National Maritime Foundation

Space and Maritime Security

Ajey Lele

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Preface

This monograph addresses the relevance of Space Technologies for Maritime Security. The work has four major verticals. It begins by a broad discussion of the concept of Maritime Security as a background. The second vertical puts in context the relevance of specific space technologies like remote sensing, navigation, and communication for maritime domain. The third vertical is a query about the relevance of space technologies to multiple maritime domains. The last vertical sums up the discussions.

For many centuries, oceans have been regions meant for merchant shipping, fishing, and oil exploration. Various navies across the world have dominated their own areas to ensure the safety to their state's interests. Ensuring safety and security at sea continues to remain the paramount activity for various agencies. In the recent past, there has been sharp increase in the activities conducted at high seas. The strength of the number of operational ports is increasing steadily. Moreover, an increase in maritime traffic is also taking place. At the same time, the threats in, and from, the seas are increasing. Such threats involve terrorist activity, piracy, smuggling, drug trafficking, etc. In addition, an increase in the frequency of sea-based natural disasters is also being observed. To address such challenges, states and other responsible actors are becoming increasingly dependent on technologies, both from safety and security point of view, as well as for ease of business.

In recent times, satellite technologies have fundamentally changed ideas about how to conduct various activities in the maritime domain.

For many decades now, there has been an increasing interest in using space-based assets for improvising various capabilities required for operating in the maritime domain. Innovative satellite-based technical applications are steadily becoming a part of various maritime activities.

It is important to acknowledge that satellites, the so called 'eyes in the skies', are all pervasive, and can monitor almost every activity happening in the sea and/or in a port. It is important for the various agencies involved in the maritime domain to ensure that these technologies are exploited correctly to derive maximum benefits for the ease of operations. Also, it is important to use these technologies innovatively so as to identify new fields for their adoption.

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Contents

Chapter 1

The Context

Security has been defined as being in a state of being free from danger or a threat. Threats to security are either external or internal, or both simultaneously. Such threats could also be categorised as military, societal, political, economic, or environmental. The Maritime sphere is also not free from security threats. Maritime security has been an issue of concern for many countries. The notion of Maritime Security has transformed overtime. A few centuries ago, sea-faring nations depended mainly on naval power to achieve their national military objectives. However, in the 21st century, sea power has expanded greatly. In addition to the military aspect of sea power, the non-military aspects of sea power such as trade and commerce as well as environmental issues have assumed greater importance. The probability of a war at sea amongst nation states has diminished considerably. The world appears to be moving beyond the Captain Alfred Thayer Mahan's (1840–1914) conceptualisation of sea power who believed in the importance of naval power as the most important factor for the survival of a state. Now, the expanse of sea power is not limited to military power alone, and has a larger geo-economics and geostrategic purposes.

There is a wide expanse of modern day sea power, both geographically and in terms of the actors involved. There is an increase in maritime disputes, and claims and counterclaims are often made over the ownership of some islands, rocks, and other artificially created structures in the sea. There are number of actors having high stakes in the maritime sphere. These include both state actors and private entities. State actors could be agencies of a states, like navies, the coast guards, the marine police, etc. Other actors could be people associated with trade and commerce. Also, there are various other unauthorised actors such as smugglers, terrorists, pirates, etc.

Oceans have always been the medium for carrying out international trade and commerce. The second most important thing apart from the production of oil/gas to global energy security is the accessibility of transportation routes for energy traffic. The success of this trade is subject to smooth access to operations on the high seas. There are multiple hazards (pollution, accidents/incidents, piracy, illegal fishing, terror attacks, and natural disasters) which can hinder the safe movement of traffic even during peacetime. In general, the management of present day maritime infrastructure involves multiple agencies.

Given the context described above, sea power in the 21st century can be seen as the ability of a nation to use the seas safely, securely, fully, and wisely to achieve its objectives. In this new security environment, there is a need for new thinking, new partnerships, and new concepts to ensure the safety and freedom of the seas for all users as well as for the security of all nations. Today, India needs to think about a broad range of cutting-edge ideas to complement the 20th century definition of a 'naval power' into a 21st century definition of 'maritime power'. The delineation of this power in the modern day context has been well defined by B. B. Stubbs and S. C. Truver as given below.

> Maritime 'Power is all about a nation's need beyond the pure military capabilities needed for war-fighting. It includes the use of the seas-to preserve maritime resources, to ensure safe transit and passage of cargo and people on its waters to protect its maritime borders from intrusion, to uphold its maritime sovereignty, to rescue the distressed who ply the oceans in ships, and to prevent misuse of oceans. These are timeless interests that collectively can be described as a nation's maritime and safety interests.[1]

It is important to note that the ambit of this power is not restricted to the maritime domain alone, and that 'the real point of sea power is not so much what happens at sea, but how that influences the outcome of events on land'.[2] Also, the effectiveness of sea power largely depends on the strengths and weaknesses of those against whom it is exercised.

The term 'maritime security' has two different connotations: one has a defence and security implication; the other has non-military one. From a military perspective, maritime security focuses on national security concerns in terms of guarding the territorial integrity of the state from armed attack or other uses of force, as well as projecting the state's interests elsewhere. States could have their own policies with regard to dealing with issues related to the non-military implications. These may depend on the type of challenges a particular state is required to address, and the nature of its economic and military dependence on global sea routes. For countries like the USA, defence implications of maritime security could also include ensuring the freedom of navigation, the flow of commerce, the protection of ocean resources as well as securing 'the maritime domain from nation-state threats, terrorism, drug trafficking, and other forms of transnational crime, piracy, environmental destruction, and illegal seaborne immigration'.[3] Maritime security related challenges for the shipping industry would mainly focus on the maritime transport system, and ensuring the safe arrival of cargo at its destination without interference or being subjected to criminal activity.[4]

Maritime terrorism and piracy are two very important challenges which, theoretically speaking, fall under the rubric of non-military threats. However, the involvement of the armed forces (directly or indirectly) is principally essential to address such threats. At the same time, the capability of any state to deal with such threats on the high seas and along the coast depends on its navel strength. It also depends on the cooperation from its maritime communities as well as effective coordination with other agencies which play a role in preventing maritime terrorism and neutralising acts of maritime terrorism before they cause any serious damage. This is especially so when preventive measures fail. Normally, various acts of maritime terrorism, big or small, are likely to be orchestrated from land in terms of their planning and execution.[5] Thus, any maritime security apparatus requires active participation from intelligence agencies which are equipped to gather actionable and preventive intelligence linked to maritime terrorism. Owing to the various challenges enumerated above, maritime security also gets defined as 'those measures employed by owners, operators, and administrators of vessels, port facilities, offshore installations, and other marine organizations or establishments to protect against seizure, sabotage, piracy, pilferage, annoyance, or surprise'.[6]

During 2008, the then United Nations (UN) Secretary General Ban-Ki-Moon had acknowledged that there is no agreed definition of 'maritime security'. Since then, the UN has taken another approach to understand the threats to maritime security. For this purpose, different activities have been identified which are commonly perceived as threats to maritime security[7]. In his 2008 'Report on Oceans and the Law of the Sea', the Secretary General Moon identified seven specific threats to maritime security. The first threat identified is piracy and armed robbery against ships which particularly endangers the welfare of seafarers as well as the security of navigation and commerce. Second, terrorist acts involving shipping, offshore installations and other maritime interests. And, in view of the widespread effects, this also includes any significant economic impact that may result from such an attack. The third threat identified is illicit trafficking in arms and weapons of mass destruction. The fourth is illicit trafficking in narcotic drugs and psychotropic substances. The fifth is smuggling and trafficking of persons by sea, the risks posed due to the common use of unseaworthy vessels, the inhumane conditions on board, the possibility of abandonment at sea by smugglers, and the difficulties caused to those undertaking rescues at sea. The sixth threat is illegal, unreported, and unregulated (IUU) fishing in the light of the identification of food security as a major threat to international peace and security. Finally, there is the threat of intentional and unlawful damage to the marine environment. This is seen as a particularly grave form of maritime pollution due to its potential to threaten the security of one or more states, given its impact on the social and economic interests of coastal states.

Broadly, the above list covers wide ranging apprehensions concerning maritime security. Apart from these activities, it is also important to note that agencies like the International Maritime Organizations (IMO) draw a distinction between maritime safety and maritime security: 'Maritime safety refers to preventing or minimizing the occurrence of accidents at sea that may be caused by sub-standard ships, unqualified crew or operator error, whereas maritime security is related to protection against unlawful, and deliberate, acts'.[8]

For the purpose of this work, the various dimensions of Maritime Security (also safety) are important. This work debates the significance of space technologies exclusively for the maritime domain. From a security perspective, different elements of maritime domain could have different priorities. For example, the Coast Guard conducts mainly three maritime security activities: Port Security, Vessel Security, and Facility Security. A Navy operates various platforms at sea: boats, frigates, submarines, etc. In the context of the maritime domain, since the overall infrastructure (mainly the assets available at sea and in port) is technology intensive, there is an increasing dependence particularly on Space Technologies. This is essentially because all modern maritime (and others too) state-of-art structures, platforms, and sensor systems, are dependent on space technologies.

Notes

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8. See P.K. Mukherjee and M.Q. Mejia Jr, 'The ISPS Code: Legal and Ergonomic Consideration', in M.Q. Mejia Jr (ed.), *Contemporary Issues in Maritime Security*, Malmo: World Maritime University, 2004, pp. 33, 34

Chapter 2

Comprehending from Space

It needs to be appreciated that in the increasingly polarised world, the maritime environment is also becoming increasingly complex. Space technologies have multiple utilities and capabilities to respond under a dynamic environment. The existing space based systems are launched to cater for various requirements, and the maritime requirement is only one of such requirements. There are few systems in space which have multiple utilities, and some are launched specifically to cater for maritime requirements. Also, space technologies offer specific services, and it depends mainly on the user as how best these could be utilised in a suitable manner.

Since time immemorial, inter-state trade has been happening via sea routes. The notion of security on the seas in some form or other has persisted for a long time. Major global wars have been fought in and from the seas. With evolution in warfare, the nature and methods of fighting at sea have changed. The Navy is an integral and most important part of the maritime domain, and so it would be prudent to consider it as an important element for understating the relevance of space technologies for its proper functioning.

There was a significant amount of technology domination during World War II:, radars, weapon guiding systems, long-range rockets (V-2), and nuclear weapons. It made clear that any future warfare would be governed by technological developments. Based on the experiences of World War II and the early years of the Cold War, the major powers had started investing in technologies to ensure that they would have a technological edge. In the quest for having suitable technologies in place, the US Department of Defence (DOD) in general, and the Navy in particular, were able to identify various deficiencies. No doubt such identification must have helped them to decide on their research and development.

The difficulties acknowledged were as follows.

- Long-haul wireless communications were limited to the high-frequency (HF) band, and were often not available as a result of little understood changes in the environment
- Navigation was inaccurate and uncertain—even when the Navy's Long Range Navigation (LORAN) system was available, inaccuracies were generally in the range of 1 to 2 miles
- Environmental knowledge (regarding winds, wave height, cloud cover, storms, temperature, and sea conditions) was limited to the local area of an observer, and forecasting capabilities were limited or non-existent
- Except for HF transmissions, the ability to track and identify beyond-line-of-sight (BLOS) targets or transmitters did not exist
- Weapon delivery accuracy was appallingly poor, being limited by the lack of precise knowledge of the geolocations of both the weapon release platform and the target
- Target surveillance and identification were limited to the questionable capabilities of reconnaissance aircraft whose survival over enemy terrain was tenuous
- Surface-to-surface rockets had a maximum range of about 200 miles and an apogee of about 60 miles, used single-stage non-gimbaled engines, delivered a unitary payload, and were highly unreliable in their performance;

- The ability to identify and locate the site of a clandestine detonation of a nuclear weapon was rudimentary.

Although the above mentioned difficulties were identified, yet the US Navy had no game plan for overcoming them. However, the US Navy did make systematic investments in support of basic and applied research. Eventually, all this became an important step in the development of space technologies.[1]

It is important to note that, during World War II, the advantage that naval aircraft offered as observation platforms for wide-area surveillance, reconnaissance, and targeting at sea became obvious. These operations gave the Navy experience and insight into the potential advantages of the even higher altitudes of artificial earth satellites that were to support naval and military operations in the future. Another reason why the Navy felt the need for new and improvised communication systems was their experience in the Korean conflict, post-World War II. At this time, the Navy's ship-to-shore long-haul communications relied on the medium and high frequency (MF and HF) portion of the radio frequency spectrum. Unfortunately, these signals do get hampered by meteorological conditions, solar activity, and the time of day. Also, at the end of the Korean Conflict, severe cuts in the Navy budget resulted in the closure of many overseas communication stations. But still, the Navy was required to have a reliable and wider area coverage communications network owing to Cold War responsibilities.[2] This was the context for the development of new communication systems, and space technologies provided a perfect option.

Following an open approach, this monograph discusses both specific technologies/applications for explicit maritime security activities as well as more general issues wherein the importance of assets in space are discussed with reference to the entire maritime domain.

Human beings have continued to explore the universe owing to curiosity and scientific reasons since time immemorial. It is a well-known fact that primitive tribes used the sky as a guide for path-finding. It is probable that ever since humans first noticed the regular movement of the sun and the stars, the concept of time as well as day and night began. It is believed that prehistoric humans first recorded the phases of the moon some 30,000 years ago. Medieval humans mostly used various star position based techniques for track detection and location identifications. It was Nicolaus Copernicus who, during 1543, put forward the argument that the earth was not at the centre of the universe. After him, the astronomer Galileo Galilei actually used a telescope to observe the planets and stars. Since then, various planets and stars have become the reference for various activities. In the present era, in addition to these objects in the sky, humans have put some artificial objects there to assist their survival and make life more comfortable. Such objects are called satellites, and presently humans have developed a significant dependence on them.

Satellites have multiple utilities in almost every field of life, and technological progress in various satellite related technologies have increased their importance in human lives. Satellite technologies and satellite based applications also play an important role in ensuring maritime security. Indeed, the maritime realm is one of the earliest domains in which space based objects were found useful in assisting its functioning. Direction finding techniques based on the position of starts are the earliest known navigational techniques used in sea travel.

In the modern world, navigation involves monitoring and controlling vehicles on land, in water, or in air/space. Navigation can also be viewed as an instrument or mechanism to fix the position and direction of an object. These techniques are based on trigonometry, and owe their origin to the science of astronomy which is probably the oldest of all the sciences used to demonstrate the finding of a location by using the positions of the stars in the sky. Since then, techniques for navigation have evolved significantly and, for some years now, satellite based navigation is in use.

More than six decades have passed since the first satellite reached space. During this period, phenomenal technological developments have taken place in various fields directly or indirectly related to satellites. From rocket engines to optics to sensors to smart materials, and from digital systems to lasers to artificial intelligence to bio and nano technologies, significant developments have taken place. These have assisted the further evolution of space sciences and space technologies.

Satellite technology has increased the human understanding of planet earth manifold. Satellites have increased our knowledge about the overall topography and terrain on planet earth. From glaciers to mountains to forests to deserts to farmlands to oceans, satellite technology has made us more aware about the intricate details of these features. This technology has increased our understating about the climate and weather. Today, both urban and rural life has developed a significant dependence on various inputs from space. Almost every function of human activity like managing agriculture sector, industries, trade and economics, travel and tourism, health care, education and sports have satellite dependence. Also, these technologies are a major help in disaster management. Presently, specially designed satellites are launched for monitoring climate change and studying global warming.

Satellites are almost universally made to reach space for the purposes of meteorology, remote sensing, communication, and navigation. These satellites come in all shapes and sizes, and are positioned in different orbits depending on their character and utility. Theoretically, a satellite is just an electronic unit with specific sensors, and the inputs received from this system could be used for various purposes including for strategic requirements. Satellite technologies are inherently dual-use in nature, and hence offer benefits for both civil and military purposes. Satellites provide real-time information/observations/signals, and this information can be used as per the requirements of the user, and this need could be in fields ranging from agriculture to the military.

In recent times, function specific satellites are being launched which cater to specific requirements. Explicit payloads are getting designed for military purposes too. It is important to note that be it a military or civilian requirement, the basic factions of a satellite broadly remain the same. For example, a strategic satellite can be launched for meteorology, communication, navigation, surveillance and reconnaissance purposes. What is different is the quality of single resolution of a satellite, the revisit time of the satellite, and the area covered for observations. Also, day and night visibilities, the ability to observe in thickly vegetated/snowbound or underwater regions are some of the prerequisites for designing the sensors onboard these satellites. For strategic purposes, spy satellites also get launched.

In a few cases, even some civil commercial satellites are found being used for several military tasks, including command assistance and military logistics support. Military satellites are also used for geodesy, or the study of the earth's shape and size. Data from geodesic surveys is important to the military, as it is used for map making, positioning, navigation, and for a variety of other missions.[3] The use of space technology could also significantly contribute towards the enforcement of international rules and legislation; it also facilitates the updating of rule-making policies.

As mentioned earlier, from the strategic perspective, the essential desirable inputs required from satellites are in the arena of reconnaissance, navigation, and communication. Such satellites could provide inputs to all the arms of various defence establishments, namely the Army, the Air Force, and the Navy. Also, establishments in place of policing duties and to tackle other internal security challenges, the coast guard, and the marine police get relevant inputs from satellite services. There are specific satellites developed essentially to cater to maritime needs. The employability of the satellites in the maritime domain depends on the interests of the user. The agencies which are required to manage/monitor/coordinate the amount of maritime traffic mostly depend on communications and navigational satellites. Few states would be interested in using satellites for the purpose of information gathering, and would depend on remote sensing/earth observational satellites. Also, satellite systems are used in cargo tracking, identification, and security.

Oceans constitute more than two-thirds of the earth's surface, and play a significant role in the global climate system. Even today, the role of the ocean in the climate and the formation of the weather are not fully understood. It has been observed that within the hydrosphere, the ocean tends to have a stabilizing effect on physical climate. However, all the processes in the ocean which determine its role in climate change are properly understood. Also, there is less knowledge about the relationship between processes occurring at different length and time scales. Being fluid, the ocean constantly changes across a wide spectrum of scales, from centimetres and seconds for small surface waves to thousands of kilometres and several decades for the exchange of water in ocean basins between the surface layer and the abyss. Interactions between biological, chemical, and physical processes in the ocean occur at all scales in between these extremes.[4] For a more precise understanding of all these processes, the inputs received form satellite remote-sensing systems are being found extremely useful. There are varieties of ways in which satellite data assists the scientific study of the ocean.

Ocean Atmosphere

Observations of various parameters of atmosphere at, in, and above the sea are very important. It is impossible to track the weapons of an entire oceanic system either from ships or any sea based platforms. Inputs from the systems from space based systems have dramatically changed the knowledge of the oceans as well as the various parameters governing the climate. Developments in senor technologies have revolutionised the availability of data from the oceans. Such high accuracy and reliable data is of enormous utility for undertaking various activities in the oceans.

Space based ocean monitoring systems have considerably changed the understanding of the core meteo-marine parameters, the ability to monitor the status of the marine environment, and predict its evolution. The United Nations Scientific, Cultural and Educational Organization's (UNESCO) Intergovernmental Oceanographic Commission (IOC) promotes international cooperation, and coordinates programmes in marine research, services, observation systems, hazard mitigation, and capacity development.[5]The data from satellites gets plugged into its Global Ocean Observing System (GOOS). Such data has wider utility in studies of oceanic processes (physical, biological and geochemical). A variety of users, from environmental policy makers to various national and regional research as well as meteorological forecasting services to ordinary citizens, depend on these inputs. The interdisciplinary nature of scientific and environmental challenges requires the designing of special operational systems that monitor meteorological forcing as well as physical, geochemical and biological processes. Such availability of an integrated data system also allows the improving of the numerical modelling of climate and weather.[6]

Presently, specifically designed satellite systems capable of providing extensive coverage of all of the world's ocean regions are available. This is dynamic process, and various new satellites/replacement satellites are continually getting added. Depending on the requirement, most of them are designed specifically to serve the maritime industry. They facilitate voice, video, and data services to a variety of maritime platforms, including merchant, cruise, and government vessels. Providing real-time data as well as communication links for safety and efficiency for maritime business is vital. Satellites allow real-time communication which is essential for ship and cargo surveillance, or vessel monitoring. It also assists ship to ship, ship to rig, ship to shore, as well as amongst crews and passengers. Video conferencing facilities and video data downloading facilities are required for the purposes professional work, interacting with the family/friends at home, and entertainment.[7]All this eventually, directly or indirectly, helps to improve the performance and efficiency of the platforms operational at sea.

Satellites have been used to observe the ocean since the 1970s. The following table presents some satellite-based instruments which are designed for specific purposes.[8] This table offers a glimpse of instruments on-board satellites which are meant to collect environmental information.

Table 1

Instrument type	Ocean parameter measured	Instrument name	Satellite
Spectro radiometer	• Chlorophyll content • Organic and mineral content • Sea surface temperature • Sea Ice Cover	MODIS MERIS	Aqua (NASA, USA) Envisat (ESA, Europe)
Infrared radiometer	• Sea surface temperature (SST)	AVHRR AATSR MODIS SEVIRI GOES	(NOAA, USA) + METOP (Eumetsat, Europe) Envisat (ESA, Europe) Aqua, Terra (NASA, USA) MeteoSat (Eumetsat, Europe) (NOAA, USA) DMSP (NASA, USA)
Microwave radiometer	• Atmospheric water vapour content • Atmoshperic water liquid content (cloud) • Rain rates • Sea-ice concentration, type, extent • SST • Salinity	SSM/I TMI AMSR-E MWR JMR, AMR	DMSP (NASA, USA) TRMM (NASA, USA) Aqua (NASA, USA) + (developed by JAXA, Japan) Envisat (ESA, Europe) Jason-1, Jason-2 (Cnes, France + NASA, USA)

Altimeter	• Sea-surface height • Ocean surface wind speed • Wave height • Sea ice	Poseidon-2 RA-2 Poseidon-3	Jason-1 (CNES, France + NASA, USA) Envisat (ESA, Europe) Jason-2 (CNES, France + NASA, NOAA, USA + Eumetsat, Europe)
Scattero-meter	• Wind speed and heading (10 m above ocean surface) • Rain • Sea ice concentration	ASCAT	Metop (Eumetsat, Europe)
Synthetic Aperture Radar (SAR)	• Wind • Surface wave field • Sea ice monitoring		Radarsat-1, Radarsat-2, Canada Envisat, Europe

Oceanography studies are about studying the deep sea and shallow coastal oceans. The expanse of this branch of science is enormous and involves the understating of various fields such as ocean currents, waves, plate tectonics, and sea floor geology. Oceanography is an interdisciplinary science, and involves connections with various branches of science like physics, chemistry, biology, and geology. Knowledge of operational oceanography is essential for undertaking almost any maritime activity. To understand oceans, a significant amount of inputs about various ocean-atmospheric parameters are required. Oceans are vast and sparsely occupied, and thus face limitations of data collection. Getting various inputs from ship based platforms is expensive. Moreover, such platforms are not available over the vast expanse of the oceanic region. The best platforms for getting the desired inputs are satellites or balloons (near-space craft). Over the years, significant developments in the science of oceanography have occurred owing to satellite remote sensing on oceans.

A few typical cases of the identification of oceanic parameters are cited below to provide an idea about such measurements derived from the use of satellites.[9]

- Sea Surface Temperature (SST) assessments are known to be one of the most reliable standards of measurement from satellites. SST is important because of its relationship to the heat budget (global warming); it also has diagnostic value regarding knowledge about currents, upwelling, etc. SST is important even for fishery industry because it helps identify areas for high catchment. These values are estimated via a process of passive measurements. Traditionally, IR sensors with infrared emissions do provide strong signals but have limitations in the atmosphere when obscured by clouds. Microwave based sensors, on the other hand, can see through clouds, and also provide other data regarding wind speed, water vapour, rain, ice, etc.

- Active measurement using microwave radar are undertaken to know the Sea Surface Height (SSH). In this case, a pulse sent from satellite to earth and a measurement of return time is undertaken. The height of the surface can be measured from the time delay of the return signal. Subsequently, with appropriate processing and averaging, it is possible to calculate the following: ocean currents, eddies, deviations in ocean surface due to bathymetry, inputs with regard to gradual sea level rise due to global warming, and deviations in ocean surface due to internal physical variability (heat, salinity).

- Wind and Wind Stress measurements are undertaken with the use of microwave radar to get 'vector winds' that is, speed and direction. For this purpose, a pulse is sent from a satellite to the ocean's surface. The magnitude of the back scatter signal is related to ocean surface roughness, and the angle at which the microwave energy strikes the target which is dependent on the sea surface wind conditions allows the derivation of wind speed and direction.[10]

- Meteorological research has succeeded in identifying specific weather parameters required to forecast the arrival, movement, and decay of various individual weather systems. One such weather system, which originates in the high seas and moves towards land surface causing systems that bring about damage, is the tropical cyclone (also known as hurricanes or typhoons). During last few years, meteorologists have developed expertise in forecasting the formation of such systems, their development, the possible track of their movement, and landfall. This has become possible owing inputs from satellites, as has also the nature and movement of cloud systems and a few other specific atmospheric parameters. For this purpose, specific sensors have been designed, and satellites are launched with such payloads.

Some important sensors which satellites carry for storm forecasting are the Scanning Multichannel Microwave Radiometer (SSMR), the scatterometer, the altimeter, and the Synthetic Aperture Radar (SAR). The table below provides important details of sensors/instruments which have contributed to our understanding of tropical cyclones. Specific facts about the satellites/sensors are available at Annexure 1 at the end of the monograph.

Table 2

Instrument	Frequency	Swath Width	Resolution	Satellite/sensor
Radiometer	6.6, 10, 18, 21, 37, 89 GHz	500–1500 km	300 to 15 km	SEASAT SMMR SSM/I TMI
Rain Radar	C-band, 13.8 GHz	215 km	4.3 km	TRMM radar

Scattero-meter	Ku-band C-band	500–1800 km 500 km (1000 km)	12.5, 25, 50 km 25–50 km	SASS NSCAT QuikSCAT/ SEAWINDS AMI ASCAT
Altimeter	Ku-band, 14.6 GHz	5–7 km	5–7 km	ERS1/2 TOPEX-Poseidon Jason 1/2
SAR/ SCAN-SAR Wide	C-band	Variable SCANSAR, 500 km	100 m	SEASAT ERS1/2 RADARSAT1/2 ENVISAT

Microwave remote sensing of tropical cyclones has contributed tremendously to insights about their structure and lifecycle. This has helped diagnostics and the forecasting of these storms accurately. Microwaves provide a greater understating of the processes happening inside the cloud and storm systems with the help of radiometers and rain radars. One can look through non-raining clouds for surface wind speed with scatterometers, and observe circulation in low pressure systems early in their development. Altimeters allow the determination of oceanic heat content for the potential development of cyclones. SAR sensors allow high resolution looks at wind fields and surface waves.[11]

Spaces-borne synthetic aperture radars (SARs) on board various satellites are known to provide more accurate information. Over the years, various agencies have acquired millions of high-resolution images of ocean scenes. These images have been used for applications such as wave and wind retrievals, ship detection, monitoring of sea ice, as well as the interpretation of signatures of surface current gradients over oceanic fronts, internal waves, and shallow-water bathymetry. SAR technology is best suited for oil spill monitoring, especially over wide areas. The continuous up-gradation of SAR sensors is taking place to overcome some limitations. For example, techniques have been evolved to permit the direct retrieval of line-of-sight surface current fields from SAR data.[12]Also, instruments like the scatterometer play an important role in provide information about ocean surface roughness while the radar altimeter in space assists in measuring the height of the sea surface.

Maritime Surveillance

In general, surveillance is the systematic observation of aerospace, surface or subsurface areas, places, persons, or things, by visual, aural, electronic, photographic, or other means. Maritime or sea surveillance is about observing the surface and sub-surface areas of the sea. Such observations are undertaken for the purpose of locating, identifying, and determining the movements of ships, submarines, and other vehicles, friendly and enemy, proceeding on or under the surface of the world's seas and oceans.[13]

Maritime surveillance is a domain of great importance both for business purposes as well as strategic ones. States singularly or jointly have put various maritime surveillance initiatives in place to enhance search and rescue operations, provide effective response to accidents and disasters, monitor fisheries, prevent pollution, as well as support law enforcement and national defence. Such initiatives demand the generation of real time wide area maritime operational images. The surveillance mechanism constitutes multiple platforms, like coastal, airborne and satellite. In addition, inputs from intelligence data to radar systems available with a few other agencies are integrated in order to provide a comprehensive operational picture.[14] In literature, and also in practice, surveillance mostly gets clubbed with intelligence and reconnaissance (these activities are almost akin to surveillance), and the three together get sign posted as ISR, particularly when surveillance is referred to in strategic context. Mostly, reconnaissance is viewed as issue specific activity while surveillance could be viewed as continuous process (though this is not always the case).

Surveillance is a key element while exercising national sovereignty at sea. One of the main purposes of carrying out surveillance is to identify and deter infringements to regulations. Such infringements could be intentional or non-intentional. In such cases, the systems also include law enforcement and compliance monitoring mechanisms. The surveillance systems include reporting/messaging systems which rely on the ships to provide information, such as VMS (Vessel Monitoring Systems), AIS (Automatic Identification System), and the many non-automatic reporting systems and regimes, as well as sensor systems such as radars and cameras that collect information about ships without their cooperation.[15]

The features of the targets that require to be tracked in a maritime environment vary greatly. Some of the important properties of the targets are the following:

- Size (ranging from jet-skis to large oil tankers)
- Material (ranging from rubber boats to metallic vessels)
- Speed (ranging from stationary to very fast moving)
- Direction (some targets can change direction rapidly while others cannot)
- Visibility of target (some targets have a good contrast to the ocean while others are intentionally camouflaged)

For any successful surveillance system, it is essential that it has the capabilities to discern the above features. Any maritime system employed for surveillance also needs to differentiate between man-made structures in the sea and animal life. It also needs to be capable of tracking multiple targets under various atmospheric situations, like rain, snow, storms, etc. Naturally, all such requirements influence the choice of the surveillance methodology.[16]

For nation-states it is essential to keep close watch on happenings in and around the seas, and ensure the safe use of the seas. Maritime borders need to be managed. For this purpose, it is important to improve and optimize the activities of maritime surveillance and interoperability. Such activities deal with various small troubles as well as with greater threats related to safety of navigation, the application of regulation to protect the marine environment, fisheries control, the fight against trafficking of all kinds, illegal migration, and security in general. Various mechanisms have been used to undertake surveillance. For the purpose of better time and spatial coverage, the best option presently available is the use of space sensors, which are capable of providing global coverage. Space based surveillance is complementary to terrestrial solutions; they allow controlling open sea areas that are not covered by any other surveillance system. Such systems are found more useful owing to the following main characteristics.

- Overall surveillance on a large scale,
- Enabling day/night operation capacity,
- Independence from local meteorological conditions,
- Independence from national borders,
- Data accuracy, availability and integrity[17]

Using satellite technology for maritime surveillance offers various advantages. These systems provide information and also lead to finding alternatives to achieve objectives. The inputs received can be interpreted for various purposes including business requirements and security challenges. Space technology brings new evidence (more or less reliable) to prove the reality of any threat or risk. Some technological systems currently in use, aboard and ashore, allow nearly real time monitoring of conditions of navigation, the route, the position of the surrounding vessel, its identity, and its cargo. Various spatial means offer, to the crew under supervision as well as the controllers, the option of limiting the occurrence of events at sea using communication or visualization tools.[18]

At times, systems for surveillance (satellites or otherwise) get designed with the purpose of monitoring surface and low-level air activity within the 200 nautical miles (nm) of Exclusive Economic Zone (EEZ). These systems also assist authorities to more efficiently monitor various illegal activities such as drug trafficking, smuggling, piracy, illicit fishing, and illegal immigration. In addition, the system may be used for tracking icebergs, environmental protection, search and rescue, resource protection, sovereignty monitoring, and the remote sensing of ocean surface currents and winds.[19]However, these systems also have some limitations, and may not be able to cater for all the possible hazards. The process of creating an integrated maritime surveillance system will no doubt always remain in dynamic state owing to continuous developments in the field of sensor technologies as also because the nature of threat is unlikely to remain static.

Satellite based systems are expected to detect the objects/targets which are either stationary or moving in the oceanic area. These objects could be of various shapes and sizes. Such objects should be visible during day and night, and through sea cluster. The movement of these objects could vary: slow, but continuous to much higher speeds (from few knots to hundreds of knots). Also, in some cases, the movement needs to be monitored for many days. Thus, along with the very high resolution (a few meters or even less), the sensor should have the capability to penetrate denser mediums. The important applications of maritime surveillance include the Automatic Identification System (AIS) and Vessel Traffic Services (VTS). Also, satellites are expected to multi-task by integrating other services, such as weather and environment information, navigational inputs, and assist in route planning. Real time and secured communication of voice and data/imageries are also a prerequisite.

Stand alone maritime surveillance systems (private or public) are of no use unless they are networked with other important systems required for decision making. Inter-operability is a technical imperative. From the perspective of cooperation between the actors controlling human activities at sea, public-private relations have to be organized even though the two dimensions are pursuing different interests. For any integrated maritime surveillance (IMS) system, the technologization of the surveillance and inspection rules does not distinguish between private and public spheres. It interferes in all areas, and is now a component of the very organization of maritime activities.[20]

Synthetic Aperture Radar (SAR) imagery has great potential in observing and monitoring the maritime environment. Knowledge about the position and type of vessels may provide for a wide variety of applications, such as maritime traffic safety, fisheries control, and maritime border surveillance.[21]Ocean surface monitoring for ship detection via SAR is a major area of research and development for the remote sensing scientific community. Some such systems are already playing an important role in maritime traffic control, maritime border surveillance, fisheries control, and search & rescue.

In order to draw maximum benefits from SAR data and also to overcome some of the limitations of this data, various techniques are getting developed. For example, one such useful technique is the identification of bright targets over a dark background. This technique allows reducing the amount of data and, at the same time, allows increasing the range swath, with no resolution loss. Such techniques are particularly suitable to ocean monitoring for ship detection applications.[22] Such target identification is can be required under different situations. However, the maritime domain poses many challenges for the design of an effective maritime surveillance system. Particularly, crime activities taking place in the high seas pose the challenge of tracking moving vessels in the presence of a moving dynamic background (the ocean). In such cases, a background subtraction method is employed, with a real time approximation of level-set-based curve evolution to demarcate the outline of moving vessels in the ocean.[23]

Ship detection with satellite based SAR has been in vogue since the 1980s. In recent times, the miniaturization of space technology is found providing additional benefits for space based surveillance systems. Primarily, smaller nations are expected to gain much from them in the surveillance of economic ocean zones and adjacent waters of interest. On the sensor side, a mixture of active and passive sensors, and cooperative and non-cooperative techniques are providing new opportunities for maritime surveillance. Micro-satellites with passive sensors onboard are helping in ship detection.[32]Also, radar satellites do offer much help. The passive detection of navigation radars by a high performance radar detector onboard a micro-satellite in a 600 km circular orbit are in a position to decide the geographic position of maritime vessels accurately. In addition the following important feature will also be known.[24]

- Additional information about the ship's identity
- A much wider swath (1200 km), allowing more frequent coverage
- Most cost effective option for smaller states
- The satellite directly in the state's control the dream of small states to own a satellite becomes a reality

Modern day maritime surveillance system is a combination of various software and hardware modules which together provides the surveillance inputs. Micro satellites, SAR technology, radar satellites, etc. have revolutionised space based surveillance. In addition, satellite based communication allows far better real time coordination. A typical space based maritime surveillance system which is put in place by the European Union (EU) is explained below. It may be noted that the system discussed below involves major infrastructure. However, smaller states could establish a system with a limited mandate and area of operation. Such systems would require limited space capabilities.

Copernicus

Copernicus is the world's largest single earth observation programme, some portions of which have been in operation since 2008 and some are still in the making. It belongs to the European Space Agency (ESA). It offers continuous coverage of the entire globe, and has high quality earth observation capacity. This facility is of much help to various agencies involved in undertaking maritime activities. This programme pulls together all the information obtained by the Copernicus environmental satellites as well as air and ground stations, and provides a comprehensive picture of the 'health' of Earth. The geo-spatial information service offered by the Copernicus caters mainly to six interacting themes: land, ocean, emergency response, atmosphere, security, and climate change. The space component of Copernicus involves observation satellites and associated ground segments, with missions observing land, atmospheric, and oceanographic parameters.[25]

Maritime Surveillance is one of the three priority areas addressed by the security dimension of Copernicus. Here, the overall objective is to ensure the safe use of sea, and to secure maritime borders. In order to fully operationalize the service, three specific projects have been identified to undertake specific research: DOLPHIN, NEREIDS, and SIMTISYS.[26]

The DOLPHIN (Development of Pre-operational Services for Highly Innovative Maritime Surveillance Capabilities) project is involved in developing new methods and algorithms for processing satellite radar and optical images in order to improve the detection and monitoring of sea faring vessels. This facilitates the mitigation or prevention of piracy, illegal immigration and goods trafficking, illegal fishing, and accidents at sea. The major focus of DOLPHIN is to devise methodologies which would serve as the basis for pre-operational Copernicus services for Maritime Surveillance.

The NEREIDS (New Service Capabilities for Integrated and Advanced Maritime Surveillance) project is aimed at supporting the development of an integrated vision of Maritime Policy and Maritime Surveillance, with implications for a number of different maritime domains, such as illegal trafficking, illegal immigration, fisheries control, piracy, etc. The purpose here is to develop a system of systems that provides a complete and meaningful maritime picture, and overcomes various technological drawbacks.

The SIMTISYS (Simulator for Moving Target Indicator System) project aims to support the use of space borne radars mounted on single or formation-flying satellites through the development of a software simulator. This tool will be useful and powerful in assisting users (such as the coast guard) with the detection and tracking of small vessels in the context of pre-defined scenarios.[27]

China's Maritime Surveillance Architecture

To have a broad idea about how developed nation states invest in a space based maritime surveillance architecture, the example of China is discussed below. Universally, maritime surveillance systems include a range of non-space based facilities. These include ship and shore based systems and specific radar installations. The same is the case with China. However, apart from these resources, China is found making a significant amount of investment in the maritime satellite sector.

China is an interesting case study. This is because in spite of Beijing's satellite capabilities being cutting-edge in many respects, it still has to do much more to match the potential of the USA. There are likely to be major gaps in the coverage of every satellite application. However, having understood the importance of the possessing capabilities for the maritime ISR, China is found making significant investments towards having satellite assets. It has also been found using commercially available information to cater to their requirements. The sources of Chinese space imagery include almost all of the major providers, including Spot Image (Europe), Infoterra (Europe), MDA (Canada), Geo Eye (USA), and Digital Globe (USA).[28]

In China's satellite development, maritime surveillance is the key focus area. It is one of the eight key areas specified by China's 863 State High-Technology Development Plan. China's first series of dedicated maritime monitoring satellites have been designed and developed by China Academy of Space Technology (CAST), and all related administrative issues (receiving, processing, archiving, managing, and distributing all collected data and products) are overseen by the State Oceanic Administration (SOA). Broadly, inferring from China's sensor development capabilities, it could be presumed that China's reconnaissance skilled satellites are expected to comprise electro-optical, multi/hyper-spectral, and synthetic aperture radar (SAR) capabilities.

The following table identifies some of the main satellites systems developed and operated by China for maritime surveillance.

Table 3

Haiyang	Ocean monitoring constellation
Huanjing	Disaster monitoring
Yaogan	Conducts scientific experiments, surveys on land resources, estimates crop yield, and supports natural disaster reduction and prevention
Tianhui	Conducts scientific experiments and supports land resource surveys and territory mapping with a stereoscopic imaging payload
Ziyuan	Earth resources, cartography, surveying, and monitoring
Fengyun	Weather satellites

Haiyang-1A

It is obvious that these satellites are dual-use satellites, and are not necessarily in every case been officially recognised by China as maritime surveillance satellites. Amongst the above, one system is discussed below in greater details to provide a bird's-eye view about Chinese investments.

China launched its first maritime observation satellite, Haiyang-1A (HY-1A), on 15 May 2002. Haiyang means 'ocean' in Chinese, and gets referred to as the HY satellite. The major function of this satellite was to monitor ocean water colour and temperature. However, a Chinese official publication had stated that 12 percent of Haiyang-1A's 2003 'satellite data distribution' is for the military. HY-1B, with an ocean colour scanner and having one day revisit period, was launched in April 2007 for surveying China's maritime periphery, including the East and South China seas. Overall, China has planned three series of launches for this category of satellites, and is likely to launch 15 Haiyang ocean monitoring satellites[29]. Some of these have now already been launched.

For example, Haiyang-2B and Haiyang-2C satellites are a part of a series of second Generation Ocean monitoring satellites, and the first satellite of the series of four, HY-2A, was launched on 15 August 2011. The objective of HY-2 is to monitor ocean dynamics and measure environmental parameters such as marine winds, sea levels, and temperatures as well as currents, tides, and storms. Mesoscale technology is used to observe ocean conditions and weather systems around the world. The launch of HY-2B and HY-2C is expected to improve China's ability on mesoscale ocean supervision. Together with HY-2A, the three satellites are to enhance the ocean dynamic environment monitoring net which has been established as part of China's National Spatial Data Infrastructure. China is also planning to send its first full electric propulsion satellite into orbit by 2020.[30]

Overall, as a rapidly developing high technology, HY satellites systems are found playing an important role in both ocean economy development and the national defence construction of the state. HY satellite products are extensively used in wide domains, including ocean environment protection, ocean disaster management (comprising prevention, mitigation, warning, response, recovery and assessment), marine environment forecast, ocean resource development and management, ocean right protection and law enforcement, ocean investigations, and scientific research, etc.[31]

Some basic information in regards to each system in above table is provided in Annexure 1.

Navigation in the Seas

It has been observed that methods of navigation have changed through history. Interestingly, the history of navigation is all about directing the movement of ships and other vessels in the seas. The development of almost every device known to navigational science has been deeply influenced by naval practices.[32]A few centuries ago, seamen used to navigate with the help of star constellations in the sky (astronomy) or other geometrical methods. Navigational methods and techniques used to depend on the type of vessel, its equipment, and the condition of the waters around; the techniques used were (are) Dead Reckoning, Celestial navigation, Radio navigation, and Radar navigation. Today, sea farers have learnt much about navigation from their experiences in the high seas.

Presently, satellite based navigation systems are getting routinely used, both for navigation on land and in the seas. Present generation Smart Phones (mobile telephony) offer various features required for navigation, and this has actually lead to a revolution in navigation usage. For many years, there has been a significant global dependence on the US developed and owned Global Position System (GPS) for navigational services. However, in the recent past, a few other similar (or better) systems are in the making, and some are even partly operational. The need for accurate positioning, navigation, and timing information all around the world was projected by the militaries of different countries, many decades ago, and this gave birth to the satellite based navigation system. In the initial few years, this system was exclusively a military system. Subsequently, it also found applicability in the civilian domain. For developed militaries such systems are more particularly at the heart of their activities. They have significant utility in planning and executing the movement of their forces from one place to other. Similarly, this system permits precision in the delivery of weapons to targets.

The first satellite based navigation system was TRANIST. It was a naval navigation system developed by the US military during the 1960s. TRANSIT was developed to support the US Navy's Fleet Ballistic Missile (FBM) submarine for the initial positioning information required by the FBM Strategic Weapon System (SWS) ballistic missile. This was followed by POLARIS.[33] This system was operational until 31 December 1996. This system's operations were based on the Doppler Effect in which satellites passes through well-known paths and broadcast their signals on well-known frequencies. The frequency shifts between the received frequency and the broadcast frequency because of the movement of the satellite with respect to the receiver. By monitoring the shift in the frequency over a period of time, it is possible to identify the location.[34]

During the mid-1960's, the US Navy conducted satellite navigation experiments to track US submarines carrying nuclear missiles. With six satellites orbiting the poles, submarines were able to observe the Doppler changes, and identify the submarine's location within a matter of minutes. In the early 1970's, the Department of Defence (DoD) decided to develop a robust, stable satellite navigation system. Embracing previous ideas from Navy scientists, the DoD decided to develop a navigational system with support from satellites. This led to the launch of its first Navigation System with the Timing and Ranging (NAVSTAR) satellite in 1978. The 24 satellite system became fully operational in 1993. NAVSTAR is a network of satellites for providing global positioning system (GPS) services.

The Global Positioning System (GPS)

Today, the GPS is a multi-use, space-based radio-navigation system and is operated by the US Air Force to meet their national security, civil, commercial, and scientific needs. The GPS currently provides two levels of service: the Standard Positioning Service (SPS) and the Precise Positioning Service (PPS). Access to these is restricted to specific US agencies. The SPS is available globally, without any direct user charges[35].

Today, the GPS uses between 24 and 32 satellites orbiting around 20,000 km (Medium Earth Orbit, MEO) in space. By the triangulation method, the three satellites together are able to provide accurate information. On board, the GPS receiver stores the almanac data for continuous use. It also calculates exactly how far the satellite is from the ship (or any other maritime platform) at any given instant. Three satellites are able to provide latitude and longitude information, and with four satellites it also possible to know the altitude. By keeping a record of the ship's positions, it is possible to calculate the ship's speed. In comparison with the earlier navigational systems, the GPS is very accurate and also provides correct inputs even during stormy weather. Over the years, this system has emerged as the most reliable system for undertaking various operations at seas. The GPS information at sea is regularly replicated on other navigational paraphernalia on the bridge like radars, electronic navigational systems, and communication systems resulting in convenient, easy, and seamless navigation.[36] It is important to note that navigation is the most important aspect of various activities conducted in the seas and, for this purpose, various instruments and trained manpower are required. The GPS provides the most cost effective option.

The US Navy has significant amount of dependence on GPS and in various campaigns are found using GPS to their advantage. The world witnessed how important the use of the GPS was for the Navy during the 1991 Gulf War. For the US Navy, it was the first big time participation in a war in the post-Cold War era. This war also included littoral operations such as mine counter measures and an attack against small Iraqi missile attack boats. There was an embargo directed against Iraqi sea traffic prior, during, and after the war. This became possible owing to a sophisticated ship-tracking system devised originally to support missile attacks against the Cold War Soviet fleet. The US Navy had shore-based data fusion centres communicating with computers aboard deployed ships via satellite. The ship-tracking system was called JOTS (Joint Operational Tactical System), and its success may have been the most important lesson of the war. This system is a complete battlefield management system, capable of data fusion, control, and display, the usage of large format displays, work stations, plotters, and peripherals. More than 200 such systems were in service by 1st January 1991, including the versions with the British Canadian and Australian navies.

The GPS was only used as a direction finder; but it also was a big time enabler for navigation, manoeuvre, and fire with unprecedented accuracy in the vast desert terrain for almost 24 hours a day. This was so despite difficult conditions like frequent sandstorms, few paved roads, no vegetative cover, and very limited natural landmarks. The GPS helped towards undertaking precision bombing, providing artillery fire support, and ensuring the precise positioning and manoeuvring of troop formations, and certain Special Forces operations. In this campaign, the GPS helped in improving the performance of Tomahawks or hitherto terrain missiles. The use of the GPS systems aided the performance of the Land Attack Cruise Missile by improving the Digital Scene

Mapping Area Coordinator (DSMAC) and the Terrain Contour Mapping navigation systems. The key to improving the Tomahawk's efficiency was the modification of the missile enabling it to navigate on the basis of GPS data. That was done in the Block III version of the missile, which was first used in Bosnia a few years earlier. Given GPS guidance, the Tomahawk could be used in snap attacks, such as those against targets in Afghanistan as well as in the Sudan in 1998. The Gulf War also proved that submarines could deliver Tomahawk land-attack missiles effectively.

Iraq had a substantial mine inventory, and the naval command in the Gulf was tasked to deal with it. The usual technique used for mine hunting is tedious and time consuming. Specialized craft literally search the bottom, foot by foot, examining any suspicious object. However, this process is exceedingly tedious and time consuming. The US Navy attempted to come up with alternatives based on the use of the GPS and Mine Reconnaissance which achieved mixed results due to gaps in data collection. The presence of the GPS has made various equipment like the artillery surveyor's compass, telescope, slide rule, etc. irrelevant.

Post the Gulf War, the US Navy has used the GPS in several peacekeeping and military operations. During Operation Restore Hope in 1993, the GPS was used to air drop food and supplies to remote areas of Somalia because of the lack of accurate maps and ground-based navigation facilities. The US forces entering Haiti in 1994 also relied on the GPS. During the Balkan Crisis (1999), the GPS assisted in the delivery of aid to the Bosnians by guiding US Air Force transport planes to their drop zones at night, with food and medicine being parachuted down close to towns and villa.

GLONASS

The other fully operational system globally is the Russian constellation called GLONASS. This system has a long history. It was developed during the period of the erstwhile USSR. Subsequently, for the some years the system became partially operational owing to the financial problems faced by Russia after the end of the Cold War. However, post 2000, Russia began investing in this system, and by 2011 the system was made fully operational, with 24 operational satellites in space.

During the mid-1990s, it was observed that the GPS did have some limitations particularly in maritime usages. This was especially so during adverse conditions, such as bad weather, narrow channels, and congested harbours when the performance of the GPS was found not that satisfactory. However, the combined use of the GPS and GLONASS was found very useful, and it was realised that the combination offers many advantages compared with GPS-only use for maritime applications. It was observed that the inclusion of the GLONASS signals significantly increases the accuracy of positioning and velocity as well as the availability and the integrity.[37] GLONASS together with GPS now forms an important part of the Global Navigation Satellite System (GNSS).

From the maritime perspective there are various applications requiring GNSS reference systems. There are agencies which offer a complete range of surface position reference systems (that is, GPS+GLONASS). Some of the applications include offshore loading, multi-purpose support vessels, anchor handling, tug supply vessels, drill ships and rigs, cruise ships, and seismic surveying.[38] Using GPS/GLONASS based SATNAV (satellite navigation) receivers for maritime users, and making the governments agree to have such arrangements have been possible after it was scientifically observed that such systems could offer better results. Different maritime applications may require different levels of system accuracy. Thus, employing a combined GPS/GLONASS system has been found helpful in eliminating such issues as system availability, satellite coverage, system integrity, and time-to-alarm. Also, it has been found that having an integrity monitoring capability (that is, RAIM) to the hybrid SATNAV receiver ensures navigation and positioning reliability due to the combined satellite rich SATNAV system.[39]

China's BeiDou Navigation Satellite System

Another important system with global coverage is China's BeiDou Navigation Satellite System. This system is almost near completion, with 22 satellites already in space (by June 2016). During 2013, Chinese President Xi Jinping had unveiled one of the most ambitious plans of creating an economic (also strategic?) corridor, called the 21st Maritime Silk Road (also known as OBOR; One Belt, One Road) initiative. The actualisation of this initiative mainly involves connectivity by road / rail and the sea. This is a gigantic proposal, linking China with Europe through the Central and West Asian region. Linkages with Africa are also proposed.

Presently, China has around 125 operational satellites in orbit, mainly providing communication, remote-sensing, and navigational services. Chinese communications and remote sensing networks have near global coverage. They have already established an indigenous satellite navigational footprint over the Asia-Pacific region with their Beidou (Compass) navigation satellite network, and are expecting to widen this footprint globally in a very short period of time. Various real time inputs provided by their various satellite constellations and their BeiDou network would help them considerably in conducting various traffic planning and management activities on the land and the sea for the OBOR initiative. Presently, this 21st Maritime Silk Rode initiative is more at the level conceptualisation. However, during the phases of its development as well as when the project becomes a reality, there will be a significant amount of dependence on the BeiDou navigational system.

China is planning to collaborate with the service providers for the Russian satellite navigational system called GLONASS. Currently, GLONASS Union and the Chinese manufacturing company Norinco are planning to jointly develop and produce a multisystem receiver module for satellite navigation systems. This would eventually lead to the launch of Russian-Chinese receivers for satellite navigation systems on the 21st Maritime Silk Rode initiative.[40] All this indicates the huge role the navigational systems are likely to play in the maritime domain.

Maritime transport is a vital factor of economic development of every maritime state, and maritime transport management is an important activity. The key to the success of every shipping organization, region, and maritime country lies in the efficiency and the safety of its maritime shipping services. For this purpose, the high quality management of the maritime shipping industry is a must. There is need to ensure that maritime accidents are avoided. The movement of vessels should take place in such a fashion that the preservation of marine natural resources is ensured.[41] To make all this possible, one of the important aids is to have accurate navigation services available.

The Galileo

Today, apart from the GPS, GLONASS and the BeiDou, another global navigation system is also in the making. This is called Galileo (the European system). This system would have 24 satellites plus spares in Medium Earth Orbit. As of May 2016, a total 14 Galileo satellites have been already launched. Presently, project Galileo appears to be on track. However, this project has got much delayed owing to various reasons, including the financial challenges faced by the EU. When this project was on the drawing board, it was realised that since existing global navigational systems are providing excellent services, the Galileo network should offer some different and valuable features to attract attention and customers. Understating the importance of navigation for the maritime domain, it was probably thought that this could be one area where Galileo could develop its expertise to supersede other GNSS networks.

Galileo began with idea of identifying specific projects which could help offer value additions in their services. For the maritime domain (directly or indirectly related) three specific projects have been identified.[42] They are as follows.

- Galileo and EGNOS for Waterway Transport: GALEWAT
- Maritime Galileo: MARGAL
- GEM

The overall aim of the three projects is to raise awareness regarding Galileo, and examine avenues for their multimodal application. The focus is on the efficiency, safety, and optimization of marine transportation. It is expected that many other marine activities such as fishing, oceanography, or oil and gas exploitation will also benefit from the availability of Galileo's services. Research is also being done regarding the possibility of extending the use of Galileo's services towards leisure boats and for safety-of-life-at-sea (SOLAS) in every phase of maritime navigation (ocean, coastal, port approach, and harbour manoeuvres), and under all weather conditions.

For marine navigation, as regulated by the International Maritime Organization (IMO), Galileo will be will be used to implement the automatic identification systems (AIS) and vessel traffic management systems to increase navigation safety, collision prevention, and economic benefits. It can be used for several maritime commercial activities like fishing (it will help locate traps and nets); the optimization of fleet management; cargo monitoring, delivery and loading schedules; correctly identifying the location of shipping containers; automatic piloting; and Barge tracing. For example, Sciro in Italy is involved in developing a system using GNSS that automatically tracks containers inside a terminal. This will reduce container handling time and costs, and increase service levels and terminal productivity. For inland waterways, the accuracy and integrity of navigation data are essential to automate precise manoeuvres in narrow rivers and canals.

Broadly, the advantages of using EGNOS and Galileo for maritime operations are as follows.

- In combination with other GNSS systems, Galileo will allow for faster alert localization and message detection, a more precise localization of the distress beacon, and higher availability.
- Through its Search and Rescue service, Galileo will offer a return link confirming the distress signal was received which has proven to drastically improve the chances of survival.
- Differential GNSS (D-GNSS) provide additional improvements for maritime applications with an additional need of precision.

Some of the specific details about the three projects identified are as follows.

GALEWAT

- The Galileo and EGNOS for Waterway Transport (GALEWAT) project is fully funded by the European Space Agency (ESA).
- The project was established in 05/2003 with the focus of demonstrating the feasibility of the introduction of EGNOS in the upcoming River Information Services (RIS).
- River Information Services (RIS) are based on a concept for harmonized information services to support traffic and transport management on inland waterways, including the necessary interfaces to other transport modes.
- The project operates in the fields of waterway operation and management, navigation, maritime electronics, telecommunication, and IT industries.
- The project aims at the realization of a first step towards the introduction of EGNOS and finally GALILEO into the upcoming RIS all across Europe.

Further more some more objectives of the project are as follows.

- Identification of user requirements related to AIS and EGNOS service parameters for transport efficiency as well as safety related value added services within RIS.
- Replacement of conventional RIS local differential GPS (DGPS) stations by direct reception of the EGNOS signal in shipboard transponders.
- Bridging outages of the EGNOS signal in space (SIS) by retransmitting the EGNOS differential corrections and integrity data via AIS base stations in areas without direct EGNOS reception such as mountains and bridges.

The GALEWAT system is composed of several segments such as:

1. The Ship segment: five ships that are equipped with AIS transponders; one of the ships is equipped with the so-called 'extended ship equipment' which is able to output position fixes in various modes of operation (that is, GPS stand alone, GPS augmented by EGNOS from direct Signal-in-Space (SIS)

2. The Shore segment: comprises mainly of two AIS base stations that are also able to receive the EGNOS SIS, and to broadcast re-formatted EGNOS information through the AIS data link

3. The Regional segment: consists of terminals, located for example nearby the locks.

4. The Operator segment: can be represented by a national control centre (for example, used by the Supreme Shipping Authority) storing all traffic information provided by the RIS in a large database.

As already mentioned, one special feature of the GALEWAT system concept is the EGNOS over AIS principle. That is, EGNOS information is received at shore stations, re-formatted, and again broadcast over the AIS communication link. Two other important points to remember are: first, when analysing the potential use of EGNOS for inland waterways, the question of signal availability is a critical issue; second, due to the environment around the shoreline of the rivers/canals, the danger of losing line-of-sight to the EGNOS satellites is quite high

MARGAL

- Maritime Galileo or MARGAL is a 50 per cent co-funded by the EU.
- It was launched in the frame of the Galileo-related activities of the Sixth Framework Programme (FP6) for R&D of the EC (European Commission), managed by the GJU (Galileo Joint Undertaking).
- It began in 2004.
- The project is focused on future requirements for maritime navigation, which have already been expressed formally by IMO (International Maritime Organisation) and other authorities.
- This includes future requirements for important performance parameters, such as accuracy, integrity, continuity, and availability as well as functionality related to security and safety at sea.

The MARGAL project focuses on the maritime use of Galileo. These uses are twofold:

- The demonstration of an end-to-end value added navigation services in the inland waterway domain.
- For port approach and harbour navigation in the maritime domain.

The objectives of the MARGAL project are:

- The distribution of EGNOS correction in Inland Waterways and Ports.

- The provision of infrastructure and user terminals for EGNOS integrity monitoring.
- Link integrity monitoring to practical user cases.
- To use enhanced positioning integrity in applications providing better safety and security in ports and inland waterways.
- Provide basis for a smooth transition from GPS to Galileo.

The project specifically addresses the following challenges:

- Port and harbour approach
- Navigation, monitoring and docking
- Inland waterways monitoring
- Precise navigation and
- Calamity abatement

The project also consists of the MARGAL prototype system which will take advantage of the improved accuracy and integrity that EGNOS and Galileo will provide for enhanced vessel safety, in all areas of navigation.

GEM

- This is a project funded under the Galileo Activity E work stream, running from January 2004 to December 2005 to undertake some of the support actions needed for Galileo.
- GEM is fully funded by the European Union (EU) through the Sixth Framework Research and Development Programme which is being administered on behalf of the EU by the Galileo Joint Undertaking (GJU).
- The project addresses a wide range of issues, and is broken down into a number of discrete, independent work packages that are running autonomously.

The principal objectives of this work package are to

- draft the standards necessary for Galileo, and possibly EGNOS, to be recognised as part of the World Wide Radio Navigation System (WWRNS) by the International Maritime Organization (IMO),
- facilitate this recognition process and,
- develop the standards necessary for Galileo, and possibly EGNOS, to be deployed and utilised by the maritime sector, both European and globally,
- As of today, information and action papers have been submitted to the relevant International Maritime Organization (IMO) committees. In particular the Sub Committee on the Safety of Navigation (NAV) has accepted the need to develop Galileo receiver performance standards in advance of the Galileo service being available, as well as paving the way for Galileo to be recognised by IMO as a component of the World Wide Radio Navigation System (WWRNS)

The Regional Navigation Satellite System (RNSS)

Apart from the above disused GNSS, countries like Indian and Japan are developing the Regional Navigation Satellite System (RNSS). Japan's regional navigation satellite system is known as the Quasi Zenith Satellite System (QZSS). The development of this system was authorized by the Japanese government in 2002. This system is a four satellite system, and is expected to be operational by 2018. Japan is also ensuring that they will augment the strength of the GPS. For this purpose, Japan has developed the MSAS (Multi-Functional Transport Satellite, MTSAT Satellite based Augmentation System). This is essentially an overlay system for increasing the accuracy of GPS navigation by transmitting differential information. This satellite also provides weather related inputs.

India is developing an Indian Regional Navigation Satellite System (IRNSS) to provide itself and neighbouring countries with the Position Navigation and Timing (PNT) service. This project is likely to become operational during 2017. This is a seven satellites constellation, built and operated by India with indigenous capability. Three satellites are in GSO and 4 are in non-GSO (inclined 29 degrees with equatorial plane).[43] All these seven satellites have already been launched, and some critical tests are underway before declaring this system operational. The operational name of this system has been announced as NAVIC (NAVigation with Indian Constellation). The maritime influence of navigation is evident from this name too because, in many Indian languages, NAVIC means sailor or navigator. India has also developed the GPS-Aided Geo Augmented Navigation (GAGAN) system. GAGAN is interoperable with GPS, and provides greater reliability than GPS alone. GAGAN has been designed primarily for civil aviation purposes; however, its utility for navigation in the case of ship based aircraft cannot be ruled out.

Space based navigational aids can become dysfunctional owing changes in space weather. The problems in ionosphere, solar storms, etc. could impact the accuracy of navigation. More importantly, the biggest challenge the users of any navigational system face is from the intentional jamming of navigational signals. Essentially, any GPS signal is a weak radio wave, and such waves can be jammed or distorted by using a GPS jammer.[44] However, intentional GPS interruptions have been taking place for a long time, especially with the easy and widespread availability of GPS. Moreover, the change in the global security scenario is expected to increase jamming activity in the future.

There are reports about North Korea (DPRK) jamming GPS signals with the aim of creating disruptions in air and naval traffic near the demilitarized zone that separates North and South Korea. Possibly, such activity has been taking place since 2010. North Korea is known to have developed its GPS jamming capability in response to GPS-guided weapons that could be used by both the South Korean and US forces in the event of a war. DPRK is known to maintain a regiment-sized GPS jamming unit near the capital Pyongyang, and battalion-sized units near the demilitarized zone. There are speculations that North Korea could have purchased truck-mounted GPS jammers from Russia with a range of thirty to sixty miles. During March 2016, DPRK reportedly broadcast jamming signals on a hundred occasions, and a total of 962 planes and nearly 700 fishing vessels got affected because of this.[45]

Modern ships which are mostly big in size are highly automated, with networked navigational systems including differential GPS (DGPS) which offers more accurate positioning (to one meter) than the conventional GPS. However, the maritime DGPS receivers are highly sensitive, and can be easily disrupted by using 50 pounds jammer devices which are widely available on the market. Such disruption, particularly when ships are navigating through narrow inshore waters, can result in inaccurate positional information, leading to accidents. Presently, the University of Nottingham and the Royal Norwegian Naval Academy (RNoNA) are investigating how to prevent shipping GPS being jammed in potential cyber-attacks that may cause vessels to go off course and collide or run aground.[46]

Maritime Communication

Communication has been around since the dawn of life. During the early period of civilianization, humans have been found communicating with each other, using sounds and other signals. Subsequently, they have been found communicating by using direct speech, semaphore or hand signals. Semaphore signalling a technique uses six shutters, two vertical rows of three on a white background. By changing the pattern of the black and white stripes of the shutters, words and sentences can be spelt out to communicate between ships. However, a problem arises with this form of communication when one of communicators is beyond the horizon. In such cases, communicating between ships as well as from ship to shore is problematic. During the late 1800s, this led the Royal Navy to work on the ideas of Heinrich Hertz on electromagnetic radiation, and work with scientists such as Guglielmo Marconi to use radio waves as a method of communicating between ships as well as from ship-to-shore in Morse code[47].

By the mid-1800s, James Clerk Maxwell developed the theory of electromagnetism. The concept was to convert sound waves into radio waves, and use this technology for inter-ship communication. The receiving agency decoded the radio waves back into sound waves, and listen to the message they had received. By the early 20th century, the British Royal Navy had begun to adopt transmitters fitted with alternators, and used magnetic detectors with headphones.[48]

Around 1946, the US army achieved radar contact with the moon. The US Navy began commutation experiments (1954) by using the moon as a passive reflector. An operational communication link (working for 4–10 hours a day) between Hawaii and Washington DC was available during 1959–1963. Subsequently, by 1964, microwave communication was discovered. The first man made communications satellite project SCORE was launched during December 1958 and the life of the satellite was 12 days. During the period 1962–1964, experimental programmes were undertaken for medium-altitude Telstar and Relay satellites as well as the synchronous-altitude Syncom satellites. These experimentations finally lead to the beginning of operational satellite communications during 1965.[49]

Around the same time, the world's first satellite communications ship, *USNS Kingsport* (T-AG-164) was completed, and formally accepted from the Bureau of Ships by the Military Sea Transportation Service. Complex equipment for tracking, sending messages and commands, as well as receiving data from communication satellites were operated by the US Naval Research and Development Satellite Communications Group, assigned to KINGSPORT.

In reality, this ship was initially built as *SS Kingsport Victory*, a cargo ship that served during the Second World War. In 1961, the ship was converted into the first satellite communications ship, was renamed *Kingsport*, and classified as AG-164 and operationalized as *USNS Kingsport*. In the 1960s, the navy experimented with the use of commercial satellites for its communications relay requirements under Project ADVENT. However, the project got cancelled owing to the intricacy of the spacecraft, and was substituted by the Initial Defence Communications Programme (IDCP) which provided the Pentagon with its first near-geosynchronous communications system. However, under the early phases of Project ADVENT, the navy equipped a ship to demonstrate advanced communications capabilities the *USNS Kingsport* (T-AG-164). This ship was furnished with: a shipboard communications terminal, advanced tracking and telemetry equipment, anti-roll stabilization tanks, and a 30-foot, gyro stabilized, computer-oriented, triaxial parabolic antenna housed in a 53-foot plastic air pressurized radome. The antenna assisted in the precision tracking of high altitude satellites. This system began operating in the Army Ground stations using NASA's Syncom satellites. Subsequently, the *USNS Kingsport* made its first transmission via satellite when Syncom II was launched into orbit in 1963.

This was followed by the first demonstration of two-way satellite communication: from an aircraft in flight to a ship underway. It took place between a Navy aircraft off the Virginian coast and the *USNS Kingsport* near Morocco. During 1964–65, this ship operated between Pearl Harbour and Guam in support of further communication experiments. It remained operational in the communications support role till 1965, and finally it got converted into a bathymetric and acoustic survey ship, supporting undersea surveillance[50].

In 1964, the US Navy had established the world's first operational ship-shore satellite communications system. The purpose behind this was to provide telecommunications support to the various US Navy ships deployed in various parts of the world (in the high seas) for the purposes of SIGINT gathering. This communications system was developed under the garb of technical research, and was named the 'Technical Research-Ship Special Communications System (TRSSCOM)'. This system was based on the Communications Moon Relay (CMR) concept. To get the equipment for TRSSCOM, the Naval Research Laboratory disestablished the Communications Moon Relay (CMR) link between Hawaii and Washington DC. CMR antennas were installed at Cheltenham, Maryland (for the Second and Sixth Fleets); Wahiawa, Hawaii (for the Third Fleet); and Okinawa (for the Seventh Fleet). This system went operational with the USS *Oxford* on 25 February 1964, and provided support to the intelligence collection missions of various ships. The TRSSCOM system got suspended in the fall of 1969 owing to some reasons including reliability. This brought to a close the first operational satellite communications programme in the US Navy.[51]

A major boost in the use of satellites for maritime communications took place when the International Maritime Organisation (IMO) decided to develop an international maritime satellite system during 1972. The IMO is a body under the United Nations which was established in 1948; the IMO Convention entered into force in 1958. This organization was established

> "to provide machinery for cooperation among Governments in the field of governmental regulation and practices relating to technical matters of all kinds affecting shipping engaged in international trade; to encourage and facilitate the general adoption of the highest practicable standards in matters concerning maritime safety, efficiency of navigation and prevention and control of marine pollution from ships"[52]

Naturally, the mandate of the IMO itself necessitated a system which would enable reliable and real-time communications systems.

Inmarsat

The IMO was keen to have a system which was better than terrestrial radio links. The aim was to have a system which could offer higher quality, fewer delays, more reliability, privacy, provisions for handling distress messages, as well as a higher data rate for communications between commercial ships and the international public communications networks. Various member states of the IMO agreed that a new organization the International Maritime Satellite Organisation (Inmarsat) should be formed to operate the system. During 1976, the Inmarsat Convention and Operating Agreements were opened for ratification, and the Inmarsat Convention entered into force in July 1979. Subsequently, the infrastructure as envisaged was developed in a phased manner over a period of time.[53] Initially, the Inmarsat was established as non-profit intergovernmental organisation.

However, owing to the lack of financial support from member states, this model was not sustainable. Finally, in 1998, an agreement was reached to modify INMARSAT's mission as an intergovernmental organization, to separate and privatize the organization's operational business, and public safety obligations attached to its sale.[54]In April 1999, INMARSAT was succeeded by the International Mobile Satellite Organization (IMSO) as an intergovernmental regulatory body for satellite communication, while INMARSAT's operational unit was separated, and became the UK-based company Inmarsat Ltd. The IMSO and the Inmarsat Ltd. signed an agreement imposing public safety obligations on the new company. Subsequently, in the private body, various business houses began making investments, and the company has been listed on the London exchange (2005 onwards).[55] The sales and marketing activities of the private venture are operated through five market-facing business units.[56]

- Inmarsat Maritime, focusing on worldwide commercial maritime opportunities.

- Inmarsat U.S. Government, focusing on US government opportunities, both military and civil.
- Inmarsat Global Government, focusing on worldwide (i.e. non-US) civil and military government opportunities.
- Inmarsat Enterprise, focusing on worldwide enterprise, energy, media and M2M opportunities.
- Inmarsat Aviation, focusing on in-flight voice, data, safety services and cabin connectivity, for both business and commercial air transport.

Presently, the fourth and fifth generation satellites of Inmarsat series are operational. Some of them have been launch after 2005, and some are post 2013. The entire network is able to provide almost global coverage. Inmarsat 5 (F4) is slotted for a 2017 launch.

COSPAS-SARSAT

Another agency to provide marine communication services is COSPAS-SARSAT. The INMARSAT offers two-way communication facilities while the COSPAS-SARSAT is limited to the reception of signals from emergency positions and places, with no facilities of two-way marine communications.

The International COSPAS-SARSAT Programme is a satellite-based search and rescue (SAR) distress alert detection and information distribution system. The system can detect and locate emergency beacons activated by aircraft, ships, and back country hikers in distress. This programme began as a joint effort of Canada, France, the USA, and the former Soviet Union (subsequently Russia) in 1979, and was formally constituted as an intergovernmental organisation in 1988. This system is known to rescue 5 persons on an average every day.

The System is composed of the following.

- distress beacons operating at 406 MHz.
- SAR payloads on satellites in low-altitude earth orbit and in geostationary orbit.
- ground receiving stations (LUTs) spread around the world.
- a network of Mission Control Centres (MCCs) to distribute distress alert and location information to SAR authorities, worldwide[57].

In fact, the internationally agreed upon safety procedure has been adopted by the IMO under the SOLAS (Safety of Life at Sea) Convention (Chapter IV) which is known as GMDSS (Global Maritime Distress Safety System). When a ship uses GMDSS, it sends a distress signal via a satellite or radio communication equipment. The GMDSS is also used as a medium for sending or receiving maritime safety information and as a general channel for communication. There are various elements of GMDSS, and the satellite based elements are INMARSAT, etc. Today, almost all ships are fitted with a satellite terminal for Ship Security Alerts System (SSAS) and for long range identification and tracking as per SOLAS requirements.

Various non-satellite based and satellite based elements of GMDSS have different working limitations, depending upon the service providers and capability of the equipment. Thus, a division of areas has been done for the elements as follows.

- AREA 1–20 to 30 nm from shore for VHF coast station.
- AREA 2–100 to 150 miles from land (excluding Area 1) from shore based MF coast station.
- AREA3: The area between roughly 76 north and 76 south, covered by a geostationary maritime communication satellite.
- AREA 4: The remaining sea area, including the North Pole. A ship must carry HF, MF, and VHF equipment while sailing in these areas[58].

Today, satellite based communication activities have come of age and various maritime platforms are benefiting majorly. Today's merchant ships with all modern amenities use satellite links to communicate throughout the world, in plain language, with affordable messaging, and reliable e-mail. Earlier, marine communication had several limitations and was restricted to safety messages and position reports, with periodic weather information. Also, the cost of communication was very high. However now, with the advent of the satellite era, there has been a sea change in communication facilities. Presently, communication facilities are available around the clock, and the shipping companies are able to communicate in a moving ship 24 by 7. Closer control, better monitoring, and greater efficiency from a more integrated ship-shore operation have been made possible owing to the satellite telephone in cost effective manner. Now it is possible to transmit/receive large amounts of video and voice data. The technical monitoring of various the subsystems of the mother ship has become possible. This is allowing the Captains of ships to get timely advice from headquarters, resulting in both increased safety as also the optimal utilization of resources leading to cost savings. Also, far better cargo planning is becoming possible.[59]

India and Marine Communication

It is not the purpose of this monograph to discuss the entire spectrum of global marine communications faculties. It is simply not possible to do so owing to the sheer volume of such resources, both in use and in the making. However, some interesting cases are discussed below to get a sense of the nature of investments being made by both middle and major powers. The maritime domain is vast which includes the Navies and Coast-Guards of many countries as well as merchant shipping, ports, and various other facilities. Some aspects with regard to the maritime domain and the associated satellite communication facilities are discussed below.

India has a large coastline of 7,517 km to monitor. The challenges are many ranging from violent cryonic storms to the ingress of terrorists. India is required to monitor drug smuggling as also the smuggling of arms and ammunition. Issues related to counterfeit currency and the refugee flows from Bangladesh and Sri Lanka also pose various security challenges. India has one of the biggest Navies in the region. Ranging from merchant ships to energy tankers, there is a significant amount of traffic which Indian ports are required to handle. Naturally, communication is the key for various on-shore and off-shore activities. Understanding this, India launch edits first ever expulsive military satellite for the Indian Navy during 2013. It was thought that such a satellite may enable the Indian Navy to acquire blue water capabilities, and reduce its dependence on foreign satellites such as Inmarsat.

On 30 August 2013, India's GSAT-7 (Rukmini) communications satellite was successfully launched, and is presently fully operational. This satellite has been designed and developed by the Indian Space Research Organisation (ISRO), with the seven years of designed life. It has UHF, S-band, C-band, and Ku-band relay capacity. Its Ku-band capacity provides a high-density data transmission facility, both for voice and video. This satellite has been provided with additional power to communicate with smaller and mobile (not necessarily land-based) terminals. The Indian Navy has a long history of investments in technology. Over the years, the Indian Navy has made a significant contribution to India's security architecture. It has also contributed to peace building. It did a commendable job during the 2005 Asian tsunami relief effort as also in various anti-piracy operations. It is obvious that this technology-savvy service demands a dedicated and secure communications system for its activities.

GSAT-7 satellites have various utilities which provide the Indian Navy with an approximately 3,500- to 4,000-kilometer footprint over the Indian Ocean region.GSAT-7 also enables real-time networking of all its operational assets, both in the water and on the land. It also helps the Navy to operate in a network-centric atmosphere. The Indian peninsula is an extremely tricky region for operations because of its geographic location. One of the deadliest terrorist operations on Indian soil the infamous 2008 Mumbai attack was launched using the Arabian Sea route.

The operational performance of Rukmini has been very satisfactory. It is known to provide networking capabilities with various Indian Naval assets. During Theatre-level Readiness and Operational Exercise (TROPEX) in the Bay of Bengal in 2014, Rukmini was able to network about 60 ships and 75 aircraft seamlessly. With the presence of this satellite, India is in a position to cover activities up to the Malacca Straits in the east and the Strait of Hormuz to the west. This satellite also assisted Indian Naval Units (for the purposes of communication) involved in the search operation of the missing Boeing 777-200 aircraft the infamous disappearance on 8 March 2014 of Malaysia Airlines Flight 370.[60]

The US Navy and Marine Communications

The US Navy is the biggest navy in the world, and has a long history. It has ten aircraft carriers and around 3700 aircraft, more than 50 nuclear attack submarines, and various other assets. It would be of interest to know about the programmes and inventory of the US Navy in respect of its satellite communications. Some important aspects of the investments made by the US Navy towards developing/owning some (not all) satellite based communication assets are presented below.

In the space programme established by the US Department of Defence (DoD), the US Navy plays an important role. Since the Navy has unique needs for communication at sea, the Navy was always in the forefront in the space arena. It has a rich and successful heritage in space which began in 1955 with the first US satellite programme which was named Vanguard. In 1957, it was the US Navy which constructed the first complete satellite-launching facility at Cape Canaveral, Florida where Vanguard I the world's longest orbiting satellite was launched in 1958. The US Navy is responsible for DoD UHF narrowband satellite communications (SATCOM). The UHF spectrum is the military's communications workhorse for disadvantaged, tactical war-fighters on-the-move, as it is the most effective SATCOM frequency for penetrating jungle foliage, inclement weather, and urban terrain.[61]

Around the mid-1970s, the US Navy started developing a satellite communication system called FLTSATCOM (also FLTSAT). Altogether, eight satellites were launched from 1978 to 1989 into geostationary orbit. The system became operational in 1981. It was used for UHF radio communications between ships, submarines, airplanes, and ground stations of the US Navy. Most of the transponders on these satellites were simple repeaters, with no authentication or control over what they retransmitted,[62] The performance of all the satellites was not satisfactory, and there were some launching difficulties too. Eventually, by the late 1990s, FLTSATCOM satellites were gradually replaced by UFO satellites.[72]

The US Navy has established a separate Navy Communications Satellite Programme (PWW 146). The entire programme is known as the Navy's Programme Executive Office for Space Systems (PEO Space Systems). It is the sole executive agency to develop, deploy, sustain, provide engineering support, and influence space-based capabilities for naval, joint, and allied operations. This includes advanced UHF narrow band communication satellites and associated ground systems; intelligence, surveillance and reconnaissance systems; weather systems; and space related science and technology efforts. PMW 146 reports to the Navy's PEO Space Systems on the Navy's Mobile User Objective System (MUOS) and Ultra-High Frequency (UHF) Follow-On (UFO) programmes.[63] The Mobile User Objective System (MUOS) was developed as a replacement to the UFO constellation. It provides global SATCOM narrowband (64kpbs and below) connectivity for voice, video, and data for US and Allied services.

The MUOS is an Internet Protocol-based system designed to provide improved communication capabilities to users around the world, with greater than 10 times the bandwidth capacity compared with the current ultra-high frequency (UHF) constellation. The MUOS Wide band Code Division Multiple Access (WCDMA) system provides significantly increased capacity and coverage, superior voice quality, and Internet-like capabilities. These enable war-fighters more flexibility for better communication. The MUOS is a system consisting of five satellites, and four ground stations across the globe. This system first demonstrated WCDMA voice and data calls via the Army's Manpack radios in 2013; it has since conducted testing and training with each of the various service branches. The MUOS constellation and associated network will extend narrowband communications availability well past 2025. The MUOS is a five-satellite constellation, and US Navy's fifth MUOS satellite got launched on 24 June 2016.[64] The PEO Space Systems has developed a 2015–2021 Strategic Plan which identifies future challenges and measures proposed to meet them.

The table below presents a bird's-eye view about the investment made with regard to communication satellites from the US Navy's point of view. The table indicates that, currently, there are seven operational satellites. In the future, the US Navy will undoubtedly develop more such systems.

Table 4

Satellite	First launch Year	Last launch Year	No of satellites	Currently operational
FLTSATCOM (Fleet Satellite Communications System)	1978	1989	8	0

Leasat	1984	1990	5	0
LES (Lincoln Experimental Satellite)	1965	1976	9	0
MACSAT (Multiple Access Communications satellite)	1990	1990	2	0
MUOS (Mobile User Objective System)	2012	2016	5	5
SECS (Special Experimental Communication System),	1990	1990	1	0
SLDCOM (Satellite Launch Dispenser Communications)	1990	1996	4	0
Tactical Communications satellite	1969	2011	2	1
UFO (Ultra High Frequency Follow On)	1993	2003	11	1
		Total	47	7

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Chapter 3

Different Activities in the Maritime Domain

This chapter focuses on supplementary global efforts being made to increase the usage of space technologies in the maritime domain. While many of such structured efforts have already been discussed above, this chapter scans what is happening presently, and what the proposed/ future plans are. Some unconventional exertions that are being made in the seas like sea launch are discussed here. Also discussed are some private efforts being made by various industrial houses.

Space Based Maritime Domain Awareness[1]

The International Maritime Organization defines Maritime Domain Awareness (MDA) as 'the effective understanding of anything associated with the maritime domain that could impact security, safety, the economy and the environment.'[2]It is about generating actionable intelligence that can serve as the foundation for successful counter-terrorist and Maritime Law enforcement operations. Two key components of MDA are Information and Intelligence. The context for MDA is that there are always threats from emerging sets of diverse, network connected adversaries, and their nature could vary from conventional to nuclear, depending on the competence of the threat poser. Also, there are non-conventional threats from terrorists, the proliferation of illegal weapons, organized crime affiliates, drug traffickers, and cyber outlaws.

MDA investments are undertaken basically to generate actionable intelligence which is extremely important to effectively address the above mentioned threats. In addition, MDA is also a key enabler for other critical security measures such as Proliferation Security Initiative (PSI), Container Security Initiative (CSI), UN Sanctions enforcement, Counter Narcotics Operations, and Anti-Piracy Patrols. Any effective MDA allows intensified surveillance and tracking, undertakes Expanded Maritime Intercept Operations (E-MIO), and the application of lethal and non-lethal force, if necessary.

The gathering of intelligence in real time, and ensuring that it reaches the correct destination also in real-time is essentially possible only because of the presence of satellites. Naturally, in present times, the best option is to develop a space-based MDA architecture. Such architecture relies on a layered set of terrestrial, air-borne, and space-borne systems. Other than navigational and communications assistance from satellites, the MDA gathers a major part of its information from surveillance satellites, some of which are launched with specific sensors pre-designed for MDA purposes. Apart from space-based Radar imaging and Surveillance satellites, there are satellites which provide inputs on ocean temperatures, about the status of the sea ice; there are also systems facilitating automatic identification. Space based systems also complement traditional surveillance operations, and offer inputs with increased accuracy and precision. Over a period of time, space systems significantly reduce the cost of operations.

Some important developments of Space based MDA systems have been the integration of Space software with Automatic Identification Systems (AIS) and Synthetic Aperture Radar (SAR) Imaging Satellites. The AIS was developed in the 1990s as a high intensity, short-range identification and tracking network; however, at that point in time, the usefulness of space technologies for ASI was not envisaged. Since 2004, the IMO is projecting the need for AIS transponders aboard certain vessels. For example, it is compulsory for international voyaging ships with a gross tonnage of 300 or more, and all passenger ships. This allows the knowledge of information about ship position, course, rate of turn, and navigational status at regular intervals. Much of this information originates from the Ship's navigational sensors usually its Global Navigation Satellite System (GNSS: for example, GPS, GLONASS) receivers and the gyrocompass. One of the broader aims in receiving such information in real time is to ensure the avoidance of collision between two platforms on the high seas or near the coast. The idea behind a Satellite Automatic Identification System emerged after the terror attack on the World Trade center on 11 September 2001 (9/11). The basic philosophy behind the ASI is collision avoidance between vessels. Various AIS transceivers are very reliable; however, they have limitations owing to the VHF range, so the accuracy gets limited to about 10–20 nautical miles. However, the view from space is different for example the low earth orbiting satellite has a field of view over 3000 nm. These days, the S-AIS (S stands for satellite) technology has changed the way the Maritime Domain gets monitored. Some states are found making good investments in satellite systems which are useful for MDA.

It is important to note that there are some limitations with S-AIS too. These receivers can often end up viewing many AIS cells simultaneously (owing to satellite's large reception footprint), resulting in messages colliding with other messages, thus making it difficult to properly receive and decode them. In order to avoid such message collisions, currently efforts are being made to develop techniques for more clarity. The S-AIS became active in 2008. In 2007, the US tested S-AIS tracking with the TacSat-2 satellite; however, the received signals were corrupted since the simultaneous receipt of many colliding signals took place. In 2008, ORBCOMM launched AIS enabled satellites to demonstrate the ability to collect AIS messages from space. Subsequently, more satellites have been launched, mainly in coordination with the US Coast Guard. Also, a few satellites have also been launched by SpaceQuest (AprizeSat-3 and AprizeSat), Canada (exact Earth) and

Norway (AISSat-1, a six kg nano-sat) with AIS receivers. The Indian agency ISRO has launched (April 2011) the Resourcesat-2 containing an S-AIS payload for monitoring maritime traffic in the Indian Ocean Search & Rescue (SAR) zone.

The major contribution to developing a reliable and longer footprint proving S-AIS has come from ORBCOMM (July 2014) when they launched the first 6 OG2 satellites, with each OG2 satellite carrying an AIS receiver payload. This was followed by the eleven additional AIS-enabled OG2 satellites in December 2015. In comparison with the OG1 satellites which are presently much in use ORBCOMM's OG2 satellites are designed for faster message delivery, bigger message sizes, and improved coverage at higher latitudes.

During 2008, a 6.5 kg nano satellite called NTS (Nano satellite Tracking of Ships) was launched with the challenging and pioneering mission of demonstrating that AIS signals transmitted by maritime vessels could be received from space. The NTS programme was a low cost satellite programme, designed to provide rapid risk mitigation to assist in the development of a future constellation of spacecraft that could provide operational AIS from space (S-AIS) reception and dissemination. This programme has led to the development of an operational microsatellite called the Maritime Monitoring and Messaging Microsatellite, or M3MSat. This satellite for a Canadian Space Agency was launched from an Indian launcher in June 2016. The M3MSat mission is meant for improving ship detection and marine traffic management in Canadian waters by testing new technologies, including an innovative antenna meant for the improved identification of ships, and better resolution between conflicting (identification) signals in regions with high maritime traffic.[3]

The AlS has been assisting maritime agencies for some time in various fields. Globally, maritime authorities are using Satellite AIS technology to help them achieve better MDA (maritime domain awareness). Increase in piracy and terrorism related incidents are ever-evolving threats, and all maritime powers are much concerned about them. Apart from these threats, the smuggling of contraband and arms by sea has virtually become an industry in itself, as Latin American drug cartels have turned the Caribbean waters into easy streets for trafficking. Agencies have received some limited success in curbing these activities, but this requires continuous attention to such activities happening in such regions.

Also, presently conflict continues to shroud maritime activity in the South China Seas since China is at loggerheads with many states in the region. The judgment by an international tribunal in The Hague has overwhelmingly opposed Chinese claims in the region (verdict in favour of the Philippines, July 2016). However, China has rejected this judgement, and a political impasse is expected to continue in the region. To tackle all such issues fully, or even partially, S-AIS technology is of great assistance. Broadly, it is assisting maritime security forces to get to know instances of the purposeful violation of maritime boundaries as also provide help in demarcating SEZs, etc.

As mentioned earlier, the AIS was developed as a tool for collision avoidance. However, there are various additional usages of the AIS as well. States are using the AIS for tracking and monitoring the activities of their national fishing fleets. AIS are able to provide additional traffic information in the region and around, as also specific information about each vessel. This allows better fleet monitoring, traffic management and control. It also helps navigation with the help of a special application called AIS Aids to Navigation (A to N); this also helps while undertaking search and rescue operations. Apart from the collision avoidance, one of the most important draw-on of the AIS is ensuring maritime security. When used innovatively, AIS data can help authorities to identify a potential threat. Eventually, this data helps in improving maritime domain awareness leading to heightened security and control. Additionally, the AIS can be applied to freshwater river systems and lakes, and can assist in identifying any possible threat from these regions too.

The major requirement of any form of maritime intelligence is that it should be available during day and night, and even during bad weather. Due to this, satellite systems are also required to be capable of providing information under such conductions. Synthetic Aperture Radar (SAR) imaging sensors are the answer to these challenges. SAR based satellites are independent of weather conditions, and provide rapid, wide area coverage for vessel detection, and makes routine access to remote areas.

Today, several countries are developing space capabilities to enhance MDA. In order to improve the S-AIS system the following five factors are being taken into consideration

- Continuous Global Coverage and superior detection rates
- Real Time downlinks
- Ability to detect all AIS broadcasters
- Ability to handle rapidly expanding ASM
- Ability to adapt to evolving uses of the maritime VHF Spectrum

Due to a major increase in traffic in the seas, the development of additional ports, and challenges such as maritime terrorism, it is becoming important to invest more in space based MDA systems. In particular, the development in nano-satellites and cube-satellites areas seem better for the development of such systems. In general, space based MDA requires a large constellation of LEO satellites distributed in orbits that ensure coverage of the entire globe, superior detection algorithms, as well as architecture that provides real time delivery of the collected AIS information. It may not be possible for a single state to develop all the resources required for this purpose, and this necessitates global cooperation in this field. The recognition of this fact has given rise to the concept of what is now called Collaboration in Space for International Global Maritime Awareness (C-SIGMA) which allows states to share their space resources and unclassified data on maritime operations and conditions.

The Anti-ship Ballistic Missile System[4]

An anti-ship ballistic missile (ASBM) is a missile system designed to attack a warship at sea. This category of missile is a low trajectory missile, and is capable of changing direction while in flight. This missile carries a conventional warhead, and can be considered more as an impact weapon (kinetic). Such missiles are required to hit the target precisely. They have a high performance terminal guidance system. Presently, China has developed DF-21D, which belongs to ASBM category. This system is considered as a part of China's complex narrative of developing capabilities to defend their interests around the first island chain while raising the costs for any modern military to intervene in Chinese core territorial interests. The weapon is an important component of Beijing's 'counter-intervention' (Anti-Access/Area-Denial) strategy. Probably around 2014 China successfully conducted the Mach 10 test of a hypersonic glide vehicle, and some experts are of the opinion that this test could lead to the development of a second-generation ASBM.

A major requirement for the operation of China's ASBM system is the identification, location, and tracking of an Aircraft Carrier Group (ACG) in the western Pacific Ocean well before it reaches within striking distance of the Chinese mainland.

The ASBM has several high technology components such as the maneuverable missile with autonomous terminal guidance capability, and an Over the Horizon (OTH) radar, etc. In addition, the system requires assistance to locate the ACG well before it comes within the range of the OTH radar. This demands the need for an advanced space reconnaissance and broad area surveillance capability. The assistance from satellites would be necessary for the purposes of identification, location, and tracking function for the ASBM mission. After the initial inputs are received via satellite network as the threat starts coming nearer, additional help would be available in the form of OTH radar. The radar would provide the vital C4ISR inputs necessary for a successful missile strike on a moving ACG.

For space reconnaissance and area surveillance purposes, China has put in place a constellation of dedicated Yaogan Satellites. The Yaogan Weixing series consists of 'Remote/Reconnaissance Sensing Satellite' which has been launched by Chinese agencies almost for the last one decade. Chinese authorities label these satellites as systems meant for conducting land surveys, crop yield assessments, and disaster assessments. However, they are expected to be military purpose satellites. The first satellite in this series, Yaogan-1, was launched on 27 April 2006 (China's first SAR-equipped satellite). The first eight satellites got launched during the first three years. Since 2010, there has been a significant increase in the launching of the satellites in this series and, till date, 31 satellites have been launched in addition to the satellites launched till 2009. In recent times, the three satellites launched in this series during 2015 are with more advanced sensors, and are meant for continuing the process of data gathering. Yaogan-30 probably an electro-optical observation satellite was launched on 15 May 2016.

The Yaogan series satellites could be grouped based on their various orbital and technical characteristics. It is expected that specific groupings of a few satellites together could be undertaking functions like identifying, locating, and tracking the ACG. Some satellites are ELINT capable, and are expected to undertake broad area surveillance over the oceans (possibly scan a 3500 sq km area) and provide the first course fix for identifying and locating an ACG in the Pacific Ocean. Satellites with SAR sensors would provide all weather as well as day and night imaging capabilities. Other satellites with high resolution optical imaging capability would complement various functions. China's investment in the ASBM is expected to force major powers like the USA to develop similar (but different) systems, and to develop counter-measures to nullify the relevance of this system. It is difficult to forecast exactly what type of system would evolve in the future. However, in all probability, some systems would continue to depend on satellite systems for undertaking various functions.

Sea Launch

The sea is found as a convenient terrain for rocket launches. Since the late 1990s, a few satellites have been launched by undertaking sea launches. Scientists have found such launches (from mobile maritime launch platforms) as one of the attractive ways to launch geostationary earth orbit (GEO) satellites. A sea-based launch system allows a launch from the optimum position on the earth's surface for geostationary satellites. This allows increased payload capacity and reduced per-kg launch costs when compared to conventional ground based launches. Also, there is a possibility for an extended satellite life owing to a lower propellant expenditure upon the final GEO injection.[5] This is because any rocket launched from the equator benefits from the earth's rotation, providing the satellite with more momentum to help it reach orbit faster, using less fuel. As a result, a rocket can carry heavier, more powerful satellites that will stay in orbit longer that is, past the typical 15-year lifespan[6].

A consortium for Sea Launch got established in 1995, and the first rocket launch took place in 1999. This consortium was a group of four companies from Norway, Russia, Ukraine, and the USA, and was managed by Boeing with participation from the other shareholders. The facility was operated by the Russians, and Zenit 3SL rockets were used for undertaking commercial launches from mobile sea platforms. Till 2013, Sea Launch had assembled and launched thirty one rockets, with three failures and one partial failure.[7]

Unfortunately, due to financial and geopolitical complications, in 2014, Sea Launch had to stop operations. As of 27 September 2016, the Sea Launch SA a major share holding company and S7 Group (S7 Group is the largest private aviation holding company in Russia) has reached an agreement regarding Sea Launch assets purchase.[8] However, more formalities are required to be undertaken, and it could take some more time to research the launches. Presently, for almost two decades, only one agency has been involved in undertaking such launches. However, it would be of interest to watch if more players enter this filed.

There are a few offensive systems which are fired from the platforms in the sea, and they require significant help from the satellites. One such system is the submarine-launched ballistic missile (SLMB). There are also cases when a sea based platform has been used to attack a satellite in the space. On 21 February 2008, the USA has demonstrated their ASAT (anti-satellite) capabilities by destroying their own non-responsive satellite at an altitude of 240 km. This kill was achieved by using their sea-based Aegis missile defence interceptors.

Participation in Research and Development

The development of space technologies from the perspective of maritime requirements are increasingly found getting more focus. Presently, there are various projects under progress globally relating to the use of space technologies in the maritime domain. While it is not the purpose of this monograph to discuss all of them some have already been discussed it is important to mention that both state agencies as well as private players are involved in such developments. The USA is involved in engaging the private sector significantly. In some cases, the 'core' support has been provided by the agencies like NASA, either in the form of technology transfer or contracts, and the private sector is expected to deliver the product. Presently, some private agencies are also showing interest in conducting research, development, and innovation in the maritime space sector.

The EU Strategy for Marine and Maritime Research' (2008) underpins the EU Integrated Maritime Policy. The European Commission has a project called the Ocean of Tomorrow (2010) which has undertaken research on various aspects which could assist the various forces involved in meeting challenges in ocean management. The European Commission is also funding a programme called Horizon 2020 (2014–2020).[9] Under this programme, an attempt has been made to ascertain a system which could resolve the challenge of simultaneous operations of various platforms in the high seas and also along the shores. The main focus behind developing any such system is to ensure improved health and safety in multi-use marine platforms. Also, the mandate involves that the options offered should be economically feasible and environmentally sustainable. It is obvious that most of the options identified would have a satellite element in some form or other.

There are some requirements which emerge suddenly while operating in the high seas, or during natural disasters, or also otherwise. At times, there are specific requirements for ships or other platforms operating in the seas. These require more precise and timely data than that made routinely available by the satellite systems. For example, there could be situations with the oil, gas, and mining industries operating in the high seas requiring specific data. The need for such data could range from infrastructure planning divisions, stack measuring, the gathering of business intelligence on competitors, to managing fires or other security incidents. To address situations like these, Airbus Defence and Space have programmes like One Tasking.[10] It offers customers an intuitive and cost-effective way to rapidly task a satellite for providing 24/7/365 access to Airbus Defence and Space's high-resolution and wide-swath satellite sensors. The company has a team of dedicated in-house experts to ensure that the requested area is captured on time, and in line with the customer's requirements.

SRI International (SRI) is an American non-profit research institute. This organization was founded as the Stanford Research Institute in 1946, but was formally separated from Stanford University in 1970. It came to be known as SRI International in 1977. The institute focuses on creating world-changing solutions to make people safer, healthier, and more productive. This organization has established a Space and Marine technology Laboratory. This unit provides innovative engineering and operations solutions for use in the extreme conditions of space and marine environments. Their main clientele is various US defense and intelligence community organizations as well as civil space organizations and commercial entities.

Their Marine and Space Sensing group develops marine instrumentation and miniature instruments suitable for space. Projects undertaken by this group involve design, development, experiments, deployment, and the operation of advanced sensors and their systems. The organization checks their sensors under different extreme environments and undertakes modifications if required. This to the development of following projects:

- Sensing solutions and technology innovations for the oil gas industry.
- Marine system-sensing solutions for the U.S. Navy and other defence organizations.
- Contributions to monitoring and mitigating ocean acidification and global climate change.
- Advanced sensor solutions for environmental science and monitoring.

- Microsystems development for space applications and the use of small satellites for marine science.

The organization is well equipped to provide consultancy on the following:

- High-performance marine chemical sensors, for use in unattended pervasive networks. In situ mass spectrometer (MS) systems for aquatic and other harsh environments, novel power sources, and micro-fabrication of MS components and systems.
- Optically based instruments and systems for real-time, in situ monitoring of oceanographic and environmental processes. Expertise ranges from optical and electronic design to image processing and chemical oceanography.
- Software and hardware design, development, and field deployment for marine and space operations[11].

Oil Spills

On many occasions, the marine atmosphere gets contaminated owing to human activities. In particular, some incidences of oil spill have known to cause damage over a specific region. An oil spill is 'an accidental release of oil into the body of water, as from a tanker, offshore drilling rig, or underwater pipeline, often presenting a hazard to marine life and the environment.'[12].

If oil spills are to be identified immediately after the incident, then there is a need to monitor enormous areas of the location of spill and adjoining regions 24 by 7. At times, this becomes difficult because of the absence of the correct type of satellite over the region. It has been noticed that, many times, the best view of oil spill comes from up in space. Earth observation satellites such as the TerraSAR-X or Radarsat-2 ire pulses from their radars towards the sea. These pulses are reflected back up to the satellite as echoes. The amount of echo that returns tells a lot about the ocean surface.[13] The movement of oil after the leak depends on sea currents, sea surface height, sea surface temperature, tides, etc. and meteorological satellites assist in knowing more about it. Essentially, inputs from the remote sensing and meteorological satellites assist in identifying the magnitude of an oil slick on the ocean surface. Further, based on modelling results (a numerical model for forecasting), a specific target area gets finalized for undertaking specific aerial observations.

The Deepwater Horizon oil spill of 2010 (or the Gulf of Mexico oil spill of 2010) is the largest marine oil spill in recent history. On 20 April 2010, an accidental explosion happened in the Deepwater Horizon oil rig, located in the Gulf of Mexico, around 65 km off the coast of Louisiana. It was estimated that around 4,900,000 barrels of oil had leaked into the gulf. NASA provided significant assistance to study the spread and impact of this oil spill. Moreover, for many months after the spill, images from space continued to provide useful information. For example, images acquired on 24 May 2010 by the Multi-angle Imaging Spectro Radiometer (MISR) instrument aboard NASA's Terra spacecraft provided information with regard to the encroachment of oil from the Deepwater Horizon rig into Louisiana's wildlife habitats. The source of the spill was also visible in the images. Various studies were carried out during the spill using satellite derived information. For example, the Experimental Marine Pollution Surveillance Report (EMPSR) was produced by trained satellite analysts in the Satellite Analysis Branch (SAB), within the NOAA (National Oceanic and Atmospheric Administration) Office of Satellite Data Processing and Distribution. These analysts used data from numerous imagery sources, including from the Synthetic Aperture Radar (SAR) as well as high resolution visible imagery, along with various ancillary data sources.[14] This particular case was also a challenge for satellite imagery analyst. Indeed, certain limitations in the satellite imagery became evident during the entire phase of cleaning operations.

Ocean Topography Analysis

Most of the world's deep oceans remain poorly charted because of the limitations of technology in providing the small details. However, space technology plays a major role in identifying the hidden secrets of the oceans. Satellites have assisted in discovering thousands of new seamounts. Ancient rifts hiding under seafloor sediments along with thousands of uncharted underwater mountains have been revealed by satellite images. All this information has been presented in the October 2014 issue of the *Science* magazine.

The European Space Agency's CryoSat-2 and NASA's Jason-1 both oceanography satellites specifically designed to track sea level changes have provided significant amounts of very useful new information. For example, knowledge about the location of seamounts helps in fisheries management and conservation. Marine wildlife normally congregates around such topographic features. Also, information regarding the roughness of the seafloor helps in better understanding the movement of sea currents.

Based on satellite derived inputs, the mapping of the world's oceans has been carried out, including the Gulf of Mexico, the South China Sea, and the South Atlantic. There is no doubt that what has been mapped (ocean floor topography) with the help of satellites would have required at least 200 years to be completed if mapped by ships. The new information is expected to help geologists study undersea mineral resources and increase knowledge about the behaviour of deep-sea currents flow across the seafloor. The CryoSat-2 satellite takes sea surface readings from its 400km high orbit, which helps reefing gravity maps. However, the resolution of the satellite images is not capable of identifying very small objects on the sea floor (such as any fallen aircraft, or a boat drowned in the sea owing to an accident).

Currently, the following information based on studies carried out by satellite data is available.

- Several thousand seamounts, roughly 1 to 2 km high, previously unknown.
- Subsea ridges jutting at a southward angle from South America and Africa—the latter some 800 km long and 100 km wide—once joined, but severed more than 83 million years ago by a spreading South Atlantic.
- An 'extinct' ocean ridge stretching under the Gulf of Mexico, where the ocean crust spread apart when it was tectonically active[15].

Today, satellites are in a position to increase knowledge about various happenings over and in the sea. Interestingly, there are some challenges which nation states would be required to address owing to the transparent seas. In particular, it is feared that adversaries would be able to identify the movements of big underwater vehicles and submarines. Detecting submarines via satellite is a form of Non-Acoustic Anti-Submarine Warfare (NAASW). Various space based sensors could be put in use in NAASW. Satellite technology can assist in checking the subtle undersea disturbances caused by submarines, small changes in wave patterns on or beneath the sea surface, or minor variations in ocean temperatures.

The Milky Sea

Although human beings have conquered the seas for many centuries, sea-travel still remains an enigma. Even today, sailors encounter various mysterious events for which, many a time, no logical explanations are available. However, owing to better scientific understanding, and because of the boom in increasing observation and monitoring capabilities, some mysteries are getting resolved. Scientists and sailors are finding some answers owing to space technologies. One such mystery which got resolved (at least partially) a few years ago was about the so called Milky Sea.

For hundreds of years, sailors have told tales of a mysterious event encountered by them far out in the open ocean. They have witnessed miles and miles of pale, milky, glowing waters, sometimes stretching as far as the eye can see. There have been various reports about the appearance of Milky Seas in the Indian Ocean, where there are many trade routes, and near Indonesia. For many years, no one took the sailors seriously and the scientific community largely ignored them. Then, in 2005, a group of scientists led by Steven Miller (of the Naval Research Laboratory in Monterey, California) decided to take a closer look at the issue. His group began their research by using archival satellite data. Various relevant satellite images were studied, and raw data was analysed from the region where various incidences were reported. In particular, an incident (in 1995)reported by a British merchant vessel, the *S.S. Lima* in the north-western Indian Ocean was studied minutely.

Archival data from the US Defence Meteorological Satellite Programme was used. A study was carried out over the area identified by the *S.S. Lima*. The study discovered a shining and huge bright area off the horn of Africa (around 15,400 sq km in area). This was visible for three nights during late January. The previous excursion from the same region had reported the presence of bioluminescent bacteria, which were found to be living in association with an algal bloom. Hence, it was concluded that the bioluminescence produced by bacteria colonizing some kind of organic material present in the water were providing the glow.[16] However, many more such cases need to be studied Recent cases (if any) can now be studied more closely mainly because of the quality of satellite sensors have improved significantly, and the more recently launched satellites could provide better information.

Space Weather and SSA

Presently, when dedicated space based systems are being developed for maritime purposes, it is important for the agencies involved in managing space related assets to get associated with sectors which may not have direct and visible relevance from the maritime utility point of view. However, since the 'stature' of space technology in the maritime domain is expected to grow, it important for the agencies to develop themselves beyond the 'user' mode. It is important to develop understanding about ground infrastructure, including various satellite signal reception facilities, radars, as well as imagery interpretation formats. The methodologies used for the interpretation of satellite imagery over oceanic regions are different from those used on land. Also, there is need to invest in research on sensors which could provide more benefits from the maritime perspective.

Space weather[17] has a strong impact on environmental satellites, which are crucial modules of the Global Observing System (GOS). Also, vagaries in space weather impacts radio-communication, and solar activity impacts communication and navigational satellites. For the conduct of smooth operations at sea, the main source of observations in support of weather forecasting is obtained from the environmental satellites. However, there is a possibility of the in-orbit failure of sub-system satellites owing to space weather. Such failures could have limited or major impacts on maritime operations, depending on the nature of damage. Hence, there is a need to keep a close eye on space weather for the purposes of effective planning. As and when a sea launch becomes a routine activity, there will be an additional requirement of knowing more not only about atmospheric weather conditions but also about space weather.

Along with space weather, it is also important to keep a track of moving space debris for the conduct of any activity in space. Space Situational Awareness (SSA) is a prerequisite for space debris assessment. This is only possible if the required architecture for space surveillance is available. Presently, the US military operates the most expansive network of space surveillance sensors in the world.[18] Such a network is made up of satellites, telescopes, and ground based radar. Since the existing US military owned SSA system is incapable of tracking all the debris orbiting the Earth, there is a need to strengthen or augment the system. In future, there is a possibility that ship based observational platforms could be put in place for these purposes. Such SSA networks could also be utilised for maintaining records of all the objects launched by various organisations, and accounting for them. The infrastructure created for the purposes of space weather could also assist in this.

Notes

1 Various website have been referred to for information in this section. Some of these are http://www.coecsw.org/fileadmin/content_uploads/projects/20150423_MSA_Study_Paper_-_Final.pdf; https://en.wikipedia.org/wiki/Automatic_identification_system; http://www.globalsecurity.org/intell/systems/mda.htm, ;http://www.navalreview.ca/wp-content/;

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https://swfound.org/; http://geospatialworld.net/Magazine/MArticleView.aspx?aid=30388; accessed 15 October 2016

2 Refer for more discussion http://www.dtic.mil/dtic/tr/fulltext/u2/a463128.pdf, accessed 04 January 2017

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15 This section is based on inputs from http://news.nationalgeographic.com/news/2014/10/141002-ocean-map-satellite-gravity-science/, and http://www.bbc.com/news/science-environment-29465446, accessed 24 October 2016; see also, David T. Sandwell et al., 'New global marine gravity model from CryoSat-2 and Jason-1 reveals buried tectonic structure', *Science*, 3 October 2014: Vol. 346, Issue 6205, pp. 65–67

16 http://science.howstuffworks.com/environmental/earth/oceanography/milky-sea.htm, and http://www.atlasobscura.com/places/milky-seas and http://www.livescience.com/9387-mystery-ocean-glow-confirmed-satellite-photos.html, accessed 22 October 2016

17 Space Weather is used to designate processes occurring on the Sun, in the magnetosphere, ionosphere and thermosphere, which have the potential to affect the near-Earth environment. Refer: 'The Potential Role of WMO in Space Weather', WMO/TD-No. 1482, World Meteorological Organisation Publication, 2009

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Chapter 4

Conclusion

Various activities in the oceans and through the oceans have been taking place for many centuries. The advent of space technologies in the maritime domain is only five/six decades old. However, for the maritime domain, satellite technologies have arrived as a force multiplier. The juxtaposition of space technologies on various activities associated in the maritime sphere have brought in a revolution in maritime affairs. The intelligent usage of available satellite technology is being made increasingly in various fields of maritime activity. New ideas are being generated to design new satellites (or use existing ones more innovatively) which could provide solutions to some of the challenges directly related to various aspects of maritime security. A range of technology solutions are being offered or being researched in this regard.

Over the years, satellite technologies have evolved in the field of meteorology/oceanography, reconnaissance, communications, and navigation. Interestingly, these are the technologies which actually have a great ability to assist various activities involved in the maritime domain. All these technologies have direct relevance for various activities undertaken in the maritime domain.

In the 21st century, the security threat matrix involves both conventional and asymmetric challenges to national security. The maritime domain has been one of the principal battlefields for many centuries. The sea is no longer a benign medium, and toady it houses a range of military relevance hardware ranging from small ships to aircraft carriers to nuclear submarines. Also, various asymmetrical threats like terrorism and piracy are challenging the security mechanism of the states. All this has made the global commons vulnerable. Safety and security are the two important aspects for any ship movement in the seas. It is very important to get correct and timely inputs with regard to these, and that is what space technologies do. Indeed, navigational challenges are being brilliantly addressed by the satellite based global navigational networks.

Presently, a few agencies are working on improving the quality of the sensors. More attention is being given to developing custom made sensors for specific purposes. Such next generation sensors such as those meant for ocean colour monitoring, measuring sea surface height and temperature, salinity judgement, etc. are being worked on. Also, attempts are being made to have a better understating of sea winds, water vapour, and gaseous concentration in the atmosphere and the oceanic region. Hence, in future, much help could be expected for the maritime domain from the next generation satellites.

This is becoming possible by developing various advanced applications to retrieve relevant inputs from the vast amount of satellite data. Presently, a wide range of public and private communication technologies and other utilities are being used. Satellites are the key instruments in this complex array of communication solution utilities used for running critical infrastructure industries, including maritime assets. The utility of using a small satellite for specific purposes is increasing rapidly. Small satellites are no longer seen only as instruments of experimentation by science and engineering students. Due to various reasons (including costs), small satellites like micro, nano, and cubsats are rapidly evolving and even entering the commercial and military realms. Presently, many of them are also being developed for specific maritime purposes.

However, it is important to appreciate that satellite technologies would not be able to give answers to all challenges in the maritime domain. In certain cases, satellite systems are themselves vulnerable for instance GPS signals could be deliberately jammed. Also, remote sensing applications have their limitations. Hence, it is important to find solutions to such challenges.

Presently, the global supply chain of mainly food and energy has significant maritime dependence. Also, the bulk of global commerce takes place via sea routes. Over the years, a significant amount of modernization has taken place in the maritime domain, and space technologies have played a significant role in this. It is but obvious that dependence on the 'eyes the sky' is likely to increase in the future.

Annexure 1

[Refer Chapter 2, Table No.1]

SEASAT: The SEASAT is an experimental US ocean surveillance satellite launched on 26 June 1978. It was the second satellite carrying synthetic aperture radar (SAR). It was the first designed for the remote sensing of the Earth's oceans. The mission was designed to demonstrate the feasibility of a global satellite monitoring of oceanographic phenomena, as well as to help determine the requirements for an operational ocean remote sensing satellite system. Its specific objectives were to collect data on sea surface winds, sea surface temperatures, wave heights, internal waves, atmospheric water, sea ice features, and ocean topography.

SMMR: The scanning multichannel microwave radiometer (SMMR) was a five-frequency microwave radiometer flown on the SEASAT and Nimbus 7 satellites. It measured dual-polarized microwave radiances, at 6.63, 10.69, 18.0, 21.0, and 37.0 GHz, from the Earth's atmosphere and surface. Its primary legacy has been the creation of areal sea-ice climatology for the Arctic and the Antarctic.

SSM/I: The special sensor microwave/imager (SSM/I) is a seven-channel, four-frequency, linearly polarized passive microwave radiometer system. It is flown on board the United States Air Force Defence Meteorological Satellite Program (DMSP) Block 5D-2 satellites. The instrument measures surface/atmospheric microwave brightness temperatures (TBs) at 19.35, 22.235, 37.0 and 85.5 GHz. The four frequencies are sampled in both horizontal and vertical polarizations, except the 22 GHz which is sampled in the vertical only.

TRMM: The Tropical Rainfall Measuring Mission (TRMM) was a joint space mission between NASA and the Japan Aerospace Exploration Agency (JAXA) designed to monitor and study tropical rainfall. The term refers to both the mission itself and the satellite that the mission used to collect data. TRMM was part of NASA's Mission to Planet Earth a long-term, coordinated research effort to study the Earth as a global system.

TMI: The TRMM Microwave Imager (TMI) was a passive microwave sensor designed to provide quantitative rainfall information over a wide swath under the TRMM satellite. By carefully measuring the minute amounts of microwave energy emitted by the Earth and its atmosphere, TMI was able to quantify the water vapour, cloud water, and the rainfall intensity in the atmosphere. It was a relatively small instrument that consumed little power. This, combined with the wide swath and the quantitative information regarding rainfall, made TMI the 'workhorse' of the rain-measuring package on the Tropical Rainfall Measuring Mission.

SASS: A microwave scatterometer was used to determine the vector wind over the world's oceans. The technique is based on the sensitivity of microwave radar backscatter to the centimetre length ocean waves created by the action of the surface wind.

NSCAT: The NASA Scatterometer (NSCAT) was used to measure wind speeds and directions over at least 90 per cent of the ice free global oceans every 2 days under all weather and cloud conditions. Its configuration includes an array of antennas that radiate microwave pulses at a frequency of 14 GHz across broad regions of the Earth's surface. This array of six, 3-m-long antennas will scan two 600-km bands of ocean.

QuikSCAT/SEAWINDS: The NASA QuikSCAT (Quick Scatterometer) is an Earth observation satellite carrying the Sea Winds scatterometer. Its primary mission is to measure surface wind speed and direction over the ice free global oceans. Observations from QuikSCAT have a wide array of applications, and have contributed to climatological studies, weather forecasting, meteorology, oceanographic research, marine safety, commercial fishing, tracking large icebergs, and studies of land and sea ice, among others.

AMI: The Active Microwave Instrument (AMI), operates at a frequency of 5.3 GHz (C-band, VV-polarised), and combines the functions of a Synthetic Aperture Radar (SAR) and a Wind Scatterometer (WNS). Through its set of four antennae, the Earth's surface is illuminated, and the back scattered energy is received to produce data on wind fields and wave spectra (WNS mode), as well as to produce high resolution images (SAR mode) of the Earth's surface.

ASCAT: The Advanced Scatterometer (ASCAT) is used to determine information about the wind for use primarily in weather forecasting and climate research. Data from ASCAT also finds applications in a number of other areas, such as the monitoring of land and sea ice, snow cover, and soil moisture. ASCAT uses its radar to measure the electromagnetic back scatter from the wind-roughened ocean surface, from which data on wind speed and direction can be derived. The measuring principle relies on the fact that winds over the sea cause small-scale disturbances on the sea surface, which modify its radar back scattering characteristics in a particular way. These back scattering properties are well known, and are dependent on both the wind speed over the sea as well as the direction of the wind with respect to the point from which the sea surface is observed.

ERS1/2:The European Remote Sensing satellite (ERS) was the European Space Agency's first Earth observing satellite programme using a polar orbit. ERS-1/2 carried an array of earth observation instruments that gathered information about the Earth (land, water, ice and atmosphere) using a variety of measurement principles.

TOPEX-Poseidon: The TOPEX/Poseidon was a joint satellite mission between NASA (the US space agency), and CNES (the French space agency) to map the topography of the ocean surface. The first major oceanographic research vessel to sail into space, the TOPEX/Poseidon helped revolutionize oceanography by proving the value of satellite ocean observations. The TOPEX/Poseidon flew with two on board altimeters sharing the same antenna. These were TOPEX: the NASA built Nadir pointing Radar Altimeter using C band (5.3 GHz) and Ku band (13.6 GHz) for measuring height above the sea surface; and Poseidon: the CNES built solid state Nadir pointing Radar Altimeter using Ku band (13.65 GHz).

Jason-1: is a satellite oceanography mission to monitor global ocean circulation, study the ties between the ocean and the atmosphere, improve global climate forecasts and predictions, and monitor events such as El Niño and ocean eddies. It is the successor to the TOPEX/Poseidon.

Radarsat-1/2: is Canada's commercial Earth observation satellite. It utilizes the synthetic aperture radar (SAR) to obtain images of the Earth's surface to manage natural resources and monitor global climate change. Radarsat-1 uses a synthetic aperture radar (SAR) sensor to image the Earth at a single microwave frequency of 5.3 GHz, in the C band (wavelength of 5.6 cm).

Envisat ('Environmental Satellite'): was a large Earth observing satellite by the European Space Agency (ESA); it was the world's largest civilian Earth observation satellite. Envisat carried an array of nine Earth observation instruments that gathered information about the Earth (land, water, ice, and atmosphere) using a variety of measurement principles. A tenth instrument, DORIS, provided guidance and control. Several of the instruments are advanced versions of instruments that were flown on the earlier ERS 1 and ERS 2 missions as well as other satellites.

[Note: The information provided above has been taken from various internet based sources].

Annexure 2

[Refer Chapter 2, Table No. 3]

The Yaogan is a series of Chinese reconnaissance satellites. The first satellite was launched on 26 April 2006. The Chinese media describes the satellites as intended for 'scientific experiments, land survey, crop yield assessment, and disaster monitoring'. Yaogan 9, 16, 17, 20, 25 are military ocean surveillance satellites; each satellite employs either optical or synthetic aperture radar (SAR) sensors.

The Tianhui satellites are a part of the Ziyuan program that covers different civil and military earth observation as well as remote sensing programs and mapping. The ZY-1 program is focused on Earth resources, and looks to have two distinct military and civil branches. The ZY-2 program is reportedly used for aerial surveillance. The ZY-3 series are used for stereo mapping. The first satellite of the three satellite group was launched on 28 August 2010.

The Huan Jing series of satellites are small Chinese Earth observation satellites, operated by the China Centre for Resources Satellite Data and Application (CRESDA). The satellite constellation is composed of a number of small satellites, the ground system, and the application system. It provides all-weather (3 to 100 m metre) imagery. The Huan Jing constellation consists of two small optical satellites, the HJ-1A and the HJ-1B (launched on 6 September 2008) and one radar satellite, the HJ-1C (launched on 18 November 2012).

The Ziyuan or Zi Yuan is a series of remote sensing satellites. The ZY-1 (Ziyuan-1) series is jointly operated by China and Brazil. Zi Yuan-1 series satellites are designed for global coverage, and include cameras to make optical observations as well as a data collecting system to gather data on the environment. The first satellite of the series was launched on 14 October 1999. The ZY-2 (Ziyuan-2) is sometimes reported to be a civilian Earth observation system; at other times it is reported to being China's first high-resolution military imaging satellite. Both are reportedly used for area surveillance. The ZY-3 (Ziyuan-3) series represents China's first high resolution, stereoscopic mapping satellites for civilian use.

The Haiyang is a family of observation, scientific and operational Chinese satellites devoted to oceans, and developed by the space agency CNSA on behalf of NSOAS. This family includes three generations of satellites: two HY-1 satellites which were launched into orbit on 15 May 2002 and 11 April 2004 respectively, and are responsible for measuring temperature and ocean colour. The HY-2 satellites the first of which was launched on 15 August 2011 are intended, among other things, to study ocean dynamics while the HY-3 satellites carry sensors operating in the visible, infrared, and microwave waves.

The Fengyún are China's weather satellites launched in polar orbit and geosynchronous orbit meteorological satellites since 1988. On 11 January 2007, China destroyed one of these satellites (FY-1C) in a test of an anti-satellite missile. The FY-1 series satellites are polar orbiting meteorological satellites, consisting of four satellites. FY-2 series satellites are in geostationary orbiting meteorological satellites. FY-3 and FY-4 are the second generation of Chinese polar orbiting meteorological and in geostationary orbiting meteorological satellites, which are the follow-on to the FY-1 and FY-2 series.

[Source: All inputs are from various Gunter's Space Pages (web pages)]

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