thermal Infrared Radiometer flown on NASDA's MOS
WIFS	Wide Field Sensor flown on ISRO's IRS
174-K	IR atmospheric sounder flown on Russia's METEOR satellite

9 Summary of Appendices

The following appendices provide a tabular summary of past (Appendix A), present (Appendix B), and intended future (Appendix C) satellite-borne remote sensing systems, along with a qualitative ranking (high, medium, low) of their applicability to coastal resource management issues. Appendix D provides summary details on specific sensors aboard a wide variety of current and proposed remote sensing platforms. Appendix E summarizes the potential application of NASA's proposed 36-channel MODIS platform.

Appendix A is a tabular compilation of many of the older satellite-borne remote sensing systems deployed since the first successful launches in the late 1950's. The platform on which the sensor was flown, the major applications for the data, the mean wavelength of the spectral band(s) for the detector, and the spatial resolution of the sensor are provided. From the sensor attributes, resource managers can understand why there have traditionally been only limited uses for satellite-borne remote sensing for coastal and estuarine applications.

Appendix B is a brief table of some of the remote sensing systems that are active at the time of this report. From this table, it is clear that present satellite-borne remote sensing systems—optimized for large-scale oceanographic and meteorological processes and for land-use applications—are better than previous systems, but continue to lack sufficient spatial and spectral resolution for extensive use in the environmentally complex coastal zone.

Appendix C is a brief tabulation of some of the satellite remote sensing systems that have been announced for future deployment by a variety of organizations. Coastal environmental management will become much more quantitative and accessible if these succeed.

Appendix D is a summary of the satellite remote sensing systems whose resolution is appropriate for use in oceanic and coastal regions. It is organized by responsible organization/company, characteristics of the platform, characteristics of the sensor, and organizational contact for additional information. This information was compiled, in part, from information contained in the ASPRS workbook *Land Satellite Information in the Next Decade* (September 1995).

The MODIS instrument to be flown on the NASA EOS AM 1 platform, currently scheduled for a 1998 launch, is summarized here. The 36 bands of MODIS are separated into categories by application and further annotated as to the intended application of each band of the instrument. This instrument may be useful for the study of ocean basin phenomena; however, for coastal and estuarine work, the 250 m resolution will not be adequate for most applications.

Summary of Qualitative Rankings

Platforms/Sensors	High	Medium	Low	*totals*
Past (1978-1988)	1	4	9	**14**
Present (operational):	10	13	32	**55**
Future (1996-2004)	38	22	40	**100**
Totals	**49**	**39**	**81**	**169**

Period	Satellite	Sensor	Band		Resolution
1978-1978	Seasat	**internal waves, water vapor/precip, sea ice, wind speed, sea surface temperature**			
		ALT (M)	13.5	GHz	2.4 km
		VIRR (M)	0.7	µm	3 km
			11	µm	5 km
		SMMR (L)	6.6	GHz	87 x 149 km
			10.7	GHz	53 x 89 km
			18	GHz	31 x 53 km
			21	GHz	27 x 42 km
			37	GHz	27 x 16 km
		SASS (L)	14.59	GHz	50 km
		SAR (H)	1.275	GHz	25 m
1978-1986	Nimbus	**est. of chlorophyll, photoplankton biomass, suspended sediments**			
		CZCS (M)	0.44	µm	850 m
			0.52	µm	850 m
			0.55	µm	850 m
			0.67	µm	850 m
			0.75	µm	850 m
	FY-1A	**clouds, ocean color, sea surface temperature, suspended sediments**			
		AVHRR (M)	0.63	µm	1.1 km
			0.92	µm	1.1 km
			0.51	µm	1.1 km
			0.56	µm	1.1 km
			11.5	µm	1.1 km
1988 +	Okean-0	**ocean temperature, wind speed, sea color, ice extent, cloud cover, precipitation**			
		MSU-M (L)	0.55	µm	1 x 1.7 km
			0.65	µm	1 x 1.7 km
			0.75	µm	1 x 1.7 km
			0.95	µm	1 x 1.7 km
		MSU-S (L)	0.62	µm	345 m
			0.9	µm	345 m
		MSU-SK (L)	0.55	µm	170 m
			0.65	µm	170 m
			0.75	µm	170 m
			0.92	µm	170 m
			11	µm	600 m
		MSU-V (L)	0.49	µm	50 m
			0.57	µm	50 m
			0.68	µm	50 m
			0.86	µm	100 m
			1	µm	100 m
			1.6	µm	100 m
			2.2	µm	100 m
			11.4	µm	100 m
		R-225 (L)	13.3	GHz	130 km
		R-600 (L)	4.9	GHz	130 km
		RLSBO (L)	13	GHz	2 km

Appendix B. Present Sensors

DMSP	**atmospheric temperature, ice, salinity, temperature, surface roughness**		
	SSMT (L)	55 GHz	180 km
	SSMI (L)	19 GHz	25 km
		22 GHz	25 km
		37 GHz	25 km
		85 GHz	12.7 km
	vegetation, ice, sea surface temperature		
	OLS (M)	0.7 µm	620 m
		11 µm	560 m
ELECTRO-GOMS series	**vegetation, temperatures, space environment**		
	BTVK (L)	0.55 µm	1.5 km
		11 µm	8 km
ERS-1	**internal waves, ice slicks, current divergence, sea surface convergence**		
	AMI-SAR imager (H)	5.3 GHz	30 m
	AMI-SAR wave (L)	5.3 GHz	30 m
	AMI-SCATT (L)	5.3 GHz	50 km
	ATSR (M)	1.6 µm	1 km
		3.7 µm	1 km
		11 µm	1 km
		12 µm	1 km
		23.8 GHz	50 km
		36.5 GHz	50 km
	RA (M)	13.8 GHz	7 km
	GOME (M)	0.51 µm	40 km
GEOSAT	**fronts, ice, eddies, geostrophic currents**		
	ALT (L)	13.5 GHz	6.8 km
GMS	**sea surface temperatures**		
	VISSR (L)	0.63 µm	1.25 km
		11.5 µm	5 km
GOES	**sea surface temperature**		
	VAS (L)	0.6 µm	1.0 km
		4 µm	4 km
		6.8 µm	10.5 km
INSAT	**vegetation, sea surface temperatures**		
	VHRR (L)	0.6 µm	2.75 km
		11 µm	11 km
IRS	**water resources, vegetation studies, coastal work, soils**		
	LISS (M)	0.5 µm	72.5 m
		0.55 µm	72.5 m
		0.65 µm	72.5 m
		0.8 µm	72.5 m
IRS-P2	**chlorophyll, suspended sediments, crop stress detection**		
	LISS II (H)	0.48 µm	36 m
		0.55 µm	36 m
		0.66 µm	36 m
		0.81 µm	36 m

Appendix B. Present Sensors continued

JERS-1	**geology, vegetation, cartography, shallow water bathymetry**		
	OPS (H)	0.56 µm	18 m x 24 m
		0.66 µm	18 m x 24 m
		0.81 µm	stereo 18 m x 24 m
		1.65 µm	18 m x 24 m
		2.07 µm	18 m x 24 m
		2.19 µm	18 m x 24 m
	ice, snow, internal waves		
	SAR (H)	1.275 GHz	18 m x 18 m
LANDSAT	**vegetation discrimination, vigor assessment, ocean color, shallow water bathymetry**		
	MSS (M)	0.55 µm	80 m
		0.65 µm	80 m
		0.75 µm	80 m
		0.9 µm	80 m
	wetland mapping less shallow water (<30), benthic communities, sea surface temperature		
	TM (H)	0.48 µm	30 m
		0.57 µm	30 m
		0.67 µm	30 m
		0.82 µm	30 m
		1.65 µm	30 m
		2.2 µm	30 m
		11.5 µm	120 m
METEOR-series	**ozone, atmospheric water**		
	174-K (L)	9.6 µm	42 km
		11.1 µm	42 km
		18 µm	42 km
		13.33 µm	42 km
		13.7 µm	42 km
		14.24 µm	42 km
		14.43 µm	42 km
		14.75 µm	42 km
		15.02 µm	42 km
	carbon dioxide, ozone, solar radiation flux, climatology, vegetation		
	BUFS-4 (L)	250-350 nm	180 km
	KLIMAT (L)	11 µm	1 km
	total atmospheric humidity and temperatures, temperature, water vapor, clouds		
	MIVZA (L)	0.86 cm	20-80 km
	MTZA (L)	20-94 GHz	20-80 km
	MZOAS (L)	6. -94. GHz	9-160 km
	ScaRaB (L)	0.2-12 µm	60 km
	total ozone, sulphur dioxide		
	TOMS (L)	0.3 µm	47 km
	water vapor, sea surface temperatures		
	MVIRI (L)	0.7 µm	2.5 km
		6 µm	5 km
		11 µm	5 km

MOS-1,2	**suspended sediments, land/water, water vapor**		
	MESSR (H)	0.55 µm	50 m
		0.65 µm	50 m
		0.75 µm	50 m
		0.95 µm	50 m
	water vapor, sea surface temperature		
	VTIR (L)	0.6 µm	900 m
		6.5 µm	900 m
		11 µm	900 m
		12 µm	900 m
	ice, sea surface roughness		
	MSR (L)	23.8 GHz	32 km
		31.4 GHz	23 km
NOAA series	**sea surface temps, vegetation, aerosols**		
	AVHRR (M)	0.63 µm	1.1 km
		0.9 µm	1.1 km
		3.8 µm	1.1 km
		11 µm	1.1 km
		12 µm	1.1 km
	HIRS (L)	0.66-14.98 µm	17.4 km
	MSU (L)	50.3 GHz	105 km
	AMSU (L)	53.7 GHz	50 km
		54.9 GHz	50 km
		57.9 GHz	50 km
		89 GHz	50 km
Ocean-01	**ocean fronts, vegetation**		
	MSU-M (L)	0.55 µm	1 km
		0.65 µm	1 km
		0.75 µm	1 km
		0.95 µm	1 km
	MSU-S (L)	0.68 µm	345 m
		0.85 µm	345 m
	ocean surface imagery		
	RLSBO (L)	3.1 cm	1.5x2.0 km
	RM-0.8 (L)	0.8 cm	15x20 km
Resource-01 series	**land/sea, vegetation, water vapor**		
	MSU-E (L)	0.55 µm	45 m
		0.65 µm	45 m
		0.85 µm	45 m
	MSU-SK (L)	0.55 µm	170 m
		0.65 µm	170 m
		0.75 µm	600 m
		0.95 µm	600 m
		10.6 µm	600 m
Resource-F1M series	**cartography, tidal marsh boundaries, benthic biota**		
	KFA-1000 (L)	0.69 µm	6 m
	KFA-200 (M)	0.65 µm	23 m

Resource-F2 series	**cartography, tidal marsh boundaries, shallow water, benthic biota cultural identification**		
	MK-4 (M)	0.41 µm	10 m
		0.49 µm	10 m
		0.54 µm	10 m
		0.67 µm	10 m
		0.68 µm	10 m
		0.84 µm	10 m
Resource-F2M series	**cartography, tidal marsh boundaries, shallow water, benthic biota cultural identification**		
	MK-4M (M)	0.67 µm	6 m
		0.54 µm	6 m
		0.64 µm	6 m
		0.84 µm	6 m
Resource-F3 series	**cartography, tidal marsh boundaries, shallow water, benthic biota cultural identification**		
	KFA-3000 (M)	0.65 µm	3 m
SIR-B SAR	**internal waves, ice, ocean fronts**		
	SAR (M)	1.282 GHz	20 m
SIR-C/X-SAR	**internal waves, ice, ocean fronts**		
	SAR (M)	1.25 GHz	40 x 10-60 m
		5.3 GHz	40 x 10-60 m
		9.6 GHz	40 x 10-60 m
SPIN-2	**cartography, tidal marsh boundaries, benthic biota**		
	KVR-1000 (H)	0.66 µm	2 m
	TK-350 (H)	0.66 µm	10 m
SPOT	**shallow water mud flat mapping**		
	HRV (H)	0.57 µm	20 m
		0.65 µm	20 m
		0.85 µm	20 m
	cartography		
	PAN (H)	0.6 µm	10 m
TOPEX/ POSEIDON	**surface elevation, geoid**		
	ALT (L)	5.3 GHz	20 x 2-10 km
		13.65 GHz	20 x 2-10 km
	TMR (L)	18 GHz	50.86 km
		21 GHz	39.76 km
		37 GHz	27.37 km

Appendix C. Future Sensors

ADEOS	**ocean color, suspended sediments**		
	OCTS (M)	0.41 µm	700 m
		0.44 µm	700 m
		0.49 µm	700 m
		0.52 µm	700 m
		0.56 µm	700 m
		0.66 µm	700 m
		0.77 µm	700 m
		0.86 µm	700 m
		3.7 µm	700 m
		8.5 µm	700 m
		10.7 µm	700 m
		11.7 µm	700 m
	coastal shallow water, benthic mapping, vegetation, ocean color		
	AVNIR (H)	0.48 µm	16 m
		0.55 µm	16 m
		0.64 µm	16 m
		0.82 µm	16 m
	PAN (H)	0.6 µm	8 m
	NSCAT (L)	14 GHz	25 km
	POLDER (H)	0.443 µm	6 km
		0.495 µm	6 km
		0.565 µm	6 km
		0.665 µm	6 km
		0.763 µm	6 km
		0.765 µm	6 km
		0.865 µm	6 km
		0.91 µm	6 km
ADEOS-II	**ocean color, suspended sediments**		
	POLDER (L)	0.443 µm	6 km
		0.67 µm	6 km
		0.865 µm	6 km
		0.49 µm	6 km
		0.565 µm	6 km
		0.763 µm	6 km
		0.765 µm	6 km
		0.91 µm	6 km
	ocean color, suspended sediments, vegetation, sea surface temperature		
	GLI 34 channels (M)	Vis-TIR	250 m

Appendix C. Future Sensors continued

ALMAZ	**vegetation, suspended sediments, ocean color**		
	MSU-E (M)	0.55 µm	10 m
		0.65 µm	10 m
		0.85 µm	10 m
	vegetation, suspended sediments, ocean color		
	MSU-SK (M)	0.56 µm	80 m
		0.65 µm	80 m
		0.75 µm	80 m
		0.9 µm	80 m
		11 µm	300 m
	sea surface slicks, internal waves, sea state		
	SAR (H)	3.49 cm	200 m
		3.49 cm	6 m
		9.58 cm	6 m
		9.58 cm	6 m
		9.58 cm	30 m
		70 cm	30 m
	vegetation, suspended sediments, ocean color		
	SILVA (H)	0.55 µm	4 m
		0.65 µm	4 m
		0.75 µm	4 m
	vegetation, suspended sediments, ocean color		
	SROSM (M)	0.41 µm	600 m
		0.44 µm	600 m
		0.49 µm	600 m
		0.52 µm	600 m
		0.56 µm	600 m
		0.66 µm	600 m
		0.6 µm	600 m
		0.86 µm	600 m
		3.65 µm	600 m
		11 µm	600 m
		12 µm	600 m
ALOS	**vegetation, imagery**		
	AVNIR-2 (H)	0.46 µm	10 m
		0.58 µm	10 m
		0.65 µm	10 m
		0.82 µm	10 m
	PAN (H)	0.54 µm	2.5 m
		0.63 µm	2.5 m
		0.74 µm	2.5 m
	imagery, ice, snow		
	VSAR (H)	15 MHz	10 m
CBERS-series	**vegetation, ocean color, ice**		
	CCD (M)	0.47 µm	20 m
		0.55 µm	20 m
		0.63 µm	20 m
		0.66 µm	20 m
		0.83 µm	20 m
	vegetation, water vapor, sea surface temperature		
	IRMSS (M)	0.8 µm	80 m
		1.6 µm	80 m
		2.2 µm	80 m
		11 µm	160 m

Appendix C. Future Sensors continued

CLARK	**vegetation, suspended sediments, ocean color**		
	PAN (H)	0.6 µm	3 m
	multispectral (H)	0.54 µm	15 m
		0.65 µm	15 m
		0.84 µm	15 m
EARLYBIRD	**vegetation, imagery, suspended sediments**		
	PAN (H)	0.62 µm	3 m
		0.54 µm	15 m
		0.63 µm	15 m
		0.74 µm	15 m
ENVISAT 1	**temperature, vegetation, cloud, aerosol, sea surface temperature**		
	AATSR (L)	0.555 µm	1 km
		0.659 µm	1 km
		0.865 µm	1 km
		1.6 µm	1 km
		3.7 µm	1 km
		10.85 µm	1 km
		12 µm	1 km
	hydrology, ice, geology		
	ASAR (M)	6 GHz	30 m
	marine biochemical, biophysical parameters		
	MERIS - 15 channels (M)	0.4-1.05 µm	300 m
	atmospheric humidity		
	MWR (L)	23.8 GHz	20 km
		36.5 GHz	20 km
	wind speed, significant wave height, sea surface toplogy, ice		
	RA-2 (L)	13.8 GHz	7 km
		3.2 GHz	7km
	atmospheric profiles of chemical components, aerosols, clouds		
	SCIAMACHY (L)	0.23-2.38 µm	3 km
EOS-ALT	**precise orbit determination**		
	DORIS (L)	2036.25 MHz	1 per 10 sec
	ice sheet height/thickness, aerosol, height distributions, wind speed		
	GLAS (L)	0.532 µm	70 x 188 m
		1.064 µm	70 x 188 m
	SSALT (L)	13.55 GHz	300 m
	TMR (L)	18 GHz	23-44 km
		21 GHz	23-44 km
		37 GHz	23-44 km

EOS-AM series	**aerosols, digital elevation, temperature**		
	ASTER (H)	3@0.5-0.9 µm	15 m
		6@1.6-2.5 µm	20 m
		5@8.0-12.0 µm	90 m
	aerosols, vegetation		
	MISR (L)	0.44 µm	240 m
		0.56 µm	240 m
		0.67 µm	240 m
		0.86 µm	240 m
	ocean color, biogeochemistry, water vapor, sea surface temperature		
	MODIS - 36 bands (M)	0.4-14.4 µm	250 m - 1000 m
	land/sea, water vapor		
	SWIR (M)	1.65 µm	30 m
		2.1 µm	30 m
		2.2 µm	30 m
		2.25 µm	30 m
		2.3 µm	30 m
		2.35 µm	30 m
	sea surface temperature, water vapor		
	TIR (M)	8.2 µm	90 m
		8.6 µm	90 m
		9.1 µm	90 m
		10.5 µm	90 m
		11.4 µm	90 m
	vegetation, cultural identification		
	VNIR (H)	0.58 µm	15 m
		0.66 µm	15 m
		0.78 µm	15 m
EOS-AM2 (LATI)	**vegetation, land/sea**		
	PAN (H)	0.7 µm	15 m
	vegetation, ocean color, suspended sediments		
	VNIR (H)	0.48 µm	30 m
		0.56 µm	30 m
		0.66 µm	30 m
		0.82 µm	30 m
	waves, water vapor		
	SWIR (H)	1.6 µm	30 m
		2 µm	30 m
		1 µm	240 m
EOS-COLOR	**ocean biology/ocean color role of oceans in global carbon and biogeochemical cycles**		
	Ocean-Color - 8 channel (M)	0.402-0.885 µm	1.1 km
EOS-PM series	**earth's outgoing radiation**		
	AIRS 2300 channel (L)	IR	13 km
EROS-1	**cultural feature identification, coastal monitoring**		
	PAN (H)	0.7 µm	1.8 m
	VNIR (H)	0.7 µm	1.5 m

ESA	**sea surface temperature, ice, snow, aerosols, vegetation**		
	AATSR (L)	0.555 µm	1 km
		0.659 µm	1 km
		0.865 µm	1 km
		1.6 µm	1 km
		3.7 µm	1 km
		10.85 µm	1 km
		12 µm	1 km
	vertical distribution of clouds, aerosol properties, winds		
	ALADIN (L)	9.4 µm	15 km
	waves, ice, sea surface winds, marine biochemical and biophysical parameters		
	ASAR (M)	6 GHz	30 m
	ASCAT (L)	6 GHz	25 km
	MERIS (M)	0.4-1.05 µm	300 m
	precipitation, ice, atmosphere temperature, sea surface roughness, soil moisture		
	MIMR (L)	6.8 GHz	3-60 km
		10.65 GHz	3-60 km
		18.75 GHz	3-60 km
		23.8 GHz	3-60 km
		36.5 GHz	3-60 km
		90 GHz	3-60 km
	wind speed, wave height, sea surface topology, ice		
	RA-2 (L)	13.8 GHz	7 km
FY-1C	**vegetation, ocean color, sea surface temperature, water vapor**		
	10 channel (L)	vis and IR	1 km
FY-1D	**vegetation, ocean color, sea surface temperature, water vapor**		
	10 channel (L)	vis and IR	1 km
GDE	**vegetation, suspended sediments, cultural features**		
	to be determined (H)	0.6 µm	1 m
IRS-1B/IRS-1C	**vegetation, suspended sediments**		
	LISS3 (H)	0.55 µm	23.5 m
		0.66 µm	23.5 m
		0.82 µm	23.5 m
		1.6 µm	70.5 m
	PAN (H)	0.62 µm	5.8 m
	WiFS (M)	0.65 µm	188 m
		0.81 µm	188 m
KOMSAT	**vegetation, ocean color**		
	PAN (H)	0.6 µm	10 m
	VNIR (H)	0.46 µm	20 m
		0.64 µm	20 m
		0.77 µm	20 m
LANDSAT 7	**vegetation, ocean color, suspended sediments, surface temperature**		
	ETM+ (H)	0.7 µm	15 m
		0.48 µm	30 m
		0.57 µm	30 m
		0.66 µm	30 m
		0.83 µm	30 m
		1.65 µm	30 m
		2.21 µm	30 m
		11.5 µm	60 m

LEWIS	**vegetation, cultural feature identification, tidal marsh boundaries**		
	HSI(pan) (H)	0.6 µm	5 m
	HSI(vnir) (H)	0.7 µm	30 m
	HSI(swir) (H)	2 µm	30 m
	LEISA(swir) (L)	2 µm	300 m
MECB SSR-1	**vegetation, suspended sediments**		
	IIS camera (L)	0.66 µm	200 m
		0.83 µm	200 m
MECB SSR-2	**vegetation, suspended sediments**		
	IIS camera (L)	0.66 µm	200 m
		0.83 µm	200 m
METOP-series	**sea surface temperature, aerosols, vegetation**		
	AATSR (L)	0.555 µm	1 km
		0.659 µm	1 km
		0.865 µm	1 km
		1.6 µm	1 km
		3.7 µm	1 km
		10.85 µm	1 km
		12 µm	1 km
	sea surface temperature, precipitation, aerosols, ice, snow		
	AVHRR/3 (L)	0.63 µm	1 km
		0.8 µm	1 km
		1.6 µm	1 km
		3.76 µm	1 km
		10.4 µm	1 km
		11.9 µm	1 km
	atmospheric chemistry, aerosols		
	HIRS/3 (L)	0.69 µm	19 km
		4.1 µm	19 km
	atmospheric temperature profiles		
	IASI (L)	3-15. µm	1 km
MSG	**sea surface temperature, clouds**		
	SEVIRI (M)	0.63 µm	1 km
		0.7 µm	1 km
		0.83 µm	1 km
		1.61 µm	1 km
		3.8 µm	1 km
		8.78 µm	1 km
		10 µm	1 km
		12 µm	1 km
	ocean color, suspended sediments, vegetation		
	SeaWifs (M)	0.412 µm	1.1 km
		0.443 µm	1.1 km
		0.49 µm	1.1 km
		0.51 µm	1.1 km
		0.555 µm	1.1 km
		0.67 µm	1.1 km
		0.765 µm	1.1 km
		0.865 µm	1.1 km

Appendix C. Future Sensors continued

OKEAN-0	**ice, precipitation**			
	DELTA-2 (L)	7	GHz	100 km
		13	GHz	100 km
		22.5	GHz	100 km
		36.5	GHz	100 km
	physical oceanography, hydrometeorology, ice and snow			
	MSU-M (L)	0.55	µm	1 x 1.7 km
		0.65	µm	1 x 1.7 km
		0.75	µm	1 x 1.7 km
		0.95	µm	1 x 1.7 km
	MSU-S (L)	0.65	µm	345 m
		0.85	µm	345 m
	land/sea, snow and ice			
	MSU-SK (L)	0.55	µm	170 m
		0.65	µm	170 m
		0.75	µm	170 m
		0.95	µm	170 m
		11	µm	600 m
	vegetation, sea surface temperature, ocean color			
	MSU-V (L)	0.48	µm	50 m
		0.55	µm	50 m
		0.68	µm	50 m
		0.84	µm	50 m
		1	µm	50 m
		1.6	µm	50 m
		2.2	µm	50 m
		11.2	µm	100 m
	temperature, ice, sea state, internal waves			
	R-225 (L)	13.3	GHz	130 km
	R-600 (L)	4.9	GHz	130 km
	RLSBO (L)	3.1	cm	2.1 x 1.2 km
	TRASSER-0 (L)	62	band	100 km
ORBVIEW	**imagery, vegetation, cultural feature identification**			
	PAN (H)	0.68	µm	1 m
		0.68	µm	2 m
	VNIR (H)	0.48	µm	8 m
		0.56	µm	8 m
		0.66	µm	8 m
		0.83	µm	8 m
PRIRODA	**vegetation, suspended sediments, ocean color, cartography, elevation cartography**			
	MOMS (H)	0.48	µm	18 m
		0.55	µm	18 m
		0.66	µm	18 m
		0.79	µm	18 m
	PAN (H)	0.64	µm	6 m
	fore,aft (H)	0.64	µm	18 m
QUICKBIRD	**vegetation, imagery, cartography**			
	PAN (H)	0.62	µm	3 m
		0.48	µm	15 m
		0.56	µm	15 m
		0.66	µm	15 m
		0.83	µm	15 m
RADARSAT	**oil spill, waves, vegetation, slicks, land cover, ice, coastal zone monitoring**			
	SAR (H)	5.36	GHz	10 m

RESOURCE21	**vegetation, suspended sediments, ocean color**		
	to be determined (H)	0.47 µm	10 m
		0.56 µm	10 m
		0.65 µm	10 m
		0.83 µm	10 m
		1.58 µm	20 m
		1.35 µm	100 m
SAC_C	**vegetation, ocean color, suspended sediments**		
	VNIR (M)	0.49 µm	150 m
		0.55 µm	150 m
		0.66 µm	150 m
		0.79 µm	150 m
	vegetation, water vapor		
	SWIR (M)	1.68 µm	150 m
SICH-1	**vegetation, land/sea**		
	MSU-S (M)	0.62 µm	410 m
		0.5 µm	410 m
	vegetation, clouds		
	MSU-M (L)	0.55 µm	2000 m
		0.65 µm	2000 m
		0.75 µm	2000 m
		0.9 µm	2000 m
SICH-2	**sea state, wind**		
	RLSBO with scatterometer (L)	3.1 cm	0.8x1.6 km
	slicks, waves, ice		
	SAR (M)	23 cm	10-50 m
SICH-3	**ice, precipitation**		
	SMR (L)	10 GHz	50 x 70 km
		18 GHz	35 x 50 km
		22 GHz	27 x 35 km
		37 GHz	15 x 21 km
		90 GHz	6 x 6 km
	vegetation, ocean color, suspended sediments, water vapor		
	SRMR (H)	0.4-0.7 µm	10-40 m
		0.8-2.4 µm	10-40 m
	precipitation, clouds, sea surface temperature		
	TSR (L)	3.0-13.0 µm	100 km
SPACE IMAGING	**vegetation, suspended sediments, ocean color**		
	PAN (H)	0.6 µm	1 m
		0.48 µm	4 m
	vegetation, suspended sediments, ocean color		
	VNIR (H)	0.56 µm	4 m
		0.66 µm	4 m
		0.88 µm	4 m
TRMM	**cloud radiation, sea surface temperature, water vapor**		
	VIRS (L)	0.63 µm	2 km
		1.6 µm	2 km
		3.75 µm	2 km
		10.8 µm	2 km
		12 µm	2 km

ADEOS AVNIR: JAPAN

Mission/Instrument name:	ADEOS / Advanced Visible & Near-Infrared Radiometer (AVNIR)
Operating organizations:	National Space Development Agency of Japan (NASDA)
Operational date:	August 1996 to July 1999
Number of satellites:	1

Satellite Orbit

Altitude: ~797 km
Inclination: ~98.6 deg, Sun synchronous
Local mean solar time at equatorial crossing: 10:30±:15 descending nodal crossing
Ground track repeat interval: 41 days and 585 orbits

Instrument Bands

		VNIR				PAN	
Band:	1	2	3	4	I	5	
Spectral range from µm:	0.42	0.52	0.61	0.76		0.52	
to:	0.50	0.60	0.69	0.89		0.69	
Signal to noise ratio:		>200	>200	>200		>200	>90
Ground sample distance m:	16	16	16	16		8	

Viewing Geometry

Instrument field of view:	5.7 deg
Scene dimension at nadir:	80 km x 80 km
Instrument field of regard:	±40 deg <-> ±700 km
Along-track tilt:	fixed nadir
Stereo capability:	cross-track

Precisions

Radiometric calibration accuracy:	Accuracy of on-board calibration using internal lamp and sunlight is ±5%
RMS ground location accuracy:	[not provided]

Collection/Return Capacity

Min. revisit time w/cross-track tilt:	3 days at equator
Onboard storage:	3 x 72 Gb (total satellite capacity)
Max. contiguous one-pass coverage:	80 km x ~5000 km = ~400 k sq km
Ground network (nominal):	1 station; additional stations can be supported within satellite resources
Avg. land data collection per orbit:	~500 k sq km
System annual land data collection capability:	300 M sq km

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ALMAZ OPTICAL: RUSSIA & SAR CORP.

Mission/Instrument name:	ALMAZ Mulit-Sensor Satellite System
Operating organizations:	Russia (RSA) & SAR Corp. (Sokol-Almaz Radar)
Operational date:	Mid 1998
Number of satellites:	3: ALMAZ 1B (1998) followed by ALMAZ 1C & ALMAZ 2

Satellite Orbit

Altitude: 397 km nominal; 388-404 km range
Inclination: 72.7 deg
Local mean solar time at equatorial crossing: n/a
Ground track repeat interval: 10.8 days and 168 orbits

Instrument Bands & Viewing Geometry

Optronic Equipment for Stereography (OES), Mulitzone High-Resolution Electronic Scanner (MSU-E), Multizone Middle-Resolution Optomechanical Scanner (MSU-SK), Spectro-Radiometer for Ocean Satellite Monitoring (SROSM)

Band:	OES	MSU-E	MSU-SK	SROSM	VIS	IR
Spectral range from µm:	0.5	0.5	0.54	10.4	0.405	0.475
to:	0.6	0.6	0.6	12.6	0.422	0.785
Spectral range from µm:	0.6	0.6	0.6	0.433	0.843	
to:	0.7	0.7	0.7	0.453	0.884	
Spectral range from µm:	0.7	0.8	0.7	0.480	3.6	
to:	0.8	0.9	0.8	0.500	3.9	
Spectral range from µm:	0.58	0.8	0.510	10.5		
to:	0.8 (PAN)	1.0	0.530	11.5		
Spectral range from µm:			0.555	11.5		
to:			0.575	12.5		
Spectral range from µm:			0.655			
to:			0.675			
Signal to noise ratio:						
Ground sample distance m:	4/2.5(PAN)	10	80	300	600	

Viewing Geometry

Instrument field of view: OES 80 km CT x 180 k AT; MSU-E 2 x 24 km; MSU-SK VIS: 2 x 300 km IR: +/-39 deg 300 km; SROSM 2 x 1100 km
Scene dimension at nadir:
Instrument field of regard: OES 30 deg <-> 300 km; MSU-E 2 x 550 km; MSU-SK VIS: 2 x 550 km IR: 300 km; SROSM 2 x 1100 km
Along-track tilt:
Stereo capability: OES 100%, using fore/aft 25 deg tilt; CE(.9) = 5 m LE(.9) = 5 m

Precisions

Radiometric calibration accuracy: [not provided]
RMS ground location accuracy: [not provided]

Collection/Return Capacity

Min. revisit time w/cross-track tilt: 3 days at the equator
Onboard storage: 32 Gb
Max. contiguous one-pass coverage: [not provided]
Ground network (nominal): 3 stations
Avg. land data collection per orbit: OES 370 k sq km; MSU-E 350-700 k sq km; MSU-SK 3.7 M sq km; SROSM 60 M sq km
System annual land data collection capability: OES 2,044 M sq km; MSU-E 1,890-4,410 M sq km; MSU-SK 20,300 M sq km; SROSM 329,175 M sq km

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ALMAZ SAR: RUSSIA & SAR CORP.

Mission/Instrument name:	ALMAZ Mulit-Sensosr Satellite System
Operating organizations:	Russia (RSA) & SAR Corp. (Sokol-Almaz Radar)
Operational date:	Mid 1998
Number of satellites:	3: ALMAZ 1B (1998) followed by ALMAZ 1C & ALMAZ 2

Satellite Orbit

Altitude: 397 km nominal; 388-404 km range
Inclination: 72.7 deg
Local mean solar time at equatorial crossing: n/a
Ground track repeat interval: 10.8 days and 168 orbits

SAR Sensors & Viewing Geometry

1-SLR-3 (side Looking Radar); 2-SAR-3 Narrow Mode; 3-SAR-10 Narrow Mode; 4-SAR-10 Intermediate Mode; 5- SAR-10 Survey Mode; 6-SAR-70

	1	2	3	4	5	6
Wavelength cm:	3.49	3.49	9.58	9.58	9.58	70
Survey slide:	left	left	left	left	left	left
View angle off nadir deg:	38-60	25-51	25-51	25-51	25-51	25-51
Beam slip angle deg:	49.1	63.3	63.3	63.3	63.3	63.3
to:	23.0	34.3	34.3	34.3	34.3	34.3
Slant range km:	518	444	444	444	444	444
to:	895	670	670	670	670	670
Effective coverage width km:	450	330	330	330	330	330
Swath width km:	450	20-30	30-55	60-70	120-170	120-170
Resolution	190-250	5-7	5-7	5-7	22-40	22-40
(range x azimuth) m:	1200-2000	5-7	5-7	15	30	30
Stereo capability:	n/a	multi-pass		multi-pass		multi-pass
Signal polarization (xmit/rcv):	V/V	V/V	H/H	V/VH,H/VH	V/V	V/VH,H/VH
Contrast sensitivity dB:	2-3	2-2.5	2-2.5	1.5-2	1-1.5	1
Avg. land data collection per orbit k:	1,400	76	80-450	80-450	80-450	330-450
Sys annual land collection capability M:	7,650	420	480-2460	480-2460	480-2460	1800-2400

Precisions

Radiometric calibration accuracy: [not provided]
RMS ground location accuracy: [not provided]

Collection/Return Capacity

Min. revisit time w/cross-track tilt: 3 days at the equator
Onboard storage: 32 Gb
Max. contiguous one-pass coverage: [not provided]
Ground network (nominal): 3 stations

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ALOS AVNIR-2: JAPAN

Mission/Instrument name:	ALOS / Advanced Visible & Near-Infrared Radiometer-2 (AVNIR-2)
Operating organizations:	National Space Development Agency of Japan (NASDA)
Operational date:	Launch February 2002
Number of satellites:	1

Satellite Orbit

Altitude: 700 km (TBR)
Inclination: 98.1 deg (TBR), Sun synchronous
Local mean solar time at equatorial crossing: 10:30±:15 (TBR) descending nodal crossing
Ground track repeat interval: 45 days (TBR)

Instrument Bands

	Multispectral				PAN		
Band:	1	2	3	4	fore	nadir	aft
Spectral range from µm:	0.42	0.52	0.61	0.76	0.52	0.52	0.52
to:	0.50	0.60	0.69	0.89	0.77	0.77	0.77
Signal to noise ratio:	200	200	200	200	70	70	70
Ground sample distance m:	10	10	10	10	2.5	2.5	2.5

Viewing Geometry

	Multispectral	PAN
Instrument field of view:	5.8 deg	2.9 deg
Scene dimension at nadir:	70 x 70 km	35 x 35 km
Instrument field of regard:	±40 deg <-> ±613 km	±1.5 deg <-> ±35 km
Along-track tilt:	fixed nadir	fixed ±40 deg + nadir
Stereo capability:	cross-track	simultaneous fore, aft, nadir

Precisions

Radiometric calibration accuracy: not available
RMS ground location accuracy: 2.5 m

Collection/Return Capacity

Min. revisit time w/cross-track tilt: MS: 2 days; PAN: 45 days at equator
Onboard storage: 706 Gb
Max. contiguous one-pass coverage: MS: 70 x 20,000 km = 1,400 k sq km PAN: 35 x 20,000 km = 700 k sq km
Ground network (nominal): Data Relay Satellite & direct transmission to ground stations
Avg. land data collection per orbit: MS: 420; PAN: 210 k sq km
System annual land data collection capability: MS: 1120; PAN: 560 M sq km

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ALOS VSAR: JAPAN

Mission/Instrument name:	ALOS / VSAR
Operating organizations:	National Space Development Agency of Japan (NASDA)
Operational date:	Launch February 2002
Number of satellites:	1

Satellite Orbit

Altitude: 700 km (TBR)
Inclination: 98.1 deg (TBR), Sun synchronous
Local mean solar time at equatorial crossing: 10:30±:15 (TBR) descending nodal crossing
Ground track repeat interval: 45 days (TBR)

Instrument Bands

Band:	L
Bandcenter Mhz:	15
Polarization:	
Signal to ambiguity ratio dB:	
Signal to noise ratio dB:	~15
Ground sample distance m:	10

Viewing Geometry

Instrument field of view:	
Scene dimension at nadir:	70 x 70 km
Instrument field of regard:	18~48 deg off-nadir range <-> 600 km
Along-track tilt:	n/a
Stereo capability:	interaferomtry

Precisions

Radiometric calibration accuracy:	not available
RMS ground location accuracy:	2.5 m

Collection/Return Capacity

Min. revisit time w/cross-track tilt: 2 days at the equator
Onboard storage: 706 Gb
Max. contiguous one-pass coverage: 70 km x 20,000 km = 1,400 k sq km
Ground network (nominal): normally use Data Relay Satellite
Avg. land data collection per orbit: 420 k sq km
System annual land data collection capability: 560 M sq km

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CBERS CCD & IRMSS: CHINA-BRAZIL

Mission/Instrument name:	China-Brazil Earth Resources Satellite (CBERS) -- CCD Camera & Infrared Multispectral Scanner (IRMSS)
Operating organizations:	Chinese Academy of Space Technology (CAST) (satellite) & Insituto de Pesquisas Espaciais (INPE)
Operational date:	October 1997
Number of satellites:	1

Satellite Orbit

Altitude: 78 km
Inclination: 98 deg, Sun synchronous
Local mean solar time at equatorial crossing: 10:30 descending nodal crossing
Ground track repeat interval: 26 days and 337 orbits

Instrument Bands

				CCD				IRMSS	
Band:	1	2	3	4	5	6	7	8	9
Spectral range from µm:	0.45	0.52	0.63	0.77	0.51	0.5	1.55	2.08	10.4
to:	0.52	0.59	0.69	0.89	0.73	1.1	1.75	2.35	12.5
Signal to noise ratio:	36.6	41.1	42.0	45.0	48.0	24	20	17	1.2K
Ground sample distance m:	20	20	20	20	20	80	80	80	160

Viewing Geometry

Instrument field of view:	8.4 deg (CCD) & 8.8 deg (IRMSS)
Scene dimension at nadir:	120 km CT x 778 km AT
Instrument field of regard:	±32 deg <-> 600 km
Along-track tilt:	fixed
Stereo capability:	Adjacent orbits

Precisions

Radiometric calibration accuracy:	Stability <1%; Internal calibrators 2% [relative??]; & External calibrators 10% [absolute ??]
RMS ground location accuracy:	200 m

Collection/Return Capacity

Min. revisit time w/cross-track tilt:	3 days at equator, 2-3 days at ±50 lat
Onboard storage:	40 Gb (experimental)
Max. contiguous one-pass coverage:	4000 km by 120 km = 480,000 sq km
Ground network (nominal):	2 stations (China, Brazil)
Avg. land data collection per orbit:	200,000 sq km

System annual land data collection capability: 250 M sq km

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CLARK: USA (NASA) & CTA

Mission/Instrument name: Small Spacecraft Technology Initiative (SSTI) "Clark" / Worldview sensor
Operating organizations: NASA Headquarters, Spacecraft Systems Div. & CTA Systems
Operational date: September 1996
Number of satellites: 1

Satellite Orbit

Altitude: 476 km
Inclination: 97.3 deg, Sun synchronous
Local mean solar time at equatorial crossing: 11:15 descending nodal crossing
Ground track repeat interval: 20 days and (TBS) orbits

Instrument Bands

	PAN			Multispectral
Band: 1	2	3	4	
Spectral range from µm:	0.45	0.50	0.61	0.79
to:	0.80	0.59	0.68	0.89
Signal to noise ratio:				
Ground sample distance m:	3	15	15	15

Viewing Geometry

Instrument field of view:
Scene dimension at nadir: Panchromatic: 6 km x 6 km; Multispectral: 30 km x 30 km
Instrument field of regard: ±30 deg <-> (TBS) km
Along-track tilt: ±30 deg <-> (TBS) km
Stereo capability: Yes - fore and aft pointing

Precisions

Radiometric calibration accuracy: [not provided]
RMS ground location accuracy: <100 m

Collection/Return Capacity

Min. revisit time w/cross-track tilt: 4-5 days at equator
Onboard storage: 1.37 Gb
Max. contiguous one-pass coverage: Pan: 34,00 sq km
Ground network (nominal): 3 stations (Livermore CA, Fairbanks AK, Kiruna SWE)
Avg. land data collection per orbit: ,000 sq km
System annual land data collection capability: 0 M sq km

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EARLYBIRD & QUICKBIRD: EARTHWATCH

Mission/Instrument name:	EarthWatch EarlyBird / Panchromatic and Multicolor EarthWatch QuickBird / Panchromatic and Multicolor
Operating organizations:	EarthWatch, Incorporated
Operational date:	EarlyBird: 1996 QuickBird: 1997
Number of satellites:	2 of each

Satellite Orbit

Altitude: 470 km
Inclination: Sun synchronous
Local mean solar time at equatorial crossing: [not provided]
Ground track repeat interval: [not provided]

Instrument Bands

	EarlyBird				QuickBird				
Band:	Pan	Green	Red	NearIR	Pan	Blue	Green	Red	NearIR
Spectral range from µm:	0.45	0.50	0.61	0.79	0.45	0.45	0.53	0.63	0.77
to:	0.80	0.59	0.68	0.89	0.90	0.52	0.59	0.69	0.90
Signal to noise ratio:				[not provided]				[not provided]	
Ground sample distance m:	3	15	15	15	1	4	4	4	4

Viewing Geometry

Instrument field of view:
Scene dimension at nadir: EarlyBird Panchromatic: 6 km x 6 km; EarlyBird Multicolor: 30 km x 30 km
QuickBird Panchromatic: [not provided]; QuickBird Multicolor: 30 km x 30 km
Instrument field of regard: ±30 deg [<-> xxx km]
Along-track tilt: ±30 deg [<-> xxx km]
Stereo capability:

Precisions

Radiometric calibration accuracy: EarlyBird: 8 bit quantization QuickBird: 11 bit quantization [calibration not provided]
RMS ground location accuracy: [not provided]

Collection/Return Capacity

Min. revisit time w/cross-track tilt: [not provided]
Onboard storage: yes
Max. contiguous one-pass coverage: [not provided]
Ground network (nominal): store-and-forward to EarthWatch stations
Avg. land data collection per orbit: EarlyBird: [not provided] QuickBird: 100 30km x 30 km = 90,000sq km
System annual land data collection capability: 34.2 M sq km

Notes

[See NASA'S "Clark" mission for additional information on EarlyBird like instrument.]
Technical exchange of sensor data with early customers is being done at a detailed level on a contract-by-contract basis.

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EOS ASTER: Japan & USA

Mission/Instrument name:	EOS-AM1 / Advanced Spaceborne Thermal Emission Reflectance Radiometer (ASTER)
Operating organizations:	Japan (MITI & Japan Resources Observation System Organization) & NASA/JPL
Operational date:	Late 1998
Number of satellites:	1

Satellite Orbit

Altitude: 705 km
Inclination: 98.2 deg, Sun synchronous
Local mean solar time at equatorial crossing: 10:30 ±15 descending nodal crossing
Ground track repeat interval: 16 days and 233 orbits

Instrument Bands

		VNIR				SWIR			
Band:	1	2	3N,B	4	5	6	7	8	9
Spectral range from µm:	0.52	0.63	0.76	1.600	2.145	2.185	2.235	2.295	2.360
to:	0.60	0.69	0.86	1.700	2.185	2.225	2.285	2.365	2.430
Signal to noise ratio h:	>140	>140	>140	140	54	54	54	70	54
Ground sample distance m:	15	15	15,17	30	30	30	30	30	30

		TIR			
Band:	10	11	12	13	14
Spectral range from µm:	8.125	8.475	8.925	10.25	10.95
to:	8.475	8.825	9.275	10.95	11.65
Signal to noise ratio h:	<0.3 K	<0.3 K	<0.3 K	<0.3 K	<0.3 K
Ground sample distance m:	90	90	90	90	90

Viewing Geometry

	VNIR	SWIR, TIR
Instrument field of view:	5 deg (5.3 deg band 3B)	4.9 deg
Scene dimension at nadir:	60 km CT	60 km CT
Instrument field of regard:	±24 deg <-> 314 km	±8.55 deg <-> 106 km
Along-track tilt:	3B tilted 27.6 deg	fixed
Stereo capability:	In-track, 3B (back) & 3N (nadir) -> B/H=0.6	

Precisions

Radiometric calibration accuracy: Bands 1-9: ±4% absolute radiometry, calibrated by halogen lamps. Bands 10-14: ± K (270-340 K). ±2 (240-370 K); cal. by onboard blackbody.
RMS ground location accuracy: VNIR: <90 m; SWIR 6 m; TIR 31.5 m

Collection/Return Capacity

Min. revisit time w/cross-track tilt: 16 days at equator, 7-9 days at ±45 lat; VNIR only: 4-7 days at equator
Onboard storage: share of EOS 140 Gb solid-state recorder
Max. contiguous one-pass coverage: VNIR, SWIR: 8% duty cycle <-> 60 km x 3400 km = 250 k sq km. TIR duty cycle and coverage twice as large
Ground network (nominal): Primary data return via TDRSS to processing and archives in Japan and at USGS/EDC, Sioux Falls
Avg. land data collection per orbit: 205 k sq km
System annual land data collection capability: 1090 M sq km

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EOS LATI (Option I): NASA

Mission/Instrument name:	EOS-AM2 / Landsat Advanced Technology Instrument (LATI) Option I
Operating organizations:	NASA & other US government (TBD)
Operational date:	2004
Number of satellites:	1, follow-on to Landsat 7

Satellite Orbit

Altitude: 705.3 km
Inclination: 98.2 deg, Sun synchronous
Local mean solar time at equatorial crossing: 10:00 descending nodal crossing
Ground track repeat interval: 16 days and 233 orbits

Instrument Bands

Instrument Bands	PAN			VNIR		SWIR			Atmos
Band:	8	1	2	3	4	5	5'	7	5 bnd
Spectral range from µm:	0.50	0.45	0.52	0.63	0.76	1.55	1.2	2.08	0.8
to:	0.90	0.52	0.60	0.69	0.90	1.75	1.3	2.35	1.4
Signal to noise ratio:		consistent with Landsat 7 continuity							
Ground sample distance m:	15	30	30	30	30	30	30	30	240

Viewing Geometry

Instrument field of view:	15 deg
Scene dimension at nadir:	185 km CT x 170 km (nominal) AT
Instrument field of regard:	±30 degrees
Along-track tilt:	fixed nadir
Stereo capability:	none

Precisions

Radiometric calibration accuracy:	Uses full aperture solar diffuser, standard ground scenes, and precise atmospheric compensation techniques to achieve 5% absolute radiometry.
RMS ground location accuracy:	< 250 m

Collection/Return Capacity

Min. revisit time w/cross-track tilt:	3 days at equator, 2 days ±60 lat
Onboard storage:	(TBD), optimized with cloud editing and lossless data compression
Max. contiguous one-pass coverage:	(TBD)
Ground network (nominal):	Primary station at USGS/EDC, Sioux Falls SD + 1 supplementary station at Fairbanks AK for real-time & playback collection to archives; cooperating intl. ground stations for local real-time collection
Avg. land data collection per orbit:	>540,000 sq km
System annual land data collection capability:	>2,800 M sq km

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EOS LATI (Option II): NASA

Mission/Instrument name:	EOS-AM2 / Landsat Advanced Technology Instrument (LATI) Option II
Operating organizations:	NASA & other US government (TBD)
Operational date:	2004
Number of satellites:	1, follow-on to Landsat 7

Satellite Orbit

Altitude: 705.3 km
Inclination: 98.2 deg, Sun synchronous
Local mean solar time at equatorial crossing: 10:00 descending nodal crossing
Ground track repeat interval: 16 days and 233 orbits

Instrument Bands

Band:	PAN	VNIR	SWIR
Spectral range from µm:	0.5	0.4	1.2
to:	0.7	0.9	2.4
No. of hperspectral chan:	1	50	24
Signal to noise ratio:		*consistent with continuity*	
Ground sample distance m:	10	20	20

Viewing Geometry

Instrument field of view:	15 deg
Scene dimension at nadir:	185 km CT x 170 km (nominal) AT
Instrument field of regard:	±30 deg (TBR)
Along-track tilt:	fixed nadir
Stereo capability:	none

Precisions

Radiometric calibration accuracy:	Uses transfer radiometer for intercomparison with (advanced?) MODIS, standard ground scenes, and Moon-look techniques to achieve 5% (TBR) absolute radiometry.
RMS ground location accuracy:	< 250 m

Collection/Return Capacity

Min. revisit time w/cross-track tilt:	3 days at equator, 2 days ±60 lat
Onboard storage:	(TBD), optimized with cloud editing, lossless data compression, hyperspectral data compression, and/or onboard data aggregation
Max. contiguous one-pass coverage:	(TBD)
Ground network (nominal):	Primary station at USGS/EDC, Sioux Falls SD + 1 supplementary station at Fairbanks AK for real-time & playback collection to archives; add'l real-time collection at intl. ground stations
Avg. land data collection per orbit:	>540,000 sq km
System annual land data collection capability:	>2,800 M sq km

Notes

Annual collection: Based on 250 scenes/day to archives. Additional scenes collected at international ground stations

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EOS MODIS: USA (NASA)

Mission/Instrument name:	EOS-AM1, PM-1 / Moderate Resolution Imaging Spectrometer (MODIS)
Operating organizations:	NASA/GSFC
Operational date:	Late 1998 (AM-1), 2000 (PM-1)
Number of satellites:	2

Satellite Orbit

Altitude: 705 km
Inclination: 98.2 deg, Sun synchronous
Local mean solar time at equatorial crossing: 10:30±:15 (AM-1); 13:30±:15 (PM-1) descending nodal crossing
Ground track repeat interval: 16 days and 233 orbits

Instrument Bands

Instrument Bands	Sharpening VNIR	SWIR	Ocean Thermal	VNIR	Atmosphere
Band:	1-2	3-4	5-7	8-19	8-36
Spectral range from µm:	0.6	0.46	1.2	0.4	1.3
to:	0.9	0.57	2.2	1.0	14.3
Signal to noise ratio:	>500				
Ground sample distance m:	250	500	500	1000	1000

(see Appendix E: MODIS characteristics at bottom of file)

Viewing Geometry

Instrument field of view:	±55 deg
Scene dimension at nadir:	±1150 km CT
Instrument field of regard:	nadir centered
Along-track tilt:	fixed
Stereo capability:	n/a

Precisions

Radiometric calibration accuracy: <3µm: 5% absolute radiometry >3µm: 1% absolute radiometry calibrated by halogen lamps, onboard blackbody, solar viewing RMS ground location accuracy:

Collection/Return Capacity

Min. revisit time w/cross-track tilt:	2 days at equator
Onboard storage:	share of EOS 140 Gb solid-state recorder
Max. contiguous one-pass coverage:	continuous operation; reflection bands on daylit side only
Ground network (nominal):	primary data return via TDRSS to processing and archives at GSFC
Avg. land data collection per orbit:	
System annual land data collection capability:	

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EROS-1,2: Israel

Mission/Instrument name:	EROS-1, 2
Operating organizations:	Israel Aircraft Industries and Core Software Technology
Operational date:	1995 & 1997
Number of satellites:	2

Satellite Orbit

Altitude: 480 km
Inclination: 97.4 deg, Sun synchronous
Local mean solar time at equatorial crossing: [not provided]
Ground track repeat interval: [not provided]

Instrument Bands

Band:	PAN	VNIR
Spectral range from µm:	0.50	[not provided]
to:	0.90	[not provided]
Signal to noise ratio:	[not provided]	[not provided]
Ground sample distance m:	1.8/11.5	

Viewing Geometry

Instrument field of view:	[not provided]
Scene dimension at nadir:	EROS-1: 11 km CT x 55 km AT; EROS-2: 15 km CT x 55 km AT
Instrument field of regard:	±30 deg <-> xxx km
Along-track tilt:	fixed nadir
Stereo capability:	[not provided]

Precisions

Radiometric calibration accuracy: [not provided]
RMS ground location accuracy: 800 m

Collection/Return Capacity

Min. revisit time w/cross-track tilt:	3 days at equator
Onboard storage:	[not provided]
Max. contiguous one-pass coverage:	11 or 15 km by 55 km = 605 or 825 sq km
Ground network (nominal):	[not provided]
Avg. land data collection per orbit:	[not provided]
System annual land data collection capability:	[not provided]

Notes

General: [These missions have not been formally announced. They are believed to be awaiting Israel government policy decisions.]
Along track tilt: EROS uses a fore-to-aft slew technique to reduce effective scene motion at the focal plane, and increase integration time.

Technical Contact

Name: [not provided]
Title:
Address:
Phone:

ERS-1/2 SAR: ESA

Mission/Instrument name: ERS-1/2 Synthetic Aperture Radar (SAR)
Operating organizations: European Space Agency (ESA)
Operational date: July 1991 & (TBS)
Number of satellites: 2

Satellite Orbit

Altitude: ~780 km
Inclination: 98.5 deg, Sun synchronous
Local mean solar time at equatorial crossing: 10:30 descending nodal crossing
Ground track repeat interval: 35 days and 501 orbits

Instrument Bands

Band: C
Bandcenter Ghz: 5.3
Bandwidth MHz: 15.55
Polarization: V/V
Integrated sidelobe ratio dB: 8
Ground sample distance m: 30 AT; <=26.3 CT

Viewing Geometry

Instrument field of view: 20.1 deg to 25.9 deg
Scene dimension at nadir: 102.5 km CT (80.4 km full performance)
Instrument field of regard: fixed 250 km offset, right from nadir
Along-track tilt: n/a
Stereo capability: none

Precisions

Radiometric calibration accuracy: n/a
RMS ground location accuracy: 1 km

Collection/Return Capacity

Min. revisit time w/cross-track tilt: 35 days at equator, 16 days ±60 lat
Onboard storage: none
Max. contiguous one-pass coverage: 10 min -> 100 km x 4000 km = 400 K sq km
Ground network (nominal): 22 stations
Avg. land data collection per orbit: 3500 sq km
System annual land data collection capability: n/a; Avg production from processing is 8000 scenes per year ==> (TBS) M sq km

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GDE SYSTEMS

Mission/Instrument name:	(TBD)
Operating organizations:	GDE Systems, Inc., et al.
Operational date:	Late 1998
Number of satellites:	at least one

Satellite Orbit

Altitude:	704 km
Inclination:	98.2 deg, Sun synchronous
Local mean solar time at equatorial crossing:	10:30 descending nodal crossing
Ground track repeat interval:	16 days and 233 orbits

Instrument Bands

Band:	1
Spectral range from µm:	0.5
to:	0.9
Signal to noise ratio:	>4
Ground sample distance m:	0.8 - 1.0

Viewing Geometry

Instrument field of view:	1.2 deg
Scene dimension at nadir:	15 km CT
Instrument field of regard:	±45 deg (CT) <-> 700 km
Along-track tilt:	±45 deg <-> 700 km
Stereo capability:	Single pass fore/aft imaging along track or within ±45 deg cross track. Maximum single pass stereo image size is 70 x 70 km

Precisions

Radiometric calibration accuracy:	not applicable
RMS ground location accuracy:	1500 m

Collection/Return Capacity

Min. revisit time w/cross-track tilt:	1.8 days at equator, 1.5 days at ±30 lat
Onboard storage:	30 Gb
Max. contiguous one-pass coverage:	15 km x 1600 km = 24 k sq km
Ground network (nominal):	7 stations
Avg. land data collection per orbit:	20,000 sq km per ground station
System annual land data collection capability:	102 M sq km (7 stations)

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IRS-1B LISS 1 & 2: INDIA & EOSAT

Mission/Instrument name:	IRS-1B (Indian Remote Rending Satellite) / LISS 1 (Linear Imaging Self Scanccer) & LISS 2
Operating organizations:	National Remote Sensing Agency (NRSA)
Operational date:	August 1991
Number of satellites:	1

Satellite Orbit

Altitude: 904 km
Inclination: 99,028 deg, Sun synchronous
Local mean solar time at equatorial crossing: 10:25±:20 descending nodal crossing
Ground track repeat interval: 22 days and 307 orbits

Instrument Bands

	LISS 1				LISS 2			
Band:	1	2	3	4	1	2	3	4
Spectral range from µm:	0.45	0.52	0.62	0.77	0.45	0.52	0.62	0.77
to:	0.52	0.59	0.68	0.86	0.52	0.59	0.68	0.86
Signal to noise ratio:	155	155	155	155	142	152	155	147
Ground sample distance m:	72.5	72.5	72.5	72.5	36.25	36.25	36.25	36.25

Viewing Geometry

	LISS 1	LISS 2
Instrument field of view:	9.4 deg	2 at 4.7 deg each
Scene dimension at nadir:	148.48 km C/T by 174 km AT	2 x 74.24 km C/T, by 87 km AT
Instrument field of regard:	fixed nadir	fixed nadir
Along-track tilt:	fixed nadir	fixed nadir
Stereo capability:	n/a	n/a

Precisions

Radiometric calibration accuracy: Uses internal calibrator; ±1 digital number (relative calibration)
RMS ground location accuracy: 1500 m

Collection/Return Capacity

Min. revisit time w/cross-track tilt: 22 days at equator
Onboard storage: none
Max. contiguous one-pass coverage: (TBS)
Ground network (nominal): 2 stations
Avg. land data collection per orbit: (TBS) sq km
System annual land data collection capability: (TBS) M sq km

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IRS-1C LISS 3, PAN, WFS: INDIA & EOSAT

Mission/Instrument name:	IRS-1C (Indian Remote Rending Satellite) / LISS 3 (Linear Imaging Self Scanner) & Panchromatic & WFS (Wide Field Sensor)
Operating organizations:	National Remote Sensing Agency (NRSA)
Operational date:	December 1995
Number of satellites:	1

Satellite Orbit

Altitude: 817 km
Inclination: 98.691 deg, Sun synchronous
Local mean solar time at equatorial crossing: 10:30±:05 descending nodal crossing
Ground track repeat interval: 24 day s and 341 orbits

Instrument Bands

	LISS 3				PAN		WFS	
Band:	1	2	3	4	5	I	3	4
Spectral range from µm:	0.52	0.62	0.77	1.55	0.5		0.62	0.77
to:	0.59	0.68	0.86	1.7	0.75		0.68	0.86
Signal to noise ratio:	>128	>128	>128	>128	>64		>128	>128
Ground sample distance m:	23.5	23.5	23.5	70.5	5.8		188	188

Viewing Geometry

	LISS 3	PAN	WFS	
Instrument field of view:	4.7 deg			
Scene dimension at nadir:	141 x 141 km	70 x 70 km	770 x 770 km	
Instrument field of regard:	fixed nadir	±26 deg <->	fixed nadir	±398 km; 0.2 deg steps
Along-track tilt:	fixed nadir	fixed nadir	fixed nadir	
Stereo capability:	n/a	cross-track	n/a	

Precisions

Radiometric calibration accuracy: Uses internal calibrator; ±1 digital number (relative calibration)
RMS ground location accuracy: 1500 m

Collection/Return Capacity

Min. revisit time w/cross-track tilt: LISS 3: 24 days at equator PAN: 5 days at equator WFS: 5 days at equator
Onboard storage: 62 Gb <-> 24 minutes of playback data consisting of (1/2 PAN swath) or (LISS 3 + WFS)
Max. contiguous one-pass coverage: playback: 14,400 km x 140 km = 2.0 M sq km (PAN)
Ground network (nominal): 2 stations (Hyderabad & Norman OK) provide real-time coverage of So. Asia & N. Am., plus playback
Avg. land data collection per orbit: (TBS) sq km
System annual land data collection capability: (TBS) M sq km

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IRS-P2 LISS 2: INDIA & EOSAT

Mission/Instrument name:	IRS-P2 (Indian Remote Rending Satellite) / LISS 2 (Linear Imaging Self Scanner)
Operating organizations:	National Remote Sensing Agency (NRSA)
Operational date:	October 1994
Number of satellites:	1

Satellite Orbit

Altitude: 817 km
Inclination: 98.691 deg, Sun synchronous
Local mean solar time at equatorial crossing: 10:30±:05 descending nodal crossing
Ground track repeat interval: 24 days and 341 orbits

Instrument Bands

	VNIR			
Band:	1	2	3	4
Spectral range from µm:	0.45	0.52	0.62	0.77
to:	0.52	0.59	0.68	0.86
Signal to noise ratio:	>127	>127	>127	>127
Ground sample distance m:	36*	36*	36*	36*

Viewing Geometry

Instrument field of view:	4.7 deg
Scene dimension at nadir:	67 km C/T, by 87 km AT
Instrument field of regard:	fixed nadir
Along-track tilt:	fixed nadir
Stereo capability:	n/a

Precisions

Radiometric calibration accuracy:	Uses internal calibrator; ± digital number (relative calibration)
RMS ground location accuracy:	2200 m

Collection/Return Capacity

Min. revisit time w/cross-track tilt:	24 days at equator
Onboard storage:	none
Max. contiguous one-pass coverage:	(TBS)
Ground network (nominal):	2 stations
Avg. land data collection per orbit:	(TBS) sq km

System annual land data collection capability: (TBS) M sq km

Notes

Ground sample distance: 32.74 x 37.39 m in object space resampled to 36m x 36m in output products

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JERS-1 OPS: JAPAN

Mission/Instrument name: JERS-1 / Optical Sensor (OPS)
Operating organizations: National Space Development Agency of Japan (NASDA)
Operational date: September 1992
Number of satellites: 1

Satellite Orbit

Altitude: 568 km
Inclination: 97.67 deg, Sun synchronous
Local mean solar time at equatorial crossing: 10:45±:15 descending nodal crossing
Ground track repeat interval: 44 days and 659 orbits

Instrument Bands

	VNIR				SWIR			
Band:	1	2	3	4	5	6	7	8
Spectral range from µm:	0.52	0.63	0.76	0.76	1.60	2.01	2.13	2.27
to:	0.60	0.69	0.86	0.86	1.71	2.12	2.25	2.40
Signal to noise ratio:	(high lev)	242 ~ 398		69 ~ 117	(low lev)	65 ~ 96		19 ~ 26
Ground sample distance m:	18.3 m CT, 24.2 m AT							

Viewing Geometry

Instrument field of view: 7.55 deg
Scene dimension at nadir: 75 x 75 km
Instrument field of regard: fixed nadir
Along-track tilt: fixed nadir, except band 4 tilted at 15.33 deg for
Stereo capability: In track with bands 3 & 4 -> B/H=0.3

Precisions

Radiometric calibration accuracy: RMS error of input radiance calibrated with AVIRIS < 0.27~4.15 W m-2 sr-1 um-1
RMS ground location accuracy: 100 m

Collection/Return Capacity

Min. revisit time w/cross-track tilt: 44 days at equator
Onboard storage: 72 Gb
Max. contiguous one-pass coverage: 75 km x 9000 km = 675 k sq km
Ground network (nominal): 15 stations
Avg. land data collection per orbit: 675 k sq km
System annual land data collection capability: 10 M sq km [suspect meant "10,000 M"]

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JERS SAR: JAPAN

Mission/Instrument name: JERS-1 / Synthetic Aperture Radar (SAR)
Operating organizations: National Space Development Agency of Japan (NASDA)
Operational date: September 1992
Number of satellites: 1

Satellite Orbit

Altitude: 568 km
Inclination: 97.67 deg, Sun synchronous
Local mean solar time at equatorial crossing: 10:45±:15 descending nodal crossing
Ground track repeat interval: 44 days and 659 orbits

Instrument Bands

Band: L
Bandcenter Mhz: 15
Polarization: H/H
Signal-to-ambiguity ratio dB: 22
Signal-to-noise ratio dB: ~6
Ground sample distance m: 18 (3 looks)

Viewing Geometry

Scene dimension at nadir: 75 x 75 km
Instrument field of regard: 335 deg range in off-nadir angle
Along-track tilt: n/a
Stereo capability: adjoining passes or orbits

Precisions

Radiometric calibration accuracy: <1dB
RMS ground location accuracy: 100 m

Collection/Return Capacity

Min. revisit time w/cross-track tilt: 44 days at equator 44 [?] days at ±30 lat
Onboard storage: 72 Gb
Max. contiguous one-pass coverage: 75 km x 9000 km = 675 k sq km
Ground network (nominal): 15 stations
Avg. land data collection per orbit: 675 k sq km
System annual land data collection capability: 30 M sq km

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KOMSAT HRC : Korea

Mission/Instrument name:	Korean Mapping Satellite (KOMSAT) / High Resolution CCD (HRC)
Operating organizations:	Korean Aerospace Research Institute
Operational date:	
Number of satellites:	1

Satellite Orbit

Altitude: 600-800 (TBD) km
Inclination: (TBD) deg, Sun synchronous
Local mean solar time at equatorial crossing: (TBD)
Ground track repeat interval: (TBD)

Instrument Bands

		VNIR		
Band:	PAN	B1	B2	B3
Spectral range from μm:	0.51	0.43	0.61	0.78
to:	0.73	0.49	0.68	0.89
Signal to noise ratio:	150	80	170	170
Ground sample distance m:	10	20	20	20

Viewing Geometry

Instrument field of view:
Scene dimension at nadir: 40 km CT
Instrument field of regard: as needed to achieve min revisit time
Along-track tilt: fixed nadir
Stereo capability: yes, LE 20 m

Precisions

Radiometric calibration accuracy:
RMS ground location accuracy: ±2,000 m

Collection/Return Capacity

Min. revisit time w/cross-track tilt: 2 days at 34 lat
Onboard storage: 1 Gb
Max. contiguous one-pass coverage:
Ground network (nominal): Korea Ground Station
Avg. land data collection per orbit:
System annual land data collection capability:

Note

General: [This material is based on functional requirements in the RFP.]

Technical Contact

Name: [not provided]
Title:
Address:
Phone:
Fax:
e-mail:

LANDSAT 5 TM: EOSAT

Mission/Instrument name:	Landsat 5 / Thematic Mapper (TM)
Operating organizations:	EOSAT
Operational date:	March 1984
Number of satellites:	1, to be replaced by Landsat 7 in 1998

Satellite Orbit

Altitude: 705.3 km
Inclination: 98.2 deg, Sun synchronous
Local mean solar time at equatorial crossing: 9:37 (mean), 9:18 (actual, 9/95) descending nodal crossing
Ground track repeat interval: 16 days and 233 orbits

Instrument Bands

Instrument Bands	VNIR				SWIR		TIR
Band:	1	2	3	4	5	7	6
Spectral range from µm:	0.45	0.52	0.63	0.76	1.55	2.08	10.42
to:	0.52	0.60	0.69	0.90	1.75	2.35	12.50
Signal to noise ratio:	52	60	48	35	40	21	0.12K
Ground sample distance m:	30	30	30	30	30	30	120

Viewing Geometry

Instrument field of view:	15.39 deg
Scene dimension at nadir:	185 km CT x 170 km (nominal) AT
Instrument field of regard:	fixed nadir
Along-track tilt:	fixed nadir
Stereo capability:	none

Precisions

Radiometric calibration accuracy:	Uses onboard lamps to achieve <10% absolute radiometry
RMS ground location accuracy:	±250 m

Collection/Return Capacity

Min. revisit time w/cross-track tilt:	16 days at equator, 8 days ±60 lat
Onboard storage:	none
Max. contiguous one-pass coverage:	real-time to ground stations only
Ground network (nominal):	15 stations
Avg. land data collection per orbit:	n/a
System annual land data collection capability:	n/a

Note

Signal to noise ratio: At minimum scene radiance for TIR band, noise-equivalent temperature

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LANDSAT 7

Mission/Instrument name: Landsat 7/ Enhanced Thematic Mapper-Plus (ETM+)
Operating organizations: NASA/GSFC (spacecraft), NOAA(s at.ops.), USGS (arc)
Operational date: December 1998
Number of satellites: 1, follow-on to Landsat 5

Satellite Orbit

Altitude: 705.3 km
Inclination: 98.2 deg, Sun synchronous
Local mean solar time at equatorial crossing: 10:00 descending nodal crossing
Ground track repeat interval: 16 days and 233 orbits

Instrument Bands

	PAN	VNIR					SWIR	TIR
Band:	8	1	2	3	4	5	7	6
Spectral range from µm:	0.50	0.45	0.52	0.63	0.76	1.55	2.08	10.42
to:	0.90	0.52	0.60	0.69	0.90	1.75	2.35	12.50
Signal to noise ratio:								
Ground sample dist:	15	30	30	30	30	30	30	60

Viewing Geometry

Instrument field of view: 15.39 degrees
Scene dimension at nadir: 185 km CT x 170 km (nominal) AT
Instrument field of regard: fixed nadir
Along-track tilt: fixed nadir
Stereo capability: none

Precisions

Radiometric calibration accuracy: Uses onboard lamps, full aperture solar diffuser, partial aperture solar imager, standard ground scenes, and intercomparison with MODIS to achieve 2% relative (band-to-band) & 5% absolute radiometry.
RMS ground location accuracy: (TBS)

Collection/Return Capacity

Min. revisit time w/cross-track tilt: 16 days at equator, 8 days at ±60 lat
Onboard storage: 380 Gb
Max. contiguous one-pass coverage: 30 min -> 185 km by 12,600 km = 1.07 M sq km
Ground network (nominal): Primary station at USGS/EDC, Sioux Falls SD + 1 supplementary station at Fairbanks AK for real-time & playback collection to archives; cooperating intl. ground stations (~18) for local real-time collection.
Avg. land data collection per orbit: 540,000 sq km
System annual land data collection capability: 2,800 M sq km

Notes

Annual collection: Based on 250 scenes/day to archives. Additional scenes collected at international ground stations.

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LEWIS: USA (NASA) & TRW

Mission/Instrument name:	Small Spacecraft Technology Initiative (SSTI) "Lewis" / Hyperspectral Imager (HSI) & Linear Etalon Imaging Spectral Array (LEISA)
Operating organizations:	NASA Headquarters, Spacecraft Systems Div., TRW, & GSFC
Operational date:	(TBS) 1996
Number of satellites:	1

Satellite Orbit

Altitude: 523 km
Inclination: 97.0 deg, Sun synchronous
Local mean solar time at equatorial crossing: (TBS) descending nodal crossing
Ground track repeat interval: (TBS) days and (TBS) orbits

Instrument Bands	HSI	HSI	HSI	LEISA
Band:	Pan	VNIR	SWIR	SWIR
Spectral range from µm:	0.45	0.4	0.9	1.0
to:	0.75	1.0	2.5	2.5
Spectral resolution nm:	5	6.25	3-8	
Signal to noise ratio:	(high rad) >200	>150		
	(low rad) >50*	>10*		
Ground sample distance m:	5	30	30	300

Viewing Geometry

Instrument field of view:	
Scene dimension at nadir:	Panchromatic: 13 km Hyperspectral: 7.7 km LEISA: 77 km
Instrument field of regard:	LEISA: ±60 deg <-> (TBS) km
Along-track tilt:	LEISA: ±15 deg <-> (TBS) km
Stereo capability:	n/a

Precisions

Radiometric calibration accuracy: Calibration by reclosable cover/diffuser & tungsten lamp Pan: <20 (absolute [not provided]) HS: <6% (relative[not provided])
RMS ground location accuracy:

Collection/Return Capacity

Min. revisit time w/cross-track tilt:	4-5 days at equator
Onboard storage:	4 Gb
Max. contiguous one-pass coverage:	(TBS) sq km
Ground network (nominal):	2 stations (TRW Chantilly VA, Fairbanks AK)
Avg. land data collection per orbit:	(TBS) sq km

System annual land data collection capability: (TBS) M sq km

Notes

Signal to noise ratio: stimated from published curve at 85% & 5% albedo, outside atm. absorption bands.
Along-track tilt:: LEISA uses forward-look for cloud cuing to HSI

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ORBVIEW

Mission/Instrument name:	OrbView-1
Operating organizations:	OrbImage, an OSC Company
Operational date:	1st quarter 1998
Number of satellites:	*Initially one satellite, to be followed by a second after 2 years*

Satellite Orbit

Altitude: 460 km
Inclination: 97.25 def, Sun synchronous
Local mean solar time at equatorial crossing: 10:30 descending nodal crossing
Ground track repeat interval: Not an exact repeating orbit [approx. 3 days and 46 orbits]

Instrument Bands

	PAN				VNIR		
Band:	1	2	|	3	4	5	6
Spectral range from µm:	0.45	0.45		0.45	0.52	0.63	0.76
to:	0.90	0.90		0.52	0.60	0.69	0.90
Signal to noise ratio:	>10	>10		>10	>10	>10	>10
Ground sample distance m:	1	2		8	8	8	8

Viewing Geometry

Instrument field of view: 1 deg
Scene dimension at nadir: 8 km x 8 km for 2 m GSD panchromatic
Instrument field of regard: ±45 deg <-> 460 km
Along-track tilt: ±45 deg <-> 460 km
Stereo capability: Same-pass stereo capability accommodated

Precisions

Radiometric calibration accuracy: Periodic radiometric and geometric calibrations will be accomplished
RMS ground location accuracy: < 15 m

Collection/Return Capacity

Min. revisit time w/cross-track tilt: 3 days at equator, 2 days ±60 lat
Onboard storage: 32 Gb
Max. contiguous one-pass coverage: 92 km by 85 km = 7820 sq km
Ground network (nominal): 3 stations
Avg. land data collection per orbit: 23,460 sq km
System annual land data collection capability: 34.2 M sq km

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PRIRODA MOMS : GERMANY & RUSSIA

Mission/Instrument name: Priroda / MOMS (Modular Optoelectronic Multispectral Stereoscanner)
Operating organizations: Germany (DARA) & Russia (RSA)
Operational date: Spring 1996 for 18 months
Number of satellites: 1

Satellite Orbit

Altitude: pproximately 400 km
Inclination: 51.6 deg
Local mean solar time at equatorial crossing: n/a
Ground track repeat interval: n/a

Instrument Bands

Band:	1	2	3	4	PAN	Fore, Aft
Spectral range from µm:	0.45	0.53	0.65	0.77	0.52	0.52
to:	0.51	0.57	0.68	0.81	0.76	0.76
Signal to noise ratio:	5	10	10	2.5		
Ground sample distance m:	18	18	18	18	6	18

Viewing Geometry

Instrument field of view: 15 deg
Scene dimension at nadir: PAN: 40 km CT x 120 km AT others: 80 km CT x 240 km AT
Instrument field of regard: fixed nadir
Along-track tilt: fixed sensor channels at +/-21.4 deg
Stereo capability: fore, aft, & nadir

Precisions

Radiometric calibration accuracy: dynamic range > 1200 gray levels; atm. corr. through concomitant MOS spectrometer
RMS ground location accuracy: 1-2 m

Collection/Return Capacity

Min. revisit time w/cross-track tilt: varying
Onboard storage: 385 Gb
Max. contiguous one-pass coverage: (TBS)
Ground network (nominal): 2 stations: Neutrelitz D & Moscow RUS
Avg. land data collection per orbit: (TBS)
System annual land data collection capability: (TBS)

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RADARSAT: CANADA

Mission/Instrument name: RADARSAT / Synthetic Aperture Radar (SAR)
Operating organizations: Canadian Space Agency
Operational date: October 1995 launch
Number of satellites: 1, with follow-ons

Satellite Orbit

Altitude: 798 km nominal
Inclination: 98.6 deg
Local mean solar time at equatorial crossing: 1800 ascending nodal crossing
Ground track repeat interval: 24 days and 343 orbits

Sar Sensors Modes Fine	Standard	Wide	ScanSar-N		ScanSar-W	Ext-H	Ext-L	
Incidence angle range deg:	37	20	20	20	20		49	10
	48	49	49	46	49		50	23
Slant range km:								
Effective coverage wid km:	500	500	500	500	500			
Nominal swath width km:	50	100	150	300	500		75	170
Nominal resolution m:	10	30	30	50	100		25	35

Instrument Bands

Band: C
Spectral range from Ghz: 5.6
Polarization: H/H
Dynamic range dB: 30
Ground sample distance m: 10-100

Viewing Geometry

Instrument field of view:
Scene dimension at nadir: 100 km x 100 km to 500 km x 500 km
Instrument field of regard: 10 - 60 deg from nadir, normally right
Along-track tilt: n/a
Stereo capability: adjoin passes or orbits

Precisions

Radiometric calibration accuracy: 1 dB within 100 km x 100 km scene
RMS ground location accuracy: 1500 km

Collection/Return Capacity

Min. revisit time w/cross-track tilt: 5 days at the equator, 3.5 days at ±30 lat
Onboard storage: 72 Gb
Max. contiguous one-pass coverage: 500 km x 6720 km = 2,260 k sq km
Ground network (nominal): 3 stations
Avg. land data collection per orbit: 2,200 k sq km
System annual land data collection capability: 4,000 M sq km

Notes

Field of regard: Twice during 5 year mission, spacecraft will be turned around for nominal 2-wk period each to provide left-looking SAR, allowing complete coverage of Antarctica

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RESOURCE21

Mission/Instrument name:	Resource21
Operating organizations:	Resource21
Operational date:	1998-1999
Number of satellites:	4 in orbit + ground spare

Satellite Orbit

Altitude: 743.4 km
Inclination: 98.36 deg, Sun synchronous
Local mean solar time at equatorial crossing: 10:30 descending nodal crossing
Ground track repeat interval: 7 days and 101 orbits (each spacecraft)

Instrument Bands

			cirrus			
Band:	1	2	3	4	5	6
Spectral range from µm:	0.45	0.52	0.63	0.775	1.55	1.23
to:	0.52	0.60	0.68	0.90	1.65	1.53
Signal to noise ratio: (high radiance)	119	140	123	171	464	
(low radiance)	49	50	36	52	133	
Ground sample distance m:	10	10	10	10	20	100+

Viewing Geometry

Instrument field of view:	15.9 deg
Scene dimension at nadir:	205 km CT x 1-4000 km AT
Instrument field of regard:	±40 deg <-> ±1270 km
Along-track tilt:	±30 deg
Stereo capability:	yes

Precisions

Radiometric calibration accuracy:	Absolute accuracy <10%; relative accuracy <2%; pol. sensitivity <5% Calibration using Sun and ground targets Atmospheric compensation by cirrus band & ground truth & atm. modeling
RMS ground location accuracy:	30 m

Collection/Return Capacity

Min. revisit time w/cross-track tilt:	Twice in 25 min per day at equator; 2-3 times in 25-50 min at 30 lat Twice weekly with nadir view only
Onboard storage:	176 Gb
Max. contiguous one-pass coverage:	205 km x 4000 km = 820 k sq km
Ground network (nominal):	3 stations
Avg. land data collection per orbit:	820 k sq km per satellite
System annual land data collection capability:	7,200 M sq km

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SAC-C MMRS: Argentina

Mission/Instrument name:	SAC-C / MMRS
Operating organizations:	Comision Nacional de Actividades Espaciales (CONAE)
Operational date:	October 1998 - October 2002
Number of satellites:	1

Satellite Orbit

Altitude: 601 km
Inclination: 97.3 deg, Sun synchronous
Local mean solar time at equatorial crossing: 11:00 [descending?] nodal crossing
Ground track repeat interval: 9 days and 14 orbits

Instrument Bands

			VNIR			SWIR
Band:	1	2	3	4	|	5
Spectral range from µm:	0.48	0.54	0.62	0.77		1.55
to:	0.50	0.56	0.68	0.81		1.70
Signal to noise ratio:	663	710	684	687		2700
Ground sample distance m:	150	150	150	150		150

Viewing Geometry

Instrument field of view:	33.35 deg
Scene dimension at nadir:	315 km CT x 315 km AT
Instrument field of regard:	fixed nadir
Along-track tilt:	fixed nadir
Stereo capability:	n/a

Precisions

Radiometric calibration accuracy:	(TBD)
RMS ground location accuracy:	2250 m

Collection/Return Capacity

Min. revisit time w/cross-track tilt:	9 days at equator, 8 days ±30 lat
Onboard storage:	16 Mb
Max. contiguous one-pass coverage:	315 km by 3500 km = 1.1 M sq km
Ground network (nominal):	4 stations
Avg. land data collection per orbit:	1,000 k sq km
System annual land data collection capability:	[not provided] M sq km

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SICH-1 MSU: Ukraine

Mission/Instrument name:	SICH-1 / Medium Resolution Scanner MSU-S & Low Resolution Scanner MSU-M
Operating organizations:	National Space Agency of the Ukraine
Operational date:	September 1995
Number of satellites:	1

Satellite Orbit

Altitude: 650 km
Inclination: 82.5 deg [97.5 deg?]
Local mean solar time at equatorial crossing: [not provided]
Ground track repeat interval: [not provided]

Instrument Bands

Instrument Bands	MSU-S		MSU-M			
Band:	1	2	1	2	3	4
Spectral range from µm:	0.55	0.1	0.5	0.6	0.7	0.8
to:	0.7	1.0	0.6	0.7	0.8	1.0
Signal to noise ratio:						
Ground sample distance m:	410	410	2000	2000	2000	2000

Viewing Geometry

Instrument field of view:		
Scene dimension at nadir:	MSU-S: 1100 km CT	MSU-M: 1900 km CT
Instrument field of regard:	fixed nadir	
Along-track tilt:	fixed nadir	
Stereo capability:	n/a	

Precisions

Radiometric calibration accuracy: [not provided]
RMS ground location accuracy: [not provided]

Collection/Return Capacity

Min. revisit time w/cross-track tilt: (TBS)
Onboard storage: [not provided]
Max. contiguous one-pass coverage: [not provided]
Ground network (nominal): [not provided]
Avg. land data collection per orbit: [not provided]
System annual land data collection capability: [not provided]

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SPACE IMAGING

Mission/Instrument name: Space Imaging; Commercial Remote Sensing System
Operating organizations: Space Imaging, Inc.
Operational date: December 1997
Number of satellites: 2

Satellite Orbit
Altitude: 628 km
Inclination: 98.1 deg, Sun synchronous
Local mean solar time at equatorial crossing: 10:30 descending nodal crossing
Ground track repeat interval: 11 days and 161 orbits

Instrument Bands	PAN		VNIR		
Band:	1	2	3	4	5
Spectral range from µm:	0.45	0.45	0.52	0.63	0.76
to:	0.90	0.52	0.60	0.69	0.90
Signal to noise ratio:	>10	>10	>10	>10	>10
Ground sample distance m:	1	4	4	4	4

Viewing Geometry
Instrument field of view: 0.93 deg
Scene dimension at nadir: 11 km CT x 100+ km AT
Instrument field of regard: ±45+deg <-> 680+ km
Along-track tilt: ±45+deg <-> 680+ km
Stereo capability: Both fore/aft and cross-track

Precisions
Radiometric calibration accuracy: External calibration, ±4.5% linearity, relative accuracy ±4.5%, absolute ±9.5%
RMS ground location accuracy: 6 m

Collection/Return Capacity
Min. revisit time w/cross-track tilt: 11 days at equator, 9-10 days at ±30 lat (at 10% tilt)
Onboard storage: 64 Gb
Max. contiguous one-pass coverage: 72 km by 140 km = 10,080 sq km
Ground network (nominal): 3 statons assumed, 4 expected
Avg. land data collection per orbit: 22 k sq km
System annual land data collection capability: 110 M sq km

Notes
Signal to noise ratio: SNR is peak to peak at Nyquist for 30 deg solar elevation, 10% low reflectivity & 2:1 contrast ratio at entrance aperture
Min revisit time: Revisit time substantially less with tilt > 10 deg

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SPIN-2 KVR-1000, TK-350: RUSSIA & commercial suppliers

Mission/Instrument name:	SPIN-2 / KVR-1000 Panoramic Camera & TK-350 Topographic Camera
Operating organizations:	Interbranch Association "SOVINFORMSPUTNIK"
Operational date:	Regular launches since 1987 with 2+ months collection per mission
Number of satellites:	1

Satellite Orbit

Altitude:	190-270 km
Inclination:	65 deg
Local mean solar time at equatorial crossing:	not applicable
Ground track repeat interval:	8-15 days and 130-240 orbits

Instrument Bands

Instrument:	KVR-1000	TK-350
Spectral range from µm:	0.58	0.58
to:	0.72	0.72
Signal to noise ratio:	n/a	n/a
Ground sample distance m:	2	10

Viewing Geometry

	KVR-1000	TK-350
Instrument field of view:	10 deg AT x 40 deg CT	75 deg [diagonal ?]
Scene dimension at nadir:	40 km AT x 160 km CT	300 km AT x 200 km CT
Instrument field of regard:	nadir ctr, pan scan	fixed nadir
Along-track tilt:	fixed	fixed nadir
Stereo capability:	none	60% or 80% AT overlap

Precisions

Radiometric calibration accuracy:	not applicable
RMS ground location accuracy:	not applicable

Collection/Return Capacity

Min. revisit time w/cross-track tilt:	8-15 days at equator, 6-12 days at ±30 lat
Onboard storage:	film
Max. contiguous one-pass coverage:	continuous running
Ground network (nominal):	n/a
Avg. land data collection per orbit:	n/a
System annual land data collection capability:	n/a

Notes

Ground sample distance:	applies to the digitally scanned output
Orbital elements:	may be adjusted during mission lifetime to collect desired scenes
Annual land data collection:	[est. 2.4 M sq km per mission of 2-3 months]

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SPOT HRV, HRVIR, HRG: France

Mission/Instrument name:	SPOT (Satellite Pour l'Observation de la Terre) / HRV (Haute Resolution Visible), HRVIR, & HRG
Operating organizations:	Centre Nationale des d'Etudes Spatiales (CNES) & SPOT Image
Operational date:	February 1986 to 1998+ (SPOT-1/2/3) ; Late 1997 to 2002+ (SPOT-4); 2000 to 2010+ (SPOT-5A/B)
Number of satellites:	3 (SPOT-1/2/3) with 2 HRV; 1 (SPOT-4) with 2 HRVIR instruments; 2 (SPOT-5A/B) with 3 HRG on each

Satellite Orbit

Altitude: 832 km Sun synchronous
Inclination: 98.7 deg
Local mean solar time at equatorial crossing: 10:30 descending nodal crossing
Ground track repeat interval: 26 days and 369 orbits

Instrument Bands

Band:	1	2	3	4	PAN
Spectral range from µm:	0.50	0.61	0.79	1.58	0.51
to:	0.59	0.68	0.89	1.75	0.73
Signal to noise ratio HRV measured:	190-240	140-250	250-270	n/a	130-205
HRVIR specified:	165	140	170	127	100
HRG specified:	120	100	120	130	120
Ground sample distance HRV m:	20	20	20	n/a	10
HRVIR m:	20	20	20	20	20
HRG m:	10	10	10	20	5

Viewing Geometry

	HRV, HRVIR	HRG
Instrument field of view:	2x 4.13 deg	3 x 4.13 deg
Scene dimension at nadir:	60 km CT x 60 km AT	
Instrument field of regard:	±27 deg <-> ±870 km	
Along-track tilt:	fixed nadir	±19.2 deg & nadir
Stereo capability:	cross-track	both along-track & cross-track

Precisions

Radiometric calibration accuracy: < 10%
RMS ground location accuracy: 300 - 500 m

Collection/Return Capacity

Min. revisit time w/cross-track tilt:	2.9 days at equator, 2.4 days 30 lat
Onboard storage:	HRV 132 Gb = 2 x 22 min x 50 Mbps; HRVIR 240 Gb = 2 x 40 min x 50 Mbps; HRG 90 Gb
Max. contiguous one-pass coverage:	HRV,HRVIR 120 x 2000 km = 240 k sq km HRG 180 x 2500 km = 450 k sq km
Ground network (nominal):	HRV 15 stations; HRVIR 15-18 stations; HRG 15-20 stations
Avg. land data collection per orbit:	HRV 260 k sq km; HRVIR 300 k sq km; HRG 400 k sq km
System annual land data collection capability:	HRV 1200 M sq km; HRVIR 1500 M sq km; HRG 2000 M sq km

Notes

Signal to noise ratio: HRV: Computed from real images HRVIR, HRG: Specification; real performance should be better
Annual collection: HRV: 3,300,000 images from 1986-1995; 1200 M sq km per year ~ 180 M cloudfree sq km per year
HRVIR: Estimate 1500 M sq km per year ~ 200 M cloudfree sq km per year
HRG: Estimate 2000 M sq km per year ~ 300 M cloudfree sq km per year

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SPOT Vegetation: France

Mission/Instrument name:	SPOT (Satellite Pour l'Observation de la Terre) / VEGETATION
Operating organizations:	Centre Nationale des d'Etudes Spatiales (CNES) & SPOT Image
Operational date:	Late 1997 to 2010+
Number of satellites:	3 (SPOT-4/5A/B)

Satellite Orbit

Altitude: 832 km Sun synchronous
Inclination: 98.7 deg
Local mean solar time at equatorial crossing: 10:30 descending nodal crossing
Ground track repeat interval: 26 days and 369 orbits

Instrument Bands

Band:	1	2	3	4
Spectral range from µm:	0.43	0.61	0.78	1.58
to:	0.47	0.68	0.89	1.75
Signal to noise ratio spec:	134	234	279	222
Ground sample distance m:	1150	1150	1150	1150

Viewing Geometry

Instrument field of view:	±50.5 deg
Scene dimension at nadir:	2200 km CT
Instrument field of regard:	fixed nadir
Along-track tilt:	fixed nadir
Stereo capability:	n/a

Precisions

Radiometric calibration accuracy:	absolute: <5%; interband & multitemporal <3%
RMS ground location accuracy:	1000 m (spec); 500 m (goal)

Collection/Return Capacity

Min. revisit time w/cross-track tilt:	1.3 days at equator, 1 day at 30 lat
Onboard storage:	2.2 Gb
Max. contiguous one-pass coverage:	2200 km x 20,000 km
Ground network (nominal):	1 primary + (TBD) local stations
Avg. land data collection per orbit:	15 M sq km
System annual land data collection capability:	70 G sq km

Notes

Satellite: To be confirmed on SPOT-5A, to be decided on SPOT-5B
Signal to noise ratio: Specification; real performance should be better

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Band	Center	Width	IFO	Purpose
	(nm or um)	(nm or um)	(m)	
Land & Cloud Boundaries				
1	645	50	250	Veg chlorophyll abs land cover trans
2	858	35	250	Cloud & vegetation land cover trans
Land & Cloud Properties				
3	469	20	500	Soil, veg differences
4	555	20	500	Green vegetation
5	1240	20	500	Leaf canopy properties
6	1640	24.6	500	Snow/cloud differences
7	2130	50	500	Land & cloud properties
Ocean Color				
8	412	15	1000	Cholorphyll
9	443	10	1000	Cholorphyll
10	488	10	1000	Cholorphyll
11	531	10	1000	Cholorphyll
12	551	10	1000	Sediments, atmosphere
13	667	15	1000	Sediments
14	678	10	1000	Cholorphyll fluorescence
15	748	10	1000	Aerosol properties
16	869	15	1000	Aerosol, atmos. properties
Atmosphere/Clouds				
17	905	30	1000	Cloud/atm properties
18	936	10	1000	Cloud/atm properties
19	940	50	1000	Cloud/atm properties
Thermal				
20	3.750	0.180	1000	Sea surface temp
21	3.959	0.060	1000	Forest fires, volcanoes
22	3.959	0.060	1000	Cloud/sft temp
23	4.050	0.060	1000	Cloud/sft temp
24	4.465	0.065	1000	Trop temp/cld fract
25	4.515	0.067	1000	Trop temp/cld fract
26	1.375	0.030	1000	Trop temp/cld fract
27	6.715	0.360	1000	Upper-trop humidity
28	7.325	0.300	1000	Mid-trop humidity
29	8.550	0.300	1000	Sfc temp
30	9.730	0.300	1000	Total ozone
31	11.030	0.500	1000	Cloud/sfc temp
32	12.020	0.500	1000	Cloud/sfc temp
33	13.335	0.300	1000	Cld height & fraction
34	13.635	0.300	1000	Cld height & fraction
35	13.935	0.300	1000	Cld height & fraction
36	14.235	0.300	1000	Cld height & fraction