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Space Technologies and Climate Change
Implications for Water Management, Marine Resources
and Maritime Transport

Chapter 4

Capabilities of Space Technologies

This chapter summarises the current contribution of space technologies to climate change research and monitoring, for fresh water, marine resources and maritime transport. Space systems and their ground infrastructure are tools that need to be used in combination with other assets. At the same time however, these systems have their own unique capabilities and can be put to uses ranging from snowmelt runoff measurement to improving safety at sea.

Introduction to satellite technologies

Space technology applications have begun to permeate many aspects of life in our modern societies. A growing number of activities – weather forecasting, global communications and broadcasting, disaster prevention and relief – increasingly depend on the unobtrusive utilisation of these technologies. Today over 30 countries have dedicated space programmes, and more than 50 have procured satellites. There are around 940 satellites operating in orbit; over two-thirds of them are communication satellites (OECD, 2007).

Launching a satellite into space to orbit either earth or another celestial body however remains a formidable challenge. Major progress has been achieved over the past few decades, including notably the successful development of several families of launchers (*e.g.* Soyuz, Ariane, Atlas, Delta), but access to space remains costly and risky. Satellites are basically platforms that can carry instruments used for diverse applications. They are often very sophisticated R&D objects with a lengthy development time (several years), although the greater recurring use of standard satellite platforms is reducing that time (six months or less for some small satellites).

Scientific research and space exploration remain two key objectives of satellite development, but the strategic and economic significance of many down-to-earth technical uses has grown, mainly because of the capacities to:

- Communicate anywhere in the world and disseminate information over broad areas, whatever the state of the ground-based network.
- Observe any spot on earth accurately and in a broad spectrum of frequencies, in a non-intrusive way.
- Locate with increasing levels of precision a fixed or moving object anywhere on the surface of the globe.

Space technologies therefore boast unique capabilities. However, there are a number of technical constraints that may lessen the usefulness of satellite signals or data for specific applications (See Annex B for basic information about the different types of satellite sensors). Primary among these limitations are the following:

- The geographic area that a sensor can cover in one satellite pass and the level of detail that can be seen (a function of the satellite swath width, orbit and sensor's resolution – as with a telescope, the more one zooms, the less global coverage one gets).

- The satellite's revisit time over one specific area (from many times a day to only once a month depending on the orbit chosen for the satellite – see Table 4.1).
- The adequacy of the onboard sensors for a particular element that needs to be observed (this depends on the choice of sensors carried on the satellite, optical or radar, and on the bands that figure in the electromagnetic spectrum).

Table 4.1. **Basics about satellites' orbits**

Orbit	Description
Low earth orbit (LEO)	Satellites in LEO orbit the earth at altitudes of between 200 km and 1 600 km. Compared with higher orbits, LEO satellites can capture images and data with better detail (better resolution), have speedier communications with earth (less latency), and require less power to transmit their data and signals to earth. However, due to friction with the atmosphere, a LEO satellite will lose speed and altitude more rapidly than in higher orbits.
Polar orbit	A majority of satellites never "see" the poles, as more often than not they are positioned in equatorial orbits to cover large populated areas. Satellites that use the polar orbit – particularly meteorological satellites – go over both the North and the South Pole at a 90-degree angle to the equator. Most polar orbits are in LEO, but any altitude can be used.
Geosynchronous/ Geostationary orbit (GSO/GEO)	The satellites in geosynchronous orbit (also known as geostationary when it has an inclination of zero degrees) are at a higher altitude, around 36 000 kilometres, forming a ring around the equator. Their orbits keep them synchronised with the earth's rotation, hence they appear to remain stationary over a fixed position on earth, and provide an almost hemispheric view. Their advantage is the frequency with which they can monitor events (three GEO satellites placed equidistantly can together view the entire earth surface, but with less precision than LEO satellites). They are ideal for some types of communication and global meteorological coverage.
Sun Synchronous Orbit (SSO)	When in sun-synchronous orbit, the satellite orbital plane's rotation matches the rotation of the earth around the sun and passes over a point on earth at the same local solar time each day.

Note: Orbital mechanics (also called flight mechanics) deal with the motion of artificial satellites and space vehicles moving under the influence of forces such as gravity, atmospheric drag, thrust, etc. There are many types of orbits other than the ones described above [*e.g.* medium earth orbit (MEO) for some navigational and communications satellites, Molniya orbits, etc.].

Scientific knowledge about climate change, fresh water and the oceans

The need to gain scientific knowledge about climate change, fresh water and the oceans, as well as the interactions among these, is increasing as changing weather patterns are having diverse impacts around the world. Many activities also call for operational monitoring of the oceans. This section reviews the contributions of space technologies.

An unforeseen but now indispensable role for satellites

In the context of climate change, calls for sound data on the state of the environment from decision makers and the public are growing. Since the beginning of the space age, space-based observations of climate variables have been made by operational meteorological systems and satellite R&D missions. Satellite capabilities – whether for dedicated missions or not – are now increasingly matching data requirements.

The scientific accomplishments enabled by satellite use are numerous. Reliance on space-based observations, telecommunications and navigation has grown internationally over the years, although significant gaps remain in data measurement capabilities and their continuity. For many years, R&D satellite missions were not specifically designed for climate observation and monitoring, and some scientific breakthroughs have been almost accidental. Two examples provided below concern findings on the earth's ozone layer and global precipitation measurements.

In the early days of civilian meteorological satellites in the late 1970s, a NASA mission was launched to study weather patterns by mapping global ozone (Spector, 2007). The Nimbus 7 satellite carried a new R&D sensor dubbed the Total Ozone Mapping Spectrometer (TOMS). Scientists soon realised that some of the data collected by TOMS were more significant than they had initially anticipated, as the instrument allowed them to study ozone in the upper and lower atmosphere in a way that had never been done before, more frequently, and with far greater detail. The data from TOMS led to the detection of long-term damage to the ozone layer above the Arctic, the Antarctic and heavily populated areas. Research conducted using the data led to the passage of the Montreal Protocol in 1987, an international agreement restricting the production of ozone-depleting chemicals. Originally intended to be operational just a few years, the TOMS instrument was not retired until 2007 after more than thirty years of use on different satellites. It has been succeeded by the Ozone Monitoring Instrument, a more advanced spectrometer that currently flies on NASA's Aura satellite.

A second illustration is the Tropical Rainfall Measuring Mission (TRMM) satellite, another recent "example of unexpected 'bonuses' often accruing from a scientific mission" (NRC, 2008). The TRMM satellite was launched in 1997 by NASA in co-operation with the Japan Aerospace Exploration Agency. The mission demonstrated the feasibility of obtaining near-real-time global coverage of precipitation observations from space. This made meteorologists better able to measure spatial and temporal variability of rainfall in the tropics, especially over the oceans (NRC, 2008). TRMM also proved the worth of a number of technologies (*e.g.* the feasibility of paired radar and passive microwave systems in space) and yielded scientific results (*e.g.* showing that a multisensor reference satellite could calibrate data from other space-based observational systems; mapping by radar of the three-dimensional structure of precipitating weather systems and so predicting, *inter alia*, tropical cyclone tracks and intensity). The TRMM mission was originally intended to last three to five years but has enough fuel to remain in orbit until 2012. It could be followed by the Global Precipitation Measurement Mission in 2013. The GPM Mission includes a core satellite that makes measurements and carries dual-frequency precipitation radar and a passive microwave sensor. The data from this satellite are to be inter-calibrated with those from international operational and research satellites carrying similar microwave sensors. The overall system could provide global estimates of precipitation approximately every three hours.

There are many other examples of past and current scientific accomplishments where satellite data played a role (Table 4.2).

Table 4.2. **Examples of scientific accomplishments involving earth observations and landmark satellites**

Accomplishment	Satellites
Monitoring global stratospheric ozone depletion, including Antarctica and Arctic regions	TIROS series, Nimbus 4 and 7, ERS 1, ERS-2, Envisat
Detecting tropospheric ozone	Nimbus 7, ERS 2, Envisat, Aqua, Aura, MetOp
Measuring the earth's radiation budget	Explorer 7, TIROS, and Nimbus
Generating synoptic weather imagery	TIROS series, ATS, SMS, MetOp
Assimilating data for sophisticated numerical weather prediction	Numerous weather satellites, including the TIROS series, NOAA's GOES and POES, Eumetsat's MetOp, ERS 1, ERS-2, Envisat
Discovering the dynamics of ice sheet flows in Antarctica and Greenland	Radarsat, Landsat, Aura, Terra, Jason, ERS-1, ERS-2, Envisat
Detecting mesoscale variability of ocean surface topography and its importance in ocean mixing	Topex/Poseidon, ERS 1, ERS-2, Envisat
Observing the role of the ocean in climate variability	TIORS-N and NOAA series, ERS 1, ERS-2, Envisat
Monitoring agricultural lands (a contribution to the Famine Early Warning System)	Landsat, Spot series
Determining the earth reference frame with unprecedented accuracy	Lageos , GPS

Source: Adapted from NRC, 2008.

The main advantages of using satellites for climate change can be summarised (Payne *et al.*, 2006):

- Data are collected year-round and can provide information when field data collection is not possible, due to remote locations limiting on-the-ground access or to bad weather conditions.
- For certain applications there may be reduced costs when compared to traditional field data collection methods in remote environments (land cover classification for example).
- Given the geographic extent of oceans, *in situ* observations alone cannot adequately characterise dynamics. Remote sensing systems can capture a synoptic view of the landscape.
- Remote sensing provides additional information that can supplement more intensive sampling efforts and help extrapolate findings.

Responding to specific requirements for climate and ocean variables

This section reviews in more detail some of the current data required by scientists and decision makers with regard to climate and ocean variables, and determines whether they may rely on space-based systems. It appears that in many cases satellites have furnished very useful data over the years, although some inherent limitations still exist.

Essential climate variables

Existing satellites collect data on key earth parameters – or essential climate variables, ECVs –from the atmosphere, oceans, and land. A large number of those variables are used by national and international groups, such as the United Nations Framework Convention on Climate Change (UNFCCC), to research and monitor the climate. Over the years several international co-ordination bodies – in particular the Committee on Earth Observation Satellites (CEOS) and the Global Climate Observing System (GCOS) – have, together with space agencies and scientific groups, developed detailed requirements for satellite-based climate observations.[1]

One important aspect is that sensors all have their particular strengths and weaknesses. Thus no one sensor can be used for every aspect of monitoring, because of different spatial resolution (detailed metric *vs.* large kilometric view), spectral resolution (infrared *vs.* other bands), temporal resolution (revisit time), and atmospheric conditions. Even when tasked with the same mission, space systems usually have their respective specificities. For example, there are currently several satellite systems from different countries measuring sea surface temperature, but each instrument measures the temperature at a slightly different depth and with very different accuracy (ESA, 2008).

Despite those limitations, a large number of essential climate variables depend on satellite data. Based on a list submitted by the GCOS at the request of the UNFCCC to provide a global and internationally agreed set of climate change variables, a total of 34 ECVs benefit from space observations (Table 4.3).

Overview of the information flow in water remote sensing

Remote sensing from space relies on several parameters to draw data from water bodies. Many physical and biological phenomena have a "surface signature". This means that large lakes or snow cover for example provide signals that can be detected from space.

To generalise, a space-borne sensor carried onboard a satellite detects in its fields of view the surface signature of a water-related phenomenon and reacts to it (Figure 4.1). Despite inherent noise and disturbances in the atmosphere, the sensor receives the information and then transmits it to the

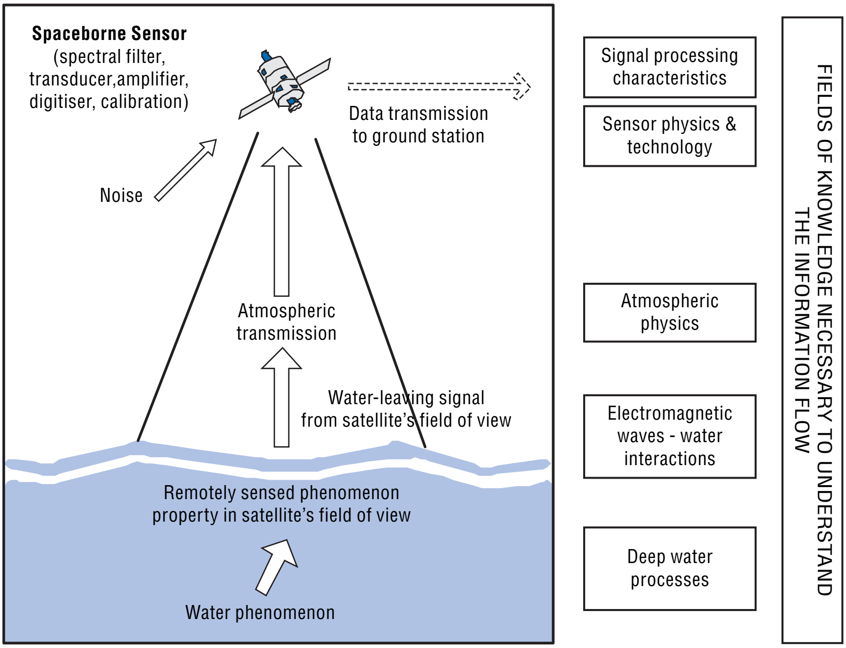
Table 4.3. **Thirty-four essential climate variables (ECVs) and their dependence on satellite observations**

Those largely dependent in italic

Domain		Essential Climate Variables (ECV)
Atmospheric (over land, sea and ice)	**Surface:**	Air temperature, *precipitation*, air pressure, surface radiation budget, wind speed and direction, water vapour
	Upper-air:	*Earth radiation budget (including solar irradiance), upper-air temperature [including Microwave Sounding Unit (MSU) radiances], wind speed and direction (especially over the oceans), water vapour, cloud properties*
	Composition:	*Carbon dioxide*, methane, *ozone*, other lasting greenhouse gases, *aerosol properties*
Oceanic	**Surface:**	*Sea surface temperature*, sea surface salinity, *sea level, sea state*, *sea ice*, current, *ocean colour (for biological activity)*, carbon dioxide partial pressure
	Sub-surface:	Temperature, *salinity*, current, nutrients, carbon, ocean tracers, phytoplankton
Terrestrial	River discharge, water use, ground water, lake levels, *snow cover, glaciers and ice caps*, permafrost and seasonally frozen ground, *albedo, land cover (including vegetation type)*, fraction of absorbed photosynthetically active radiation (FAPAR), leaf area index (LAI), *biomass*, *fire disturbance, soil moisture*	

Source: CEOS, 2006.

Figure 4.1. **Information flow in water remote sensing**



Source: Adapted from Robinson, 2004.

ground station. Only properties at the water surface can be detected, although in some cases observing the surface can also provide some information about what is happening beneath.

As an example, internal waves – a dynamic phenomenon centred dozens of metres below the sea surface – can be revealed in considerable spatial detail in certain radar imagery because of their surface roughness signature (Robinson, 2004). For the "water colour", which helps determine water quality and detect pollution, the uppermost few metres can be observed; the temperature, roughness and water height parameters can only be observed at the surface. To provide a proper interpretation of the observed surface signatures, a number of fields of knowledge presented in the right column of the figure (*e.g.* sensor physics and technology) need to be taken into consideration.

It is also possible to measure elements of the global water cycle using diverse space-based systems. The estimated residence times for water range from one week (*e.g.* biospheric water) to 10 000 years (*e.g.* ground water) – hence the need for reactive, timely and long-term observations. Among the key parameters of the overall water cycle, four are particularly important:

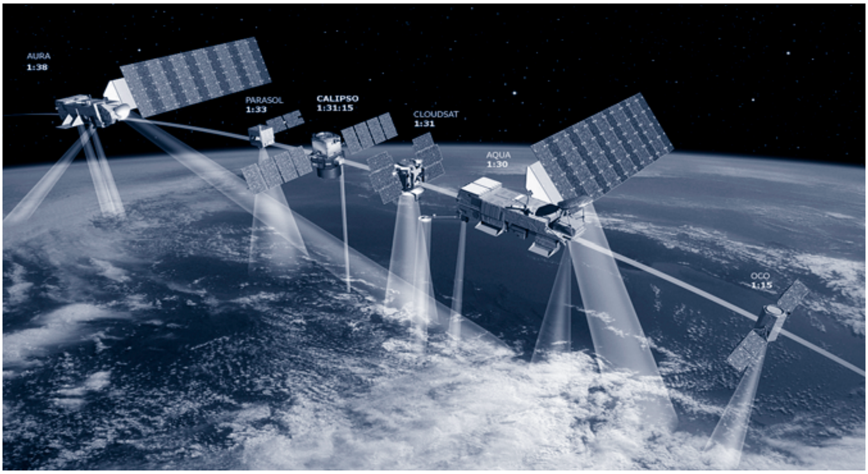
- *Precipitation* occurs in a variety of forms (*i.e.* rain, hail, freezing rain, sleet, snow).
- *Evaporation* is the physical process by which a liquid (*i.e.* water) or solid substance (*i.e.* snow) is transformed to the gaseous state.
- *Evapotranspiration* can be defined a bit differently depending on the scientific angle used, but it consists generally of the sum of transpiration (*i.e.* evaporation of water from plant leaves) and evaporation from water in the soil (*e.g.* rivers, lakes).
- *Water runoff* is composed of a mixture of water and soil (along with any other organic or inorganic substances); it is caused by precipitation, snowmelt, over-irrigation, or other water coming in contact with the earth and carrying matter to streams, rivers, lakes and other surface water bodies. A water runoff can be a source of pollution, carrying polluted substances over large areas in the case of storms.

Studying the atmosphere (cloud, water vapour, precipitation and wind)

Measuring the water in the atmosphere contributes to existing knowledge about the global water cycle and sends early warnings of possible problems, such as drought or floods due to lack of or excessive precipitation and pollution. Several space-borne systems are used to monitor clouds, water vapours, precipitation and winds on different spatial and temporal scales, although ground systems are still the main components of the architecture (*e.g.* networks of pluviometers for continuous direct local measurements, ground-based radars).

Cloud cover – Cloud cover information from space has been provided over the past decade mainly from three instruments flying on different US and European satellites: the Advanced Very High Resolution Radiometer (AVHRR), the Moderate Resolution Imaging Spectrometer (MODIS) and ESA's Medium Resolution Imaging Spectrometer (MERIS) (ISU, 2004). Those instruments were not primarily intended to measure clouds, so they can experience difficulties in areas of heavy cloud cover. As of June 2008, five different satellites – four from NASA and one from CNES dubbed the "Afternoon Constellation" or "A-Train" – provide data on the interactions of clouds, pollution and rainfall (Figure 4.2). The satellites, which each carry the AVHRR, MODIS or MERIS instruments, pass over the equator within a few minutes of each other in the afternoon around 13:30 (local time) each day, allowing for near-simultaneous observations and measurements of clouds over a precise area by different means. The combination of data from those satellites and others has already provided (in early 2008) some unforeseen findings on the effect of pollution on clouds. A NASA team showed that South American clouds infused with high levels of carbon monoxide due to power plants or agricultural fires – classified as "polluted clouds" – tend to produce less rain than their clean counterparts during the region's dry season (NASA Goddard, 2008). More studies of the interactions between aerosols and clouds are needed to understand pollution dynamics better, and this will be facilitated as more diverse data become available.

Figure 4.2. **The "A-Train" satellite constellation studying the atmosphere**



Note: As of June 2008, five satellites are in orbit: NASA's Aqua, Aura, CloudSat, CALIPSO and CNES' PARASOL.

Source: NASA Goddard, 2008.

Water vapour in the atmosphere – Water molecules from the ocean, soil and vegetation circulate in the atmosphere through different processes, such as evaporation. Studying water vapour not only adds to the understanding of climate processes but also contributes to weather forecasting. Ground-based probe measurements are still the routine way to observe the vertical distribution of water vapour. However, the procedures for deriving data from remote sensing (*i.e.* using remotely sensed thermal infrared measurements) and navigation satellite signals (a promising technique – see Box 4.1), and then integrating them in models, have gone from experimental to quasi-operational. Infrared sensors on satellites can measure water vapour in a layer of atmosphere several kilometres above the earth's surface. Data are being received from a number of radiometer sensors that are carried on board meteorological satellites, such as NOAA's polar satellites (*i.e.* Advanced Microwave Sounding Unit B on NOAA-15, NOAA-16, NOAA-17) and the US Department of Defense's Meteorological Satellite Programme satellites (*i.e.* Special Sensor Microwave Imager or SSM/I). Based on these data and new atmospheric models, new climate patterns called atmospheric rivers have been identified (Neiman *et al.*, 2008). These are long plumes of moisture streaming over large bodies of water, which can be responsible for either heavy winter rains, major floods, or – when they are almost absent – extreme episodes of dry, hot weather in summers.

Box 4.1. **Improving weather forecasting by measuring water vapour**

Launched in April 2006, the US-Chinese Taipei COSMIC constellation (Constellation Observing System for Meteorology, Ionosphere and Climate) is a system of six micro satellites; these measure the bending of radio signals from the US global positioning system (GPS) as the signals pass through the earth's atmosphere. COSMIC can see through cloud cover and gather highly accurate data through many levels of atmosphere. Initial results show that the system's unique global coverage provides unprecedented information on the atmosphere's temperature and water vapour structure. Moreover, COSMIC data can be collected above hard-to-reach locations, such as Antarctica and the remote Pacific; that could greatly enhance the global-scale monitoring needed to analyse climate change. According to scientists working with COSMIC data, after only a few months it is possible to see the strengths and weaknesses in some forecasting models that were not possible to see before.

Source: National Center for Atmospheric Research, 2006.

Precipitation – Concerning precipitation, the data provided by ground-based measurement systems (*e.g.* meteorological and radar stations) have proved cost-effective in continuously monitoring precipitation. However, it is not possible for these ground-based systems to monitor weather conditions in remote areas, over the oceans or in less developed regions of the world. The first satellite mission dedicated to precipitation studies was NASA-JAXA's Tropical Rain Monitoring Mission (TRMM), mentioned above. In June 2008, Precipitation Radar (PR) is still the only such radar in space, providing direct, fine-scale observations of the three-dimensional structure of precipitation systems (*i.e.* unique vertical profiles of the rain and snow from the surface up to a height of about 20 kilometres), with high revisit time.

Wind – Satellite ocean surface vector wind (OSVW) data have greatly influenced how winds are measured over the oceans, particularly with the improvement of operational weather forecasting and warning capabilities (*e.g.* for hurricanes) (Jelenak and Chang, 2008). The first wind-measuring microwave radar instrument in space (with data used operationally by meteorological offices) was the scatterometer launched on ESA's ERS-1 in 1991. It was followed by NASA's Scatterometer (NSCAT), launched in 1996 aboard the Advanced Earth Observing Satellite (ADEOS). It provided continuous measurements of ocean surface wind speeds, taking 190 000 wind measurements per day and mapping over 90% of the world's ice-free oceans every two days. In doing so, it furnished more than 100 times the amount of ocean wind information then available from traditional ships' reports (NASA JPL, 1996). This mission was followed in 1999 by the launch of QuikSCAT, which provided even more detailed ocean winds data. A QuikSCAT follow-on mission is currently being considered, so as to allow data continuity and improve OSVW measurement capabilities (Gaston and Rodriguez, 2008).

Soil moisture and salinity

Soil moisture and sea/ocean salinity are important variables for climate monitoring and for efficient water management practices in local and regional communities. These parameters also significantly affect the global balance in energy and moisture, hence providing important information for climate modelling. Currently there are relatively few datasets on either soil moisture or water salinity.

Soil moisture – This is a critical component of temperature and precipitation forecasts, as well as other applications. Soil moisture measurements are usually required to depths of 1 to 2 metres, an area often referred to as the "root zone". Soil moisture content affects infiltration (*i.e.* the process of water entry from surface sources such as rainfall or irrigation into the soil), runoff, and the water available for use by vegetation. Measurement of the moisture profile through the plant rooting zone and below is, therefore, of the utmost importance. However, satellites are not capable of performing direct measurements of the moisture throughout the soil profile below the thin surface layer. Space-based measurements provide estimates of water in the upper 5-10 centimetres of soil.

Table 4.4. **List of remotely sensed oceanographic parameters, their observational class, and representative satellites and sensors they carry**

Parameter	Observational category	Satellites (sensors)
Bio-optical properties of oceanic waters (*e.g.* ocean colour)	Visible – near infrared	Envisat (MERIS), AQUA (MODIS), Orbview2 (SeaWifs)
Bathymetry (*i.e.* measurement of the depth of the ocean floor from the water surface)	Visible – near infrared	Landsat, Spot, Ikonos
Sea surface temperature	Thermal infrared Microwave radiometers	POES (AVHRR), GOES (Imager), DMSP (SSM/I), TRMM (TMI), MetOp
Sea surface salinity	Microwave radiometers and scatterometers	. .
Sea surface roughness, wind velocities, waves and tides	Microwave scatterometers and altimeters Synthetic aperture radar	ERS-2, QuickSat, RADARSAT-1, Envisat
Sea surface height, wind speeds	Altimeters	Topex-Poseidon, Jason-1, QuikSCAT
Sea ice	Visible – near infrared Microwave radiometers, scatterometers and altimeters Synthetic aperture radar	POES (AVHRR), DMSP (SSM, I), ERS-1, ERS-2, RADARSAT-1 and 2, Envisat
Surface currents, fronts and circulation	Visible – near infrared	POES (AVHRR), GOES (Imager), Topex-Poseidon, Jason-1, Envisat
Surface objects, ships, wakes and flotsam	Synthetic aperture radar	RADARSAT-1, Envisat (ASAR)

Source: Adapted and updated from Brown *et al.*, 2005.

While these suffice for some applications, many others require moisture measurements through the soil profile (CEOS, 2006). As a result, current efforts are focusing on improving hydrological models to understand and, if possible, quantify the relationship between surface soil wetness and subterranean soil moisture. In 2009, the Soil Moisture and Ocean Salinity (SMOS) mission, the second Earth Explorer mission to be developed as part of ESA's Living Planet Programme, should allow observation of soil moisture over the earth's landmasses and salinity over the oceans. Since SMOS will provide data on soil moisture content to a depth of only a few centimetres, modelling techniques are being developed to derive the moisture content within the root zone from time series of near-surface soil moisture.[2]

Salinity – Salinity can be detected from space-borne sensors only when it occurs on the surface or in the root zone of vegetation, so satellites cannot map soil salinity directly. They are used to map other parameters – such as optical reflectance at a fixed wavelength, natural gamma radiation, and electric conductivity – from which salinity models can then be derived. Demonstrations are still under way using other already orbiting multispectral satellites (*e.g.* Landsat, Spot, IRS, Ikonos) to help detect exposed salt on the surface (*e.g.* monitoring the decline in photosynthetic activity in vegetation as a result of the salt stress; detecting salinity from the type of the vegetation, which can indicate the absence of salt in the root zone). The SMOS satellite,

Table 4.5. **Overview of selected space systems with ocean-related missions**

Mission	Dates	Description
Tropical Rainfall Measuring Mission (TRMM)	1997 – present (extended until 2009, could be operational until 2012)	TRMM is a joint mission between NASA and Japan (JAXA) with five instruments, including the first Precipitation Radar (PR) in space. These instruments are used to monitor and predict tropical cyclone tracks and intensity, estimate rainfall, and monitor climate variability (precipitation and sea surface temperature).
SeaWinds (on board QuickScat satellite)	1999 – present	The SeaWinds instrument on the QuikScat mission is a quick recovery mission to fill the gap created by the loss of data from the NASA Scatterometer (NSCAT) when the ADEOS satellite lost power in June 1997. The SeaWinds instrument is a specialised microwave radar that measures near-surface wind speed and direction under all weather and cloud conditions over the earth's oceans.
Jason-1 and -2	2001 – present	Jason is a joint United States-France (CNES) oceanography mission designed to monitor global ocean circulation, discover the tie between the oceans and atmosphere, improve global climate predictions, and monitor events such as El Niño and La Niña and ocean eddies. Its successor, Jason-2, was launched in June 2008.
SeaWiFS (onboard OrbView-2 satellite)	1997 – present	The purpose of the Sea-viewing Wide Field-of-view Sensor (SeaWiFS) project is to furnish quantitative data on global ocean bio-optical properties to the earth science community. Subtle changes in ocean colour signify various types and quantities of marine phytoplankton (microscopic marine plants); this knowledge has both scientific and practical applications. NASA purchase the OrbView-2 data from Orbimage.
Aqua	2002 – present	The Aqua satellite carries six instruments, including the Moderate Resolution Imaging Spectroradiometer (MODIS) also carried by the Terra satellite, and observes the earth's oceans, atmosphere, land, ice and snow covers, and vegetation.
SeaWinds (on board ADEOS II)	2002 – present	The Advanced Earth Observing Satellite II (ADEOS II), the successor to the Advanced Earth Observing Satellite (ADEOS) mission, is a NASA-JAXA joint mission. The mission is to research global climate changes and their effect on weather phenomena.
Envisat	2002 – present	This is the largest earth observation satellite ever built. The ESA satellite carries 10 sophisticated optical and radar instruments that provide continuous observation and measurement of the earth's oceans, land, ice caps and atmosphere for the study of various natural and man-made contributors to climate change. It also provides the wealth of information needed for the management of natural resources.
ICESat	2003 – present	ICESat is a small satellite mission flying the Geoscience Laser Altimeter System (GLAS) in a near-polar orbit. GLAS measures to the elevation of the earth's ice sheets, clouds and land.

Source: NASA, 2008; ESA, 2008.

already mentioned for soil moisture detection and to be launched in 2009, should allow detection of water salinity to some degree. The US-Argentine Aquarius satellite, to be launched in 2010, should also better measure sea surface salinity (SSS) on a global basis.

Snow cover and sea ice

The cryosphere consists of sea, lake and river ice, snow cover, glaciers, ice caps and ice sheets, and frozen ground (including permafrost). It is an important part of the global climate system, and more than one-sixth of the global population lives in regions that depend on snow and glaciers for water supply. Changes to the cryosphere have significant implications for global sea levels, regional water resources and both terrestrial and aquatic ecosystems. Although 25 years of satellite data are available, the many processes involved in the cryosphere are still poorly understood. One recurring reason mentioned by scientists is the fact that many missions were of short duration and the short revisit time of satellites causes important observations to be missed (EARSEL, 2006). Despite these shortcomings, new data are becoming available and innovative applications are being developed in many countries.

Snow – The amount and timing of snowmelt runoff from snow and glaciers provide important information for the management of water resources, including flood prediction and hydropower operations. Main data sources include satellite data from polar orbiting and geostationary satellites with visible/near-infrared instruments – such as Land (remote sensing) Satellite (Landsat); Moderate Resolution Imaging Spectroradiometer (MODIS); Medium Resolution Imaging Spectrometer (MERIS); Geostationary Operational Environmental Satellites (GOES); and Advanced Very High Resolution Radiometer (AVHRR). For example, MODIS data are being used to monitor the snow cover dynamics of areas greater than 10 square kilometres, together with AVHRR data that provide continuous information on snow cover during daytime in cloud-free areas. Snow of moderate depth can be measured using passive microwave data. These systems have capabilities for day/night monitoring regardless of cloud cover. Optical and radar imagery are today used operationally in the monitoring of snow cover in Scandinavia for hydropower planning and flood prediction.

Sea ice – The safety and efficiency of sea transportation, offshore operations, fisheries and other marine activities identified in previous chapters have provided the motivation to establish sea ice monitoring and snow forecasting services in many countries, in addition to the classic weather services. These services using satellite data (from the SSM/I sensors onboard DMSP satellites, SeaWinds, Envisat, Radarsat) are usually limited to national areas of interest, although international research on the Arctic and Antarctic increasingly calls for the development of new ice monitoring instruments. A number of projects led by international consortia are developing generic sea ice data monitoring to be reused by intermediate users (including commercial value adders) who will then generate services, drawing on other information to serve specific end-users. The European Polar View project for example consists of the development and qualification of customised ice information services, including high resolution ice charts (*e.g.* for Svalbard region) and ice forecasting information services. These are all primarily based on Envisat and Radarsat data.

Table 4.6. **Requirements *vs.* capabilities for sea ice monitoring and snow cover**

Requirements	Capabilities of satellites
Spatial distribution of sea ice	The use of remote sensing for detecting and monitoring icebergs still has its limitations, mainly due to the scale of the targets. Future SAR missions with increased spatial resolution, multiple frequencies and polarisations might solve some of the current problems.
Sea ice thickness and type (first-year and multiyear ice) and their variation with time	Ice thickness is more difficult to monitor than ice extent. With satellite-based techniques only recently introduced, observations have been spatially and temporally limited.
Measurements of snow accumulation and melt	Operational systems are in place in a number of countries, although information about snow depth is sometimes limited.

SeaWinds' Ku-band backscatter data are used to generate daily sea ice maps at 6-kilometre resolution. Such data can be used to monitor seasonal ice changes, and scatterometer data have already been used over the years to track the break-up of giant icebergs.[3] In 1992 a giant iceberg nearly the size of Rhode Island, known as B10A, broke away from the Thwaites glacier in Antarctica. In September 1996 the iceberg was observed floating in the Antarctic ice pack by NASA's Scatterometer (NSCAT) instrument on board Japan's Advanced Earth Observing Satellite (ADEOS). By 1999, conventional methods of tracking icebergs lost sight of B10A's location due to poor visibility and cloudy Antarctic winters. However, it was spotted again by the SeaWinds scatterometer on the Quikscat satellite in July 1999 during its first pass over Antarctica. The iceberg was then breaking up and being driven by ocean currents and winds into the shipping lane, where it posed a threat to commercial, cruise and fishing ships. More recent examples have shown that a combination of optical and radar imagery that is high resolution (10 metres or less) can improve iceberg detection (Vitaly *et al.*, 2008). More satellites are expected to be launched over the next three years with increased sensing capabilities, which should allow better coverage (*e.g.* high resolution radar satellite TerraSar-X, COSMO-SkyMed's four radar satellites constellation).

Water quality

Scientific activities are ongoing to develop new methods to extract a variety of in-water bio-optical properties from remote sensing data. The objective is to be able to monitor the quality of water bodies, detecting in particular natural and man-made pollution. Space-based sensors look primarily at "ocean colour" in waters, which refers to the presence and concentration of specific minerals or substances. The prime observables of space-based ocean colour instruments are the chlorophyll and gelbstoff concentrations in the surface layers. The concentration of chlorophyll is used to estimate the amount of phytoplankton in waters, and hence the abundance of ocean biota, while biologists use ocean colour and chlorophyll-a products to predict harmful algal blooms. The first images of ocean colour distribution were taken from space by Nimbus 7. This satellite, launched in 1978, carried a spectroradiometer instrument called CZCS (Coastal Zone Colour Scanner) (Kramer, 2002). The data of this first generation of ocean colour instruments contributed greatly to understanding the marine environment and its biological, biochemical and physical processes.

Box 4.2. **Monitoring jellyfish proliferation in seas and oceans**

The proliferation of jellyfish (also known as medusae) has been observed in seas and oceans around the world over the past decade, with increasing environmental and economic effects. In November 2007, a dense pack of billions of "mauve stinger" jellyfish, usually found in warm Mediterranean waters, killed about 120 000 salmon overnight in a fishery off the coast of Ireland north of Belfast. In spring 2008, a giant jellyfish native to Australia called Phyllorhiza punctata was detected in the waters of the Gulf of Mexico, up the eastern coast of Florida and as far north as North Carolina (ClimateScienceWatch, 2008). Two centuries' worth of local data show that jellyfish populations tend to swell every 12 years, remain stable four to six years, and then subside. However, a new population growth is expected to reach a peak in the summer of 2008 for the eighth consecutive year. The frequency and persistence of the phenomenon seem to be driven by overfishing (*i.e.* jellyfish occupy the place of many other species, including their former predators), pollution and climate change (*i.e.* warmer waters, strong ocean currents, altered ecosystems). Monitoring jellyfish populations, of which 30 000 different species have already been identified, can be performed via acoustic surveys at sea. Another method now in the experimental phase is to use computer hydrodynamic models coupled with sea surface temperature and salinity data from satellites (NOAA, 2001). The objective is to map locations where jellyfish are likely to be found, usually in moderate salinity and warm waters. For example, NOAA provides near-real-time maps of sea nettle distribution in the Chesapeake Bay, the largest US estuary, again on an experimental basis (NOAA, 2008).

Source: NOAA, 2001, 2008; Hay, 2006; ClimateScienceWatch, 2008.

Although there are many water variables that remote sensing can already detect (chlorophyll-a, suspended solids, turbidity), the complexities of water's optical properties still present difficulties in the use of satellite remote sensing for coastal and inland waters. A resolution of 100 metres signifies that the mean water quality can be detected in a pixel of 100 x 100 metres. However, the poor spatial resolution of some sensors limits their use for small lakes and archipelagos, since it becomes harder to distinguish between land and water (Kallio, 2002). Also, two classes that define the quality of optic observations are used in ocean water study. "Case 1 waters" signals that phytoplankton and their derived products are the main influence on the optical field, whereas for "Case 2 waters" there are additional seawater constituents (*i.e.* suspended sediments, dissolved organic matter), which makes it more difficult to analyse the optical field. Coastal and inland waters are usually "Case 2"; here, the current algorithms and space sensors' resolution still need to be improved (Eurico, 2005).

Box 4.3. **Measuring river flow with radar satellite**

The existing method of "streamgaging", developed in the early 1900s, consists of physically measuring the channel geometry and velocity of the water on a periodic basis. Because these data are needed over the entire range of river flow situations, personnel and equipment are often subjected to dangerous weather and flow conditions. In addition, because many of the gaging locations are remote, obtaining the data is expensive and cannot be done frequently or continuously. To measure flow at a given cross-section of a river, two pieces of information are essential: 1) water velocity; and 2) channel cross-sectional area (depth and width). Satellites equipped with radar instruments can be used with some limitations for those two types of measures. Water surface velocity can be measured at various points across the river with radar altimetry (using the Bragg scatter principle of high-frequency pulsed doppler radar signal). Hundreds of separate radar pulses are sent per second from satellites in low earth orbit over bodies of water, and the time it takes their echoes to bounce back recorded. Non-contact methods of streamgaging show great promise, but much remains to be learned. Conductivity has a significant negative effect on radar energy in water, and there are physical limits to the depth of radar energy penetration.

Source: Adapted from Hirsch 2004; Plant *et al.*, 2005.

Remote sensing from space therefore has limitations when it comes to water quality monitoring. Instruments can at present only directly detect some of the pollutants, such as oil, sediment and thermal discharges. The others can in some cases be detected by proxy, but only via ephemeral site-specific correlations between remotely sensed features and the pollutants in question. Thus fertilisers, pesticides, nutrients and colourless toxic and industrial wastes (containing, for example, heavy metals, aromatic hydrocarbons, acid, etc.) cannot be detected, but in some instances their concentrations (measured by field survey at the time of image acquisition) may be correlated with levels of substances that *can* be detected. Such ephemeral relationships may be demonstrated through experiment, but even then they can be a long way from allowing operational, cost-effective detection and monitoring of pollutants (Green *et al.,* 1999).

According to the GCOS group, the best-quality basin-wide or global data on ocean colour are currently being collected using SeaWiFS, the Medium Resolution Imaging Spectrometer (MERIS), and the Moderate Resolution Imaging Spectroradiometer (MODIS), all carried onboard different satellites. There is no guarantee, however, that either of these instruments will still be in operation a decade from now. It is therefore necessary to ensure the continuity of equal or even better-quality ocean colour measurements in the future, to facilitate chlorophyll climatology studies on regional and global scales (CEOS, 2007).

Water temperature

Over the past decade, a large number of satellites' sea surface temperature (SST) products, derived by different groups or agencies from various satellite sensors and platforms, have become available in near-real-time. Data on sea surface temperature maps notably help meteorologists predict weather and fishermen locate prime fishing areas.

The instruments used are all passive sensors (radiometers), which measure the natural radiation emitted by the earth's surface and propagated through the atmosphere. Several space instruments are available today that provide hundreds of data products with a range of spatial, spectral, radiometric and temporal scales (Table 4.7). The Advanced Very High Resolution Radiometer (AVHRR), the Along Track Scanning Radiometer (AATSR), and the Moderate Resolution Imaging Spectroradiometer (MODIS) sensors are the main sources of sea surface temperature data (CEOS, 2006). The AATSR series of instruments have for example delivered a highly accurate time series of sea surface temperature variations over a 17-year period (1991-2008), which has enabled a unique characterisation of global warming during that time (ESA, 2008).

The spatial dimension and spectral resolution of these sensors are not, however, suitable for small-scale measurements. Satellite imagery must be integrated with airborne and ground-based remote sensing systems (*i.e.* hyperspectral sensors with greater resolution) for the documentation of point areas of importance, such as around dams and industries. These systems can be hired on a case-by-case basis, but they cannot produce the temporal resolution of satellite imagery and do not provide comprehensive coverage of large basin systems (ISU, 2004).

Table 4.7. **Overview of certain space-borne sensors for ocean colour detection**

Sensor (sensor provider)	Platform	Ground resolution (km)	Swath width (km)	Spectral bands	Data revisit (days)	Dates of operations
CZCS (NASA, United States)	Nimbus 7	0.825	1 600	5 bands	2	Oct. 1978 – June 1986
OCE (NASA, United States)	Space Shuttle STS-2 (SIR-A mission)	0.90	180	8 bands	NA	Nov. 1981
MOS A, B and C (DLR, Germany)	IRS-P3 (ISRO, India); Priroda (Mir Module, the Russian Federation)	57x1.40; 0.52x0.52; 0.52x0.64	195 200 192	4 bands 13 bands 1 band	NA	March 1996 April 1996
OCTS (NASDA, Japan), POLDER (CNES, France)	ADEOS	0.70	1 400	8 bands	2	Aug. 1996 – June 1997 (some ocean colour products)
SeaWIFS (OSC/Orbimage, United States)	OrbView-2	From. 1.1 to 4.5	From 2800 to 1500	8 bands	2	Aug. 1997 – present
OCI (NSPO, Chinese Taipei)	ROCSAT-1	0.80	691	6 bands	NA	Jan. 1999 – present
OCM (ISRO, India)	IRS-P4 (OceanSat1)	0.36	1 420	8 bands	2	May 1999 – present
MODIS (NASA, United States)	Terra	1	2 330	9 bands	2	Dec. 1999 – present
OSMI (KARI, Korea)	KOMPSAT-1	1	800	8 bands	NA	Dec. 1999 –present
MERIS (ESA, Europe)	Envisat	0.3 and 1.2	1 150	15 bands	3	2001 – present
MODIS (NASA, United States)	Aqua					2001 – present
OCS (SITP, China)	HY-1 (Haiyang-1)					2002 – present
GLI (NASDA, Japan), Polder-2 (CNES, France), SeaWinds	ADEOS-2	1 to 0.25	1 600	36 bands	2	2002 – 2003
COIS (NRL, United States)	NEMO (Navy Earthmap Observer)	0.03 to 0.06	30	210	7 (2.5 in some cases)	2003 – present

Source: Updapted from Kramer, 2002.

As mentioned by Roquet (2006), many efforts are under way at the international and European levels to validate and make available in near-real-time high-quality satellite water temperature products. Much scientific work, including impact studies, remains to be performed to define the best way of assimilating high resolution SST products into different global, regional or coastal ocean models.

Box 4.4. **Coupling essential *in situ* systems and satellites for monitoring sea level rise and ocean temperature**

- *ARGO floats* – In November 2007, the international Argo system reached a significant milestone with the launch of its 3 000th float operating in the ocean. The first Argo float was launched in 2000 to improve estimates and forecasts of sea level rise, climate and hurricanes (UNESCO, 2008). The most obvious benefit from Argo has been a marked reduction in the uncertainty of ocean heat storage calculations (a key factor in determining the rate of global climate warming and sea level rise). The steady stream of Argo data, together with global-scale satellite measurements from radar altimeters, has also made possible advances in coupled ocean atmosphere models. These have led to seasonal climate forecasts and routine analysis and forecasting of the state of the subsurface ocean. Argo data are also being used in an ever-widening range of research applications that have provided new insights into how the ocean and atmosphere interact in extreme as well as normal conditions. Maintaining the array's size and global coverage in the coming decades is Argo's next challenge. The Argo implementation programme was designed assuming for a lifetime of four years with an anticipated failure rate of 10% over that period. A constant 3 000-float array, therefore, requires 825 floats to be deployed annually.
- *Expendable bathythermographs (XBT)* – Expendable bathythermographs are devices sent from vessels to obtain information on the temperature structure of the ocean to depths of up to 2 000 metres. A small probe dropped from the ship measures the temperature as it falls through the water. By plotting temperature as a function of depth, scientists can put together a temperature profile of the water. Many different types of vessels of opportunity can be employed (*i.e.* ferries, cargo ships). For example, the NOAA has a dedicated XBT programme (SEAS) with about 80 voluntary ships. Observations from these vessels are collected and coded using the World Meteorological Organisation's bathy report format, and transmitted via the GOES and INMARSAT C satellites. Those 80 SEAS vessels produce more than 14 000 XBT observations each year.

Source: GODAE, 2007; NOAA, 2008; UNESCO, 2008.

Altimetry, geopotential height and topography

A number of satellite instruments are unique and comprehensive sources of altimetry, geopotential height and topographic data.

Altimetry from space – Altimetry is a technique used to measure height or elevation. For more than 17 years, satellite altimetry has been used to measure sea surface heights. The Franco-American mission Topex/Poseidon and ERS-1 not only demonstrated that space altimetry could work with high precision

(3 centimetres at basin level), but also provided unexpected information for monitoring oceanic phenomena (*e.g.* variations in ocean circulations such as the El Niño 1997-98 event, seasonal changes in oceans, tide mechanisms).[4] There are as of June 2008 five satellites available with altimetry instruments (Jason-1, Jason-2, Envisat, ERS-2, and the Ice, Cloud, and Land Elevation Satellite or ICESat). Continuing operational observations, via follow-up systems, should allow observation of decennial oscillations of the Atlantic and Pacific Oceans and the ongoing global rise of oceans. Those satellites are complemented by observations made using instruments placed on different multipurpose space-based systems (*e.g.* ERS, Radarsat). Initial work over a handful of large water targets has expanded to the current capability to monitor, if sometimes imperfectly, thousands of river and lake heights worldwide. As an example, ICESat, launched in 2003, carries the Geoscience Laser Altimeter System (GLAS). Its purpose is to measure the earth's polar ice sheet mass balance, cloud and aerosol heights, as well as land topography and vegetation characteristics, in some cases with sub-metre height resolution. Continuation of precision altimetry data recording is a prime concern expressed by scientists, mentioned during the 2007 International Ocean Surface Topography Science Team Meeting (Fu, 2007). That recording is key to monitoring and understanding global ocean circulation and sea level variability in relation to global climate variability. The NOAA-EUMETSAT Jason-3 satellite, NASA's Surface Water and Ocean Topography (SWOT) satellite, the AltiKa satellite, and ESA's Sentinel 3 are the next major missions planned for extending the climate data record.

Geopotential height – Aside from knowing the geometric height of a body (the elevation above mean sea level) – via altimetry, for example – another height measure used in meteorology and climate studies is geopotential height. This is the height of a pressure surface above mean sea level.[5] Since the 1940s, radiosondes have been used to measure pressure, temperature and humidity profiles. A geopotential height is then calculated by combining those data into hydrostatic equations (Haimberger, 2007). As mentioned by Jeannet, Bower and Calpini (2008), there have been tremendous advances in geopotential height measurement over the two last decades. This is partially due to newer radiosondes that use GPS signals to measure geometric height directly and convert it with high precision to geopotential height. This relatively recent use of GPS represents a real technology leap, it brings greatly improved accuracy and standardisation of measures, even if adjustments are often necessary. For example, at Mauritius, all GPS height measurements agreed on average to within ±20 metres from the surface to a 34-kilometre altitude, whereas mid-80s technology provided height measurement differences in the order of 500 metres to a 30-kilometre altitude (Jeannet, Bower and Calpini, 2008).

Topography and geomorphology (shape of the earth) – Satellite sensors can provide effective topographic and geomorphologic data. This is particularly

Box 4.5. **Tracking the world's water supplies**

Launched in March 2002, the Gravity Recovery and Climate Experiment (GRACE) is a five-year mission, still ongoing as of June 2008, to better understand the earth's gravity field. Using a pair of roving satellites 220 kilometres apart – GRACE-1 and –2 – water supply changes are measured around the world. Even if the water is captured in snow, rivers or underground aquifers, the satellites can detect the mass and trace its progress. GRACE has only been tracking world water supplies for three years, so the data cannot yet be used to determine where a water problem may emerge next, however much has been learned.

Evidence indicates that ground water is being depleted in the central valley of California, parts of India and in the Nubian Valley in Africa. The annual 21.6 millimetre water shrinkage deep in the Congo translates to 260 cubic kilometres of water lost between 2003 and 2006. Meanwhile, GRACE data show that the Nile has been receding an average of 9.3 millimetres a year while the Zambezi has receded 16.3 millimetres (the measurements take into account water flowing in the river, that in the soil and ground water). Africans consume about 136 cubic kilometres of drinking water a year, so the losses in the Congo over a three-year period are, very roughly, equivalent to two years' worth of drinking water. Natural climate variation, however, can raise or lower water in a given period. During the same period, the Colorado River in the United States rose by an average of 37.5 millimetres a year.

Source: Kanellos, 2006.

useful for detecting water movements (surface and ground water) and where water is stored (aquifers, surface waters). One of the methods most widely used to create three-dimensional digital elevation models (DEMs) is radar measurement (*e.g.* Radarsat). At present, most of the information is obtained primarily from multi-band optical imagers and synthetic aperture radar (SAR) instruments with stereo image capabilities (*e.g.* Radarsat, Envisat). The pointing capability of some optical instruments allows the production of stereo images from data gathered on a single orbit (*e.g.* by ASTER) or multiple orbits (*e.g.* by SPOT series); these are then used to create digital elevation maps that render a more accurate description of terrain. The ability of SAR systems to penetrate through the cloud cover and the dense plant canopies makes the technique particularly valuable in rainforest and high-latitude boreal forest studies. Instruments such as Advanced SAR (ASAR) and Phased Array type L-band Synthetic Aperture Radar (PALSAR) will provide data for applications in agriculture, forestry, land cover classification, hydrology, and cartography.

This brief overview of satellite requirements and capabilities for climate monitoring has shown that space technologies – whether earth observation or navigation systems – are means to obtain unique types of data. Still, there are some clear technical and governance-related limitations (*e.g.* obtaining real-time data, the length of R&D missions and their transformation into long-term operational missions) that will be explored later in this report.

Controlling maritime and marine areas

As discussed in the previous chapters, a number of countries are increasingly controlling their "seas", whether for fish stock assessment and protection, offshore development, pollution management or immigration control. One constant is the growing requirement to monitor and control large maritime and marine areas. A wide variety of tools are already available to countries for doing so, often using space-based signals or data. There are two types: co-operative surveillance tools (reporting on voice via VHF radio, Automatic Identification Systems, Long-Range Identification and Tracking, fisheries vessel monitoring systems) and non-cooperative surveillance tools (coastal radar, radar satellites).

Co-operative surveillance tools

"Co-operative" systems imply the setting up of electronic devices (transceivers) on board vessels, often at the shipmaster's own cost. Ships of certain sizes or following certain sea routes are already obliged under international law to carry special communications equipment.

Automatic identification system (AIS)

The automatic identification system was developed primarily to improve maritime safety by assisting the navigation of ships.[6] AIS is a ship-borne transponder broadcasting ship, voyage, and safety-related reports via VHF; the only satellite contribution is GPS positioning (Cauzac *et al.*, 2008).

A coastal country can use information from passing vessels to obtain an almost real-time maritime picture of its home waters. It needs to establish a VHF receiving chain along the coast for AIS signals, the range of which can typically be 40–50 kilometres out from the coast. AIS serves in a vessel-to-vessel mode for collision avoidance. It is both a means for coastal states to obtain information about a ship and its cargo, and a ship-to-shore method for vessel traffic management. The advantage of AIS is that ships can be alerted to the presence of other ships – and coastal authorities can pinpoint the position of ships – that may be undetectable by traditional radar (*e.g.* because of the harsh topography of certain shorelines).

AIS has been mandatory on all new ships in international traffic since 1 July 2002. It has covered all passenger ships, tankers and other ships of 300 tons engaged in international voyages since the end of 2004. It should be fully implemented in late 2008 and include all ships of 500 tons or more in national voyages. But national and regional sharing of AIS data is already developing fast: for example, Europe-wide sharing of vessel traffic data is progressing under SafeSeaNet, based on a 2002 European Community directive (European Commission/Joint Research Centre, 2008).

Long-Range Identification and Tracking (LRIT)

In addition to AIS, all passenger ships and all cargo ships over 300 gross tons need also to carry on board by the end of 2008 (for the most recent ships) a Long-Range Identification and Tracking device, using satellite signals to carry back information to ground receivers (IMO, 2006b). This LRIT system allows coastal countries to receive information about ships navigating within 1 000 nautical miles off their coast (their identity, location and the date and time of the position). According to international law, LRIT data will be available only to authorities entitled to receive such information, since confidentiality issues are included in the regulatory provisions. Each state or regional authority will be able to access an international LRIT database, but no global interface is planned with the LRIT and AIS broadcast identification. This is partially to protect commercial confidentiality but also because the technical challenges are huge, as will be shown in the next section.

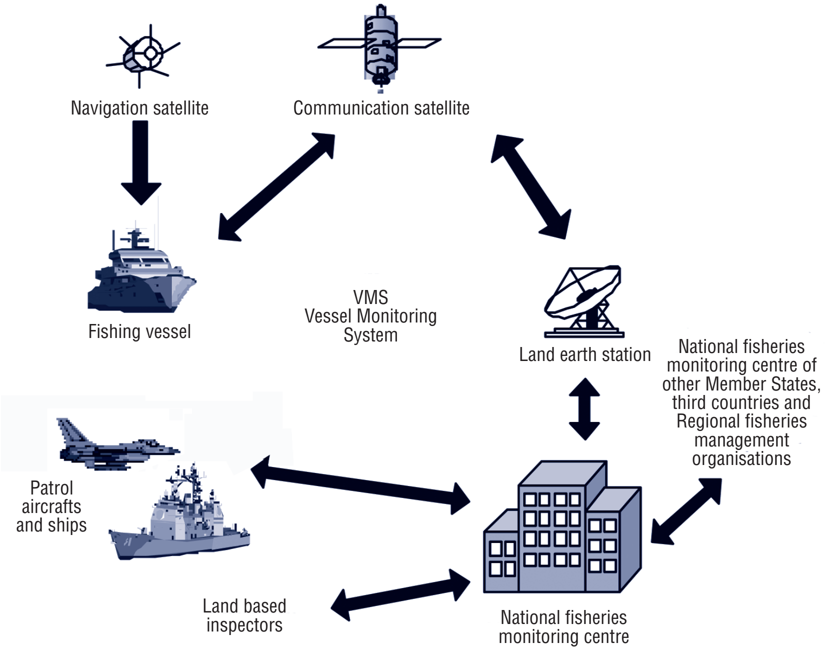
One of the more important distinctions between LRIT and AIS, apart from the obvious one of range, is that AIS is a broadcast system that sends information easily intercepted by anyone, not only coastal authorities. Data derived through LRIT will, as stated above, be available only to proper recipients. SOLAS contracting governments will be entitled to receive information about ships navigating within a distance not exceeding 1 000 nautical miles off their coast (IMO, 2006a).

Vessel monitoring system (VMS)

Fishing is by its very nature an activity that relies on spatial information inputs. The introduction of GPS devices in commercial fishing and earth observation imagery, coupled with plotters, was a major advance in fishing management. But the development of dedicated fishing vessel monitoring systems (VMS) was a real step forward in improving the monitoring and control of fisheries' activities (Figure 4.3).

Fishing vessel monitoring systems are relatively complex; they rely on equipment installed on fishing boats to provide information about the vessels' position and activity, often using satellite communications and navigation (FAO, 1999). These devices automatically send data to a satellite system that transmits them to a land base station; the station in turn sends them to the appropriate Fisheries Monitoring Centre (FMC), where the information is cross-checked with other data. The effectiveness of the system depends on the

Figure 4.3. **Vessel monitoring system (VMS) for EU's Common Fisheries Policy**



Source: EC, 2007.

reactivity of the different controlling components, which include in particular land-based inspectors and patrol vessels and aircrafts. Monitoring systems have been already in use for more than twenty years in some countries (Cauzac *et al.*, 2008) and are developing around the world. In Europe for example, national and European Community funding was made available in the early 1990s for pilot-projects, which demonstrated the reliability of satellite position monitoring and its potential for promoting the effectiveness of existing surveillance resources (European Commission / Joint Research Centre, 2008).

Non-cooperative surveillance tools

Non-cooperative surveillance systems have been increasingly used, with some success, by national authorities to check activity in their maritime and marine zones. Many countries have installed coastal ocean radars, particularly in connection with developing their Vessel Traffic Services (Box 4.6). The range available for ship detection varies greatly depending on the radar systems, from a few kilometres to more than 300 kilometres depending on weather conditions.

Box 4.6. **Description of Vessel Traffic Services (VTS)**

The purpose of a Vessel Traffic Service is to provide active monitoring and navigational advice for vessels in particularly confined and busy waterways. There are two main types of VTS: surveilled and non-surveilled. Surveilled systems consist of one or more land-based sensors (*i.e.* radar, AIS and closed circuit television sites), which output their signals to a central location where operators monitor and manage vessel traffic movement. Non-surveilled systems consist of one or more reporting points at which ships are required to report their identity, course, speed and other data to the monitoring authority. They both encompass a wide range of techniques and capabilities aimed at preventing vessel collisions, rammings, and groundings in the harbour, and assisting harbour approach and the inland waterway phase of navigation. They are also designed to expedite ship movements, increase transportation system efficiency, and improve all-weather operating capability.

The VHF-FM communications network forms the basis of most major services. Transiting vessels make position reports to a vessel traffic centre by radiotelephone and are in turn provided with accurate, complete and timely navigational safety information. The addition of a network of radars and closed circuit television cameras for surveillance and computer-assisted tracking, similar to that used in air traffic control, allows the VTS to play a more significant role in marine traffic management. This decreases vessel congestion, the number of critical encounter situations, and the probability of a marine casualty resulting in environmental damage.

Source: Adapted from US Coast Guards, 2008 and IMO, 2006a.

A relatively new tool for surveillance consists of complementary optical and radar satellite data; it is used in particular to identify ships and oil spills (Greidanus, 2008). Carried onboard the Radarsat and Envisat satellites for example, radar sensors allow day and night identification. Small vessels down to 15-30 metres can be detected in the images; this however depends on weather conditions, since the detection capabilities of ship targets are greatly influenced by the wind speed and wind direction in relation to the track of the satellite (Konsberg Satellite Services, 2008). Furthermore, although radar satellite surveillance provides wide area coverage, it is often limited by revisit times and by the time necessary to process the imagery, analyse it and exploit it (Tunaley, 2004). Therefore, it is a combination of both optical and radar imagery that allows better detection and ship recognition (Table 4.8).

Radar satellite data are also used for oil spill detection, especially because of their extensive coverage and all-weather/all-day capabilities (Wahl T., 1996; Serra-Sogas *et al.*, 2008). Distinguishing real oil spills from lookalike features (known as "false positives") is the biggest challenge of this technique (Brekke

Table 4.8. **Radar and optical satellite images for ship detection**

	Radar satellite images	Optical satellite images
Level of detail	Generally low resolution (8 to 50 metres)[1]	High resolution (< 1-10 metres)
Geographic coverage	Wide area (up to 400 kilometres areas)	Small area (10-60 kilometres)
Particular conditions	Independent of clouds, night (24h vision)	Daytime, clear skies
Main use	Use for detection	Use for recognition

1. Although new radar satellites are progressively becoming fully operational and can provide more detailed resolution (*e.g.* CosmoSkymed, TerraSARX).

and Solberg, 2005). According to a number of validation experiments using onsite airborne observations, the overall probability of successful oil detection by satellite varies from 40% to 60% (MarCoast, 2006). Different detection methods are constantly being refined, improved and benchmarked by the scientific community. But this is still very much work in progress. One lesson learned from the many demonstration projects under way around the world is that acquiring oil slick data can take a long time. A good illustration is Synthetic Aperture Radar (SAR) data from the European satellite ENVISAT. The MarCoast service guarantees a delivery time of 30 minutes after the satellite overflight, and while the SAR-IM instrument allows SAR image resolution of 30 metres in all weather and day/night detection capabilities, the frequency of passage over Mediterranean waters ranges from two to three days (Ferraro *et al.,* 2006). Another aspect is that delays may be exacerbated by conflicts between the needs of different user communities. For instance, the wide swath modes that are optimal for oil slick detection work may not offer a resolution high enough to detect small vessels. The benefits of such monitoring systems may be increased by the use of new SAR systems (*e.g.* Cosmo-Skymed, SAR-Lupe, Radarsat-2) and by possible future deployment of constellations of smaller, single-purpose satellites alongside the existing large multipurpose ones. Finally, more work is needed to calibrate the different sources of data useful to users, since there can be discrepancies between satellite ship detection reports via imagery and the AIS records in the order of several hundreds of metres (Cauzac *et al.,* 2008).

To improve the overall detection system, there is the need for co-ordination between satellite overpasses and aerial surveillance flights (Brekke and Solberg, 2005). In addition, from the users' point of view, one of the most useful elements for future systems is the integration of AIS vessel information and oil slick drift forecasting data, so as to identify vessels located in the polluted area and trace back the polluter (Figueroa *et al.*, 2008). More information on the detection of man-made pollution from space and the derived benefits is presented in Chapter 6.

Table 4.9. **Requirements *vs.* capabilities for monitoring oil pollutions**

Requirements	Capabilities of satellites
Geographic: A rapid survey of pollutants over large or remote areas which could not feasibly be surveyed from the surface	Only satellites can provide global coverage. A few radar satellites currently provide data useful for detecting large oil spills.
Timescale: Ideally daily surveillance for a strong deterrence + rapid data availability (in less than 1 hour)	As an example, the frequency of data acquisition on average (taking into account all available satellites) can be assumed to be about 2-3 days over the Mediterranean. Relative to equatorial waters, SAR coverage is 1.2 times as frequent for the Mediterranean Sea, 2.0 times more likely for the North Sea, 3 times for the Norwegian Sea and 4 times for the Barents Sea (MarCoast, 2006). Increased coverage will necessitate more satellite SAR sensors.
Oil spill scope: A synoptic overview of the pollution and clear demarcation of its boundaries	Since the pollutants can only be detected and measured if they can be differentiated from other substances in the water, sensors of high spectral resolution can provide information.
Monitoring: Once reliable calibration has been achieved, the potential for measurement of the pollutant without the need for more field survey	Again, the revisit times are currently too long to allow real-time monitoring.
Access to data: Results available through web systems operated at regional or at country level	Ongoing efforts in a number of countries to provide operational data (*e.g.* Canada, United States, France, Italy, Norway).

Table 4.10. **Civilian/dual-use radar satellites in operation**
(June 2008)

	Planned design life	Radar imaging frequency	Spatial resolution	Status
Radarsat-2	7 years	C-Band	3 to 100 metres	In operation since Dec. 2007
Radarsat-1	5 years	C-Band	10 to 100 metres	In operation since 1995
Envisat ASAR	5 years	C-Band	30 to 1 000 metres	In operation since 2002
ALOS PALSAR	5 years	L-Band	10 to 100 metres	In operation since 2006
Cosmos Skymed (4 satellites)	5 years / satellite	X-Band	1 to 100 metres	3 satellites launched (2 in 2007, 1 in 2008), next in 2009
TerraSAR-X	5 years	X-Band	1 to 15 metres	In operation since June 2007

Source: Adapted from Serra-Sogas *et al.*, 2008.

Safety at sea

The ability to communicate instantaneously from anywhere in the world and navigate with increased precision has revolutionised maritime transport activities. The use of satellites and the maturing of information technology equipment have allowed a number of relatively new commercial systems to be established in recent years, increasing safety at sea but also the requirements for ship owners and operators.

International requirements to increase sea safety

With the growth in global sea trade, governments have increasingly co-operated via the International Maritime Organisation (IMO) to improve safety at sea, developing in particular regulations pertaining to the use of new technological capabilities. The International Convention for the Safety of Life at Sea (SOLAS) Convention is today regarded as one of the most important international treaties dealing with the safety of ships, particularly merchant ships (IMO, 2006a). The first version was adopted in 1914 in response to the Titanic disaster; the latest Convention dates back to 1974 and is amended regularly, particularly in relation to new technological capabilities (IOC/UNESCO, 2005).[7] Since the late 1990s, diverse equipment – most of it using satellite telecommunications and navigation – is required on board ships.

Global Maritime Distress Safety System (GMDSS)

A hundred years after the first use of wireless technology to aid a ship in distress using the Morse code, the Global Maritime Distress Safety System became operational in 1999. It is an international integrated communications system using satellite and terrestrial radio communication to ensure that no matter where a ship is in distress, aid can be dispatched.[8] Under the SOLAS Convention, all passenger ships and all cargo ships over 300 gross tons on international voyages, including commercial fishing vessels, have to carry GMDSS-approved equipment for sending and receiving distress alerts and maritime safety information, and for general communications. Among these devices are satellite emergency positioning indicating radio beacons (EPIRB), designed to operate with the international satellite-based search and rescue system Cospas-Sarsat (Box 4.7).

This GMDSS adoption has spurred the development of maritime markets for space applications, as Chapter 5 will demonstrate. However, because of the many vessels around the world that are not subject to the Convention, in particular small commercial and leisure crafts, there is an important international requirement to maintain some of the radio procedures used prior to the introduction of the GMDSS. That way a common means of communication is available between all classes of vessels for distress and safety purposes. Building on the Global Maritime Distress Safety System, new international norms have been recently adopted, spurring again the development of a new generation of commercial communications and navigation equipment.

Ship Security Alert System (SSAS)

As piracy and terrorist attacks have increased over the past decade, the International Maritime Organization (IMO) has defined a set of mandatory requirements to improve security for ships: the International Ship and Port

Box 4.7. **The Cospas-Sarsat system**

The Cospas-Sarsat system was set up in 1982. The acronyms stand for "Space system for the search of vessels in distress" (Cospas in Russian) and "Search and rescue satellite-aided satellite tracking system" (Sarsat). The programme is the result of international collaboration by the United States, France, the Russian Federation and Canada. It provides an alert and satellite positioning aid function for the search and rescue of persons in physical distress, on land or at sea anywhere in the world. The system uses instruments onboard satellites in geostationary and low-altitude earth orbits that detect the signals transmitted by distress radio beacons and ground receiving stations that receive and process the satellite downlink signal to generate distress alerts to rescue centres throughout the world. More than 900 000 maritime, aviation, and land-based distress beacons use the system worldwide. Cospas-Sarsat is credited with assisting search and rescue forces in the saving of more than 18 500 lives since the first satellite launch in 1982.

Source: Cospar Sarsat, 2007.

Facility Security Code (ISPS). This code, which was signed in 2002 and came into force in late 2004, aims to establish an international framework for detecting and assessing security threats and taking preventive measures against security incidents affecting ships or port facilities used in international trade.[9] It has already contributed to enhancing international maritime security (OECD, 2006). The regulation stipulates that a large range of ships have to be equipped with Ship Security Alert System (SSAS). The system consists of two alarm buttons that can be activated in case of piracy or a terrorist attack, and send an alert via telecommunications satellites (usually the Inmarsat, Argos or Iridium systems). The ships that need SSAS on board include all passenger ships and all cargo vessels of 500 gross tons and upwards, particularly oil and chemical tankers, gas carriers, bulk carriers, and high-speed cargo.

Technologies and equipment

As seen in the previous section, today certain communications and navigation equipment are mandatory onboard ships. Often these devices use satellites as the backbone infrastructure for navigation signals and data communications. In parallel with mandatory apparatus, other equipment has been developed for more cost-efficient sea navigation and has more generally facilitated life onboard (*e.g.* satellite phone, Internet).

Communications services at sea and in remote areas depend mainly on commercial satellites that are in geostationary orbits (Inmarsat systems) and/or constellations in low earth orbits (Iridium, GlobalStar, OrbComm).[10]

Box 4.8. **Improving alerts in case of tsunamis via satellite communications links**

In December 2007, the Intergovernmental Oceanographic Commission of UNESCO (IOC) signed an agreement with Inmarsat, provider of global mobile satellite communications, to further upgrade and enhance the Indian Ocean Tsunami Warning System. Under the agreement, Inmarsat will provide Broadband Global Area Network (BGAN) transmission service to 50 sea level stations in the Indian Ocean. BGAN will enable transmission of sea level observation every minute, *versus* the current system that uses meteorological satellites to transmit data every 15 minutes. Time saved by faster transmission represents significant progress; in the eastern and northeastern Indian Ocean, a tsunami wave can hit the shore in about 30 minutes. Increasing the transmission frequency will provide more time and information for national warning authorities to alert coastal populations at risk.

Source: IOC/UNESCO, 2007b.

For navigation and localisation applications, signals from the GPS satellites' constellation are used the most, although other navigation systems (Glonass and Egnos, precursor to the European Galileo) and local and regional GPS augmentation systems (AWAAS) exist. The Argos satellite-based location and data collection system, using signals sent from dedicated instruments carried onboard a number of meteorological satellites, is also particularly relevant for a large number of applications and scientific research.[11]

Most commercial equipment that has been licensed for GMDSS, SSAS or AIS includes additional fleet tracking software, to enhance Vessel Monitoring Systems (VMS) and provide fleet tracking possibilities. As the equipment market has rapidly developed, companies tend to provide to the extent possible competitive integrated solutions, not only with the basic on board mandatory communications equipment, but also with extra data sensors to send back to a fleet's owner (ship speed, its heading, but also meteorological indicators at its location: air pressure, waves, wind). For example, the ShipLoc company provides a product that includes a GPS receiver (to calculate the position, heading and speed of the ship) and an Argos transmitter (to relay intermittently the information via satellite), but also the Argos satellite airtime for transmission and SSAS alert service, with continuous monitoring by operators (ShipLoc, 2008).

The standard suite of equipment that ships are required to carry (Table 4.11) depends mainly on the size of the ship and the routes taken. As the requirements for communications and navigation capabilities have grown rapidly in one decade (GMDSS, SSAS, AIS, LRIT), more equipment is coming onto the market.

Table 4.11. **Communications and navigation equipment carried onboard ships**

Equipment	Description
HF, MF and VHF radio installations	Terrestrial (non-satellite) VHF, MF and HF marine radio systems. IMO and ITU now both require that the Digital Selective Calling (DSC)-equipped VHF, MF and HF radios be externally connected to a satellite navigation receiver. That connection will ensure that accurate location information is sent to a rescue co-ordination centre if a distress alert is ever transmitted.
SART (Search and rescue transponder)	Self contained, portable and buoyant radar transponder (receiver and transmitter). SARTs operate in the 9 GHz marine radar band, and when interrogated by a searching ship or aircraft's radar, respond with a signal which is displayed as a series of dots on a radar screen. Although SARTs are generally designed to be used in lifeboats, they are often deployed on ships (two required for ships 500 gross tons or more; one required for ships of between 300 and 500 gross tons).
NAVTEX	Narrow band direct printing telegraphy (fax-like). It is an international, automated system for instantly distributing maritime navigational warnings, weather forecasts and warnings, search and rescue notices and other urgent information to ships.
Satellite emergency positioning indicating radio beacon (EPIRB)	International automatically activated radio emitter, designed to operate with the international satellite-based search and rescue system Cospas-Sarsat. It transmits to a rescue co-ordination centre identification and accurate location of the vessel in distress (increasingly using GPS receivers) from anywhere in the world.[1]
Global positioning system (GPS) device	Satellite-aided measurement system that enables a ship to locate its position anytime, anywhere, expressed in degrees and minutes of latitude and longitude.

1. System developed by Canada, France, the Russian Federation and the United States.
Source: Adapted from US Coast Guards, 2008.

Generally, the closer one navigates to the shore – and is in contact with shore-based very high frequency (VHF) and medium-frequency (MF) radio stations (often absent on the coasts of developing countries) – the less equipment is required. Since most commercial ships tend however to operate in ocean areas, within Inmarsat satellites coverage (below 70 degrees North Latitude and above 70 degrees South Latitude), they need to carry adequate satellite-based equipment. For those navigating outside Inmarsat coverage area, particularly near the poles (above 70 degrees N Latitude and below 70 degrees S Latitude), these ships must in addition be equipped with a high frequency Digital Selective Calling "HF DSC" installation. Existing communications and navigation equipment tends to be more and more integrated. For example, the International Convention for the Safety of Life at Sea now requires that Inmarsat C radio equipment have an integral satellite navigation receiver, or be externally connected to a GPS receiver for precise marine tracking purposes. In addition, the international rules for collision avoidance at sea (COLREGs) are being reviewed regularly to minimise human error, and recent maritime equipment includes GPS receivers to support piloting crews in minimising navigational errors (Statheros, Howells and McDonald-Maier, 2008).

For the sailors, satellite navigation applications offer a number of advantages, in particular with regard to voyage planning facilities, with indications such as range and bearing, estimated time of arrival (ETA) or heading to steer. Current systems can interface with a variety of equipment including printer, plotter, ground-based Loran-C navigation systems, autopilot, satellite communications and navigation computer.[12] The "autolocate" functions usually allow the pilot to compute a satellite fix anywhere in the world when the approximate position is not known within 60 nautical miles.

The backbone for communications at sea, telecommunications satellites are very effective for broadcasting over large areas – as demonstrated by the commercial success of television programming via satellite – but until recently they were not as efficient for two-way communications. While satellites are able to compete very effectively with terrestrial broadcasting services, they tend to be more costly to use for two-way communications over land areas. Moreover, latency has often reduced their ability to be used for services requiring instant interactivity.

A number of commercial satellite communications constellation companies are operational today (Table 4.12). Inmarsat was for decades the main provider of communications at sea, first as an international organisation and then

Table 4.12. **Commercial satellite communications constellations**

Company	Description and Status (May 2008)
Iridium	Iridium is a mobile satellite services provider, which operates a constellation of 66 satellites in low earth orbit. These satellites are expected to continue providing full voice and data services until 2013, by which time a second generation constellation should be in place (signature of a development contract to renew the fleet expected in mid-2009).
GlobalStar	Globalstar operates a constellation of 40 satellites in low earth orbit, offering voice and data services to users in more than 120 countries. Globalstar's products include mobile and fixed satellite telephones, simplex and duplex satellite data modems and service packages, although many Globalstar satellites are experiencing an anomaly resulting in degraded performance for two-way voice and data services at certain times. Globalstar's second-generation satellite constellation, scheduled to be launched beginning in the second half of 2009, should offer advanced wireless voice and high-speed IP Multimedia Subsystem (IMS) services.
OrbComm	ORBCOMM is a satellite data communications company focused exclusively on machine-to-machine (M2M) communications. ORBCOMM provides two-way data communications services around the world through a global network of 29 satellites in low earth orbit and accompanying ground infrastructure. ORBCOMM's transmitters are installed on trucks, trailers, railcars, containers, heavy equipment, fluid tanks, utility meters, pipelines, marine vessels, oil wells and other assets. The system can send and receive short messages, between six bytes and several kilobytes, in near-real-time, allowing users to access critical information readily, often from areas beyond the geographic reach of terrestrial systems.

Source: Iridium, OrbComm and GlobalStar corporate websites, 2008.

as commercial provider. Since its days as a specialised intergovernmental organisation, Inmarsat has provided universal services under an agreement with the IMO. The main technical challenge for the future is the development of new generations of communications satellite offering onboard processing and spot beams, as well as technical standards that will facilitate scalability and bring down costs, notably those of terminals.

Notes

1. The 2007 report from the GCOS *Systematic Observation Requirements for Satellite-based Products for Climate* summarises the main inputs of space instruments and contributes to ongoing work conducted at the UNFCCC and the Intergovernmental Panel on Climate Change.
2. CRYOSAT was ESA's first Earth Explorer Opportunity satellite. The 2004 mission was to determine variations in the thickness of the earth's continental ice sheets and marine ice cover. Its primary objective was to test and quantify the prediction of thinning polar ice due to global warming. After a launch failure in 2004, it was decided to re-launch a similar mission.
3. Data digitalisation has had far-reaching effects on the way satellite data can be used. As an example, NOAA developed in the mid-1990s an Interactive Multisensor Snow and Ice Mapping System to provide snow and ice charts, using geographic information systems (GIS) technology. Before the system was put into operation in 1997, snow and ice charts were constructed manually once a week. Today charts are produced daily, integrating near-real time data when available (Helfrich *et al*., 2007).
4. In March 2006, an international symposium was organised to take stock of "Fifteen Years of Progress in Radar Altimetry".
5. Geopotential height data are often represented on weather maps by isobar lines connecting points of equal or constant pressure height.
6. Automatic identification systems became mandatory on ships via Resolution 6 in the International Convention for the Safety of Life at Sea (SOLAS).
7. The world's oceans have been divided into thirteen search and rescue areas by the IMO, and in each area the countries concerned have delimited search and rescue regions for which they are responsible.
8. The GMDSS was developed by the International Maritime Organization (IMO) – the specialised agency of the United Nations with responsibility for ship safety and the prevention of marine pollution – in close co-operation with the International Telecommunication Union (ITU) and other international organisations. The latter include notably the World Meteorological Organization (WMO), the International Hydrographic Organization (IHO) and the Cospas-Sarsat partners.
9. Common crimes at sea may include: illegal fishing and reloading, illegal transport of goods, illegal immigration, and illegal dumping.
10. The availability of commercial satellite communications services in any particular country may be subject to government approval.
11. The Argos system enables scientists to gather information on any "object" equipped with a certified transmitter, anywhere in the world – in the oceans, deserts or polar

regions. Argos transmitters come in a variety of shapes and sizes, depending on their purpose. Their messages are recorded by a constellation of satellites carrying Argos instruments, and then relayed to dedicated processing centres. This system has been operational since 1978, and was initiated jointly by France and the United States. Its participants include those countries, India and Europe via Eumetsat.

12. The LORAN (LOng RAnge Navigation) system is a terrestrial radio navigation system involving low frequency radio transmitters that use multiple ground stations to determine the location and/or speed of the receiver. First available during the Second World War and upgraded several times since then, Loran is still used in many countries, as a complementary system to other forms of electronic navigation, including satellites.

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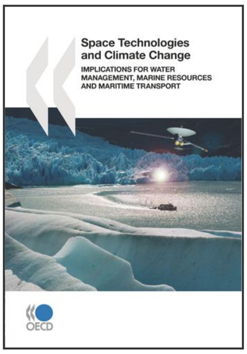
List of Acronyms

AATSR	Advanced Along Track Scanning Radiometer (instrument on board ENVISAT)
AIS	Automatic Identification System
ASAR	Advanced Synthetic Aperture Radar
ATSR-1 and 2	Along Track Scanning Radiometer (instruments respectively on board ERS-1 and ERS-2)
BRIC	Brazil, the Russian Federation, India and China
BRIICS	Brazil, the Russian Federation, India, Indonesia, China and South Africa
CNES	Centre National d'Etudes Spatiales
CZCS	Coastal Zone Colour Scanner (instrument on Nimbus-7)
DMSP	US Defense Meteorological Satellites Programme
DORIS	Doppler Orbitography by Radiopositioning Integrated on Satellite (instrument on board TOPEX/Poseidon, Jason-1, ENVISAT and the Spot satellites)
DSC	Digital Selective Calling
EEZ	Exclusive Economic Zone
ENVISAT	ENVIronment SATellite
EPIRB	Emergency Position Indicating Radio Beacon
ERS-1 and 2	European Remote Sensing Satellites
ESA	European Space Agency
EUR	Euro (currency of European Union)
FAO	Food and Agriculture Organization
GDP	Gross domestic product
GEOSS	Global Earth Observation System of Systems
GHG	Greenhouse gases
GMDSS	Global Maritime Distress and Safety System
GMES	Global Monitoring for Environment and Security
GOES	Geostationary operational environmental satellites
GOME	Global Ozone Monitoring Experiment (instrument on board ERS-2)
GOMOS	Global ozone measurement by the occultation of stars (instrument on board ESA's ENVISAT satellite)
GOOS	Global ocean observing system
GSE	GMES Services Element

IFREMER	Institut français de recherche pour l'exploitation de la mer
IMAGE	Integrated Model to Assess the Global Environment
IMO	International Maritime Organization
IMSO	International Mobile Satellite Organization
IOC	Intergovernmental Oceanographic Commission of UNESCO
IOOS	Integrated Ocean Observing System
IPCC	Intergovernmental Panel on Climate Change
ISPS	International Ship and Port Facility Security Code
ISRO	Indian Space Research Organisation
ITU	International Telecommunication Union
LANDSAT	LAND observation SATellite
MARS	Monitoring agriculture by remote sensing
MERIS	Medium resolution imaging spectrometer [per MODIS]
MIPAS	Michelson Interferometer for Passive Atmospheric Sounding
MODIS	Moderate resolution imaging spectrometer (instrument on board NASA's Terra and Aqua satellites)
MSR	Maritime search and rescue
MWR	Microwave radiometer
NEXRAD	Next generation radar meteorological stations
NOAA	National Oceanic Atmospheric Administration
NOPP	National Oceanographic Partnership Program
NRT	Near-real-time
OECD	Organisation for Economic Co-operation and Development
POES	Polar operational environmental satellite
ROW	Rest of the world
SAR	Search and rescue
SAR	Synthetic aperture radar satellite
SART	Search and rescue radar transponder
SCIAMACHY	Scanning imaging absorption spectrometer for atmospheric cartography
SOLAS	International Convention on Safety of Life at Sea and its amendments
SSAS	Ship security alert system
SSH	Sea surface height
SST	Sea surface temperature
UNCTAD	United Nations Conference on Trade and Development
UNEP	United Nations Environment Programme
UNESCO	United National Educational, Scientific and Cultural Organization
UNFCCC	United Nations Framework Convention on Climate Change
USCG	US Coast Guard
USD	United States dollar

VMS	Vessel monitoring system
WHO	World Health Organization
WMO	World Meteorological Organization
WSIS	World Summit on the Information Society
WTO	World Trade Organization



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