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Integration of techniques related to ship monitoring : research on the establishment of Chinese Maritime Domain Awareness System

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INTEGRATION OF TECHNIQUES RELATED TO SHIP MONITORING:

Research on the Establishment of Chinese Maritime Domain Awareness System

By

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DECLARATION

I certify that all the material in this research paper that is not my own work has been identified, and that no material is included for which a degree has previously been conferred on me.

The contents of this research paper reflect my own personal views, and are not necessarily endorsed by the University.

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ABSTRACT

Title of research paper: **Integration of Techniques related to Ship Monitoring: Research on the Establishment of Chinese Maritime Domain Awareness System**

Degree: **MSc**

There are thousands of ships engaged on international voyage all around the world and numerous vessels are navigating in the waters under the jurisdiction of China. However, as one of the largest Flag States, busiest Port States and important Coastal States, China has limited effective mechanisms and supports for implementing maritime surveillance on all of its sea area. This paper concentrates on the issue of improving this situation with the help of modern technologies. It introduces the background of research topic, gives a definition of Maritime Domain Awareness (MDA), features of current techniques related to ship monitoring, status quo of IT developments home and abroad, reviews relevant researches and experiments that have been conducted and proposes general solutions to establish Chinese MDA system. In conclusion, the author proved the necessity and feasibility of establishing a Chinese MDA platform, and strived to provide prerequisites to establish such system in order to promote the capability of maritime governance and services of China MSA by taking the advantage of modern technologies.

KEY WORDS: maritime domain awareness, AIS, LRIT, SAR, maritime surveillance, vessel monitoring system

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AIS	Automatic Identification System
AMSA	Australian Maritime Safety Authority
BPM	Business Process Management
CCTV	Closed Circuit Television
CFAR	Constant False Alarm Rate
CISE	Common Information Sharing Environment
EEZ	Exclusive Economic Zone
EMSA	European Maritime Safety Agency
ESB	Enterprise Service Bus
GIS	Geographic Information System
GISIS	Global Integrated Shipping Information System
GMES	Global Monitoring for Environment and Security
IMO	International Maritime Organization
INMARSAT	International Maritime Satellite Organization[1]
IT	Information technology
LEO	Low-Earth Orbit
LRIT	Long-range Identification and Tracking

[1]: it's a name of company originated from the intergovernmental organization International Maritime Satellite Organization, and the organization is renamed as International Mobile Satellite Organization (IMSO) now.

MARPOL	International Convention for the Prevention of Pollution from Ships
MDA	Maritime Domain Awareness
MMSI	Maritime Mobile Service Identity
MSA	Maritime Safety Administration
MSC	Maritime Safety Committee
NDC	National Data Center
NM	Nautical Mile
SAR[1]	Synthetic Aperture Radar
SAR[2]	Search and Rescue
SOA	Service-Oriented Architecture
SOLAS	International Convention for the Safety of Life at Sea
SMU	Shanghai Maritime University
UNCLOS	UN Convention on the Law of the Sea
USCG	United States Coast Guard
UTC	Coordinated Universal Time
VHF	Very High Frequency
VTS	Vessel Traffic Services

Chapter 1 Introduction

1.1 Background

Shipping has served world economy for almost 5000 years and it provides a sophisticated transport service to almost everywhere on the global (Stopford, 2009), and more than 90% of world freight is carried by ships (IMO, 2012a; Lorange and Fjeldstad, 2010). According to the search result obtained from Global Integrated Shipping Information System (GISIS) on the IMO website, 108,606 unique vessels are under the status of "in service/command" as of May 15 2015. A research proved that "there are approximately 50,000 merchant ships in operation, registered to more than 150 nations" (Lorange and Fjeldstad, 2010, p.185). In other words, there are basically tens of thousands of ships engaged on international voyage all around the world today. With the economic development of China in recent decades, more and more ships join the fleets sailing on the waters under the jurisdiction of China. Results of searching IT system's database of China MSA indicates that voyages of international ships entered in or departed from Chinese ports in 2014 are 288,170 and 287,538 respectively. The number will reach 11,484,957 and 11,481,883 respectively if ships operating in domestic are also included. Trends of ships' voyages are

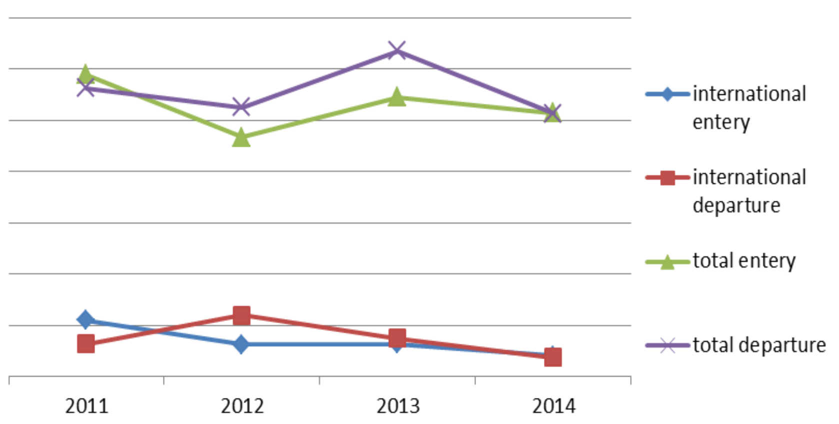

Figure 1: Trendchart of voyages entered in or depatured from Chinese ports (2011--2014)

Source: Compiled by author based on data searched from IT system of China MSA illustrated in figure 1 and more detailed information could be found in table 1. Since such huge numbers of vessels are sailing on China's waters, the competent authorities of Chinese government definitely need to implement effective measures to monitor the activities of the vessels so as to improve maritime safety, security and environmental protection.

Table 1: Statistics of vessels entered in or departured from Chinese ports

item \ year			2011	2012	2013	2014
international	entry	voyage (thousand)	**302**	**292.6**	**292.8**	**288.17**
		cargo(million ton)	1843.2	2002.4	2281.2	2292.3
		GT (million)	4258.2	4459.1	4757.7	4986.1
	departure	voyage (thousand)	**292.8**	**303.9**	**294.9**	**287.5**
		cargo(million ton)	538.3	535.4	573.4	681.7
		GT (million)	4457	4323.7	4808.3	4921.2
domestic	entry	voyage (thousand)	11630.8	10912.3	11377.5	11196.8
		cargo(million ton)	3213.2	3136.8	3617	3835.4
		GT (million)	6963.5	7323.6	7783.5	7856.5
	departure	voyage (thousand)	11483	11245.3	11916.9	11194.3
		cargo(million ton)	4446.6	370283.3	3556.1	3809.5
		GT (million)	7267.8	7278.8	8002.5	7888.4
total	entry	voyage (thousand)	**11932.8**	**11204.9**	**11670.3**	**11484.97**
	departure		**11775.8**	**11549.2**	**12211.8**	**11481.8**

Source: Compiled by author based on data searched from IT system of China MSA

It has been a consensus that 21st century is a century of ocean, thus, many countries have increased their strategic investments in marine industries (Jiang et al, 2014). Shipping industry and marine economy are playing a more and more important role in China too. A report to the 18th National Congress, one of most significant policy program for China's development, pointed out that China should enhance marine economy, protect the marine ecological environment with a view to safeguarding China's maritime rights and interests, and building China into a maritime power (Hu, 2012). Therefore, in the perspective of China's national strategy, it's necessary to be aware of the situation of Chinese maritime domain as far as possible.

Maritime Domain Awareness (MDA), as defined by IMO (2012b, p.51), is "the effective understanding of any activity associated with the maritime environment that could impact upon the security, safety, economy or environment". The concept of MDA is to fuse as many data sources as possible to a Geographic Information System (GIS) format and apply pattern recognition algorithms to the data, which characterizes the maritime traffic at the area of interest (Detsis et al, 2012). From the global perspective, some MDA systems have already been established under the support of new techniques such as LRIT, AIS, spaceborne SAR[1] and etc. For instance, CISE and GMES of the European Union, "Deep Water Plan" and AKDEMO of the United States, and RADARSAT of Canada, and those cases would be introduced in chapter 3. However, in spite of the demand of maritime surveillance in China and the operation of mature systems abroad, there has been no comprehensive DMA system integrating multi data resource in China so far.

1.2 Objectives of the research

The above mentioned background implies the necessity of the creation of measures for monitoring the status of vessels as well as the whole maritime domain. The author, as a staff of IT data center of China MSA and operator of China LRIT National Data Center (NDC), has a strong desire to explore a way to establish maritime surveillance platform via integrating multi data resources. Thus, this paper would analyze, in terms of techniques applied to merchant shipping particularly, the possibility and ways of establishing Chinese MDA system, in order to make the research:

.1 draw attention to the issues discussed in the paper;

.2 sum up potential techniques related to ship monitoring;

.3 offer a fundamental solution for integrating specific data resources;

.4 facilitate the practical development of Chinese MDA system; and

.5 provide information supports for decision-maker(s).

1.3 Necessity and feasibility from legal point of view

The author believes that maritime governance should always comply with international treaties to which the State is a Contracting Government or a party. Thus it's necessary to analyze the rights and obligations under related international conventions as well as accordingly domestic legislation.

The United Nations Convention on the Law of the Sea (UNCLOS) is acknowledged to be a "framework convention" or "umbrella convention" on the issues related to ocean (Hesse, 2015). Some critical provisions of UNCLOS in relation to monitoring of ships are summarized as follows (UNCLOS, 1982; Sohn, 2010):

.1 Article 17, Article 18, Article 19 and Article 21 prescribe the "right of innocent passage" and corresponding definitions, requirements, prejudicial behaviors and rights of legislation formulated by Coastal States;

.2 Article 22 prescribes sea lanes and traffic separation schemes in the territorial sea of a Coastal State, which empowers Coastal State to require navigation routes of foreign vessels;

.3 Article 24 and Article 25 prescribe obligation and right of Coastal State respectively, providing States with right to take necessary steps to prevent non-innocent passage;

.4 Article 56 prescribes the sovereign rights and jurisdiction of Coastal State in the Exclusive Economic Zone (EEZ);

.5 Article 95 and Article 96 prescribe immunities of warships and ships used only on government non-commercial service on the high sea; and

.6 Article 110 and Article 111 prescribe right of visit and right of hot pursuit respectively.

In summary, on the one hand, the UNCLOS stipulates obligations for Coastal States to take measures to guarantee the rights of vessels sailing on the waters under their jurisdiction; on the other hand, the UNCLOS also gives rights to Coastal States to safeguard the their own rights. Thus in order to fulfill the obligations and to perform those rights, Coastal States need to establish appropriate mechanisms to know what happens on their waters and to take effective actions whenever. With regard to this objective, the author is of the opinion that means of maritime surveillance is necessary for Coastal States and that establishing MDA system would be a good choice for implementing relevant provisions of the UNCLOS.

Besides UNCLOS, some provisions which support the aforesaid opinion are prescribed in other international treaties, for example, *SOLAS*, *MARPOL* and the *International Convention on Maritime Search and Rescue (SAR^2 Convention)*. In addition, supporting regulations are not only given by international treaties but also could be found in China's domestic laws such as *Maritime Traffic Safety Law*, *Marine Environment Protection Law* and the *Law of the People's Republic of China on the Territorial Sea and the Contiguous Zone*, etc. Since this paper does not primarily focus on legal regimes, detailed information on legislation is summarized in the Appendix A rather than to be discussed in this chapter. Whilst, the general conclusion by analyzing legal regimes is that establishing effective mechanism for maritime surveillance is allowed and even encouraged by both international conventions and domestic regulations.

Of course, it should be noted that analysis of necessity and feasibility for establishing a comprehensive system shall be based on an all-around assessment covering enough relevant aspects. However, the author considers that it's premature to discuss other factors until necessary information has been introduced. Thus more detailed analysis of necessity and feasibility would be undertaken in "section 4.1".

1.4 Methodology and primary contents of the research

This paper essentially concentrates on the following contents based on investigation method, theoretical analysis method, case study method, and experimental method as well:

.1 introduction and corresponding analyses of maritime surveillance;

.2 globally successful cases of MDA systems;

.3 feasibility study on technical issues; and

.4 proposed solution for establishing Chinese MDA system.

1.5 Chapter summary

To sum up, maritime surveillance becomes increasingly significant because issues of safety and marine environmental protection in shipping industry are widely concerned about. China, as one of the major shipping countries and a State with large area of marine territory, is closely relevant to this issue. Establishing appropriate MDA system is permitted and recommended by international and national legislation, and is supported by modern techniques. This paper conducts research on the topic of establishing Chinese MDA system by integrating techniques related to ship monitoring.

Chapter 2 Available technologies for ship monitoring

As mentioned in Chapter 1, issues of shipping safety, marine environment and marine economy are arousing more and more attention. Meanwhile some technical methods have been approached as tools of maritime surveillance for fishery monitoring, merchant vessel traffic monitoring and marine environmental protection detection. It's essential to identify and review the features of existing ship monitoring and tracking systems in advance with a view to integrating them. Hence, this chapter would briefly introduce techniques related to monitoring of merchant vessels.

2.1 LRIT

The establishment of Long Range Identification and Tracking (LRIT) of ships system was subjected to the IMO's resolution MSC.202 (81) adopted on May 19, 2006. This resolution amends chapter V of *SOLAS* and consequently binds all the Contracting Governments of the convention. LRIT is basically a message transmitting system between shipborne terminals and data centers onshore with the help of satellites, which realizes the goals of global identification and tracking of vessels so as to enhance maritime security, as initially primary aim, as well as to improve maritime safety, marine environment protection and also search and rescue. The LRIT system is composed of shipborne satellite communication equipment, Communications Service Providers, Application Service Providers, LRIT Data Centers (DCs), the International LRIT Data Exchange (IDE) and the LRIT Data Distribution Plan (DDP), whose architecture is illustrated in figure 2 (IMO, 2006; IMO, 2008). The IDE is operated by the European Maritime Safety Agency (EMSA) in Lisbon, Portugal, while the DDP server is operated in IMO headquarter in London, and 56 DCs are operating as of 2 January 2015 (IMO, 2015a).

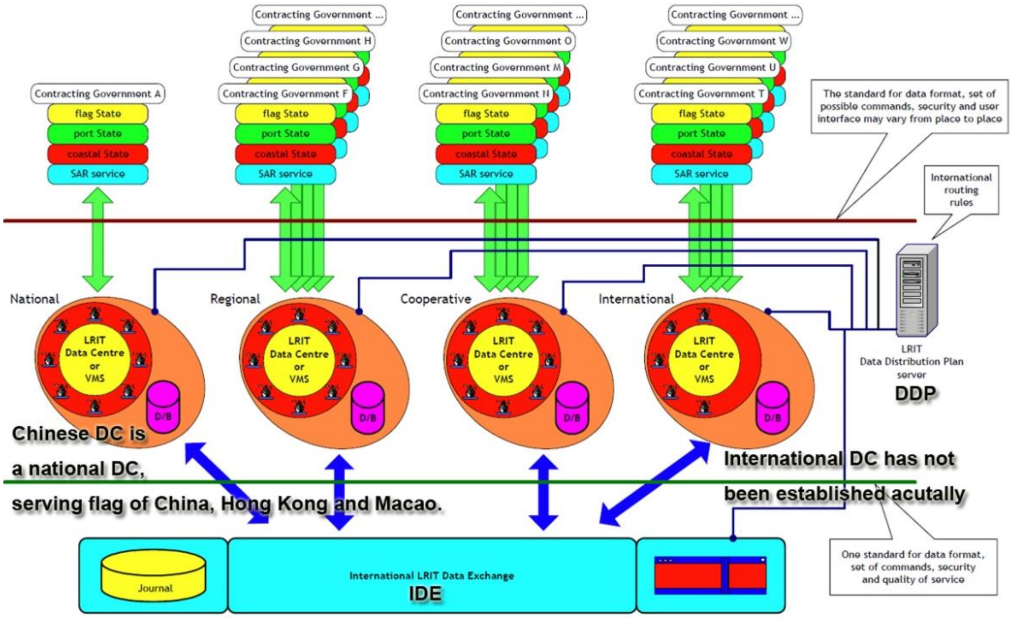

Figure 2: Architecture of LRIT system

Source: Compiled according to MSC.263(84) adopted by the IMO.

LRIT regulation principally applies to ships are of 300 gross tons or above on international voyages. Data transmitted by LRIT covers ship's identity, position and time of transmission, and those data should be sent to corresponding DC of Flag State at least 4 times per day. However, the report frequency could be increased up to 15 minutes for a specified period, or to report immediately as a result of polling request. The LRIT messages of ships could be sent from Flag State to a request state which is entitled to receive, in other words, a state could monitor a ship which calls at its port or sailing within 1000 nautical miles (NM) from its coastline. By doing so, ship's location status could be shared between states. Although the transmitted data are only three types of information, nevertheless it should be highlighted that LRIT achieve essentially global monitoring of ships and establish onshore framework of data-sharing between Member States of IMO.

Besides the aforementioned characteristics, some other features of LRIT could be summarized as (IMO, 2015b; IMO, 2008):

.1 it's a satellite-based and near-real-time data transmitting mechanism, which uses existing communication systems (INMARSAT and Iridium for example) to realize additional function;

.2 it's theoretically a global coverage system which extremely extends ship monitoring area; and

.3 it generates a SAR[2] SURPIC request to all DCs for vessels in a defined area, which could facilitate tasks of Search and Rescue.

2.2 AIS

2.2.1 General introduction

Automatic Identification System (AIS), or Universal AIS, is defined by the International Association of Marine Aids to Navigation and Lighthouse Authorities (IALA) (2004, p.14) as: "an autonomous and continuous broadcast system… It is capable of exchanging information… handle multiple reports at rapid update rates…ensuring reliable and robust operation". AIS was mainly designed for navigation safety especially for collision avoidance (be vividly shown as figure 3) at first, and is widely used because of its capability of broadcasting data about a ship to other vessels and onshore receivers nearby. The broadcast of AIS complies with SOTDMA (Self Organized Time Division Multiple Access) protocol through VHF (Very High Frequency) range, on the condition that two transmitters within range of each other would never send message at same time.

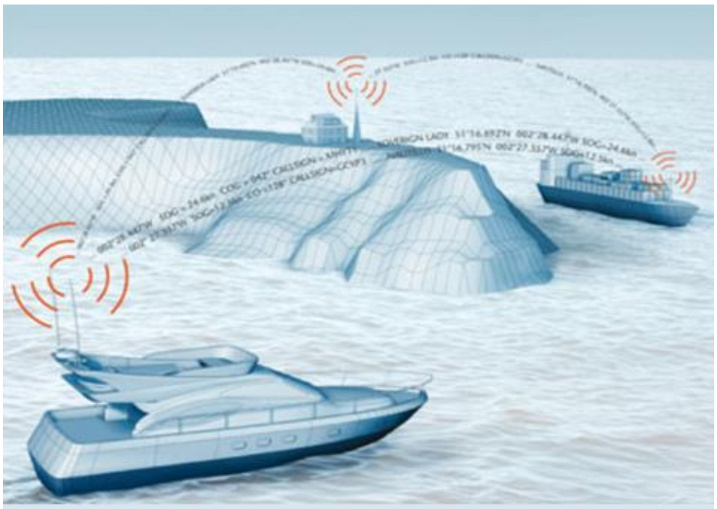

Figure 3: Demonstration of AIS's collision avoidance function
(Be aware of another ship out of sight)
Source: http://www.imo.org/OurWork/Safety/Navigation/Pages/AIS.aspx

The carriage of AIS was required by the chapter V of *SOLAS* Convention, and the carriage requirement basically applies to sea-going vessels of 300 GT and above, vessels greater than 500 GT and all passenger ships (Jun et al, 2010). Those AIS made mandatory by the convention is Class-A type. And for the ships not covered by the requirement of *SOLAS*, a type of Class-B AIS is widely used.

The IMO performance standard for AIS requires that AIS shall: (a) provide information; (b) receive such information automatically from similarly fitted ships; (c) monitor and track ships; (d) exchange data with shore-based facilities (IALA, 2004). There are four essential types of messages sent by AIS: (a) static information e.g. IMO number; (b) dynamic information such as position and speed of the ship; (c) voyage related information, for instance, ship's draught and destination; (d) Short safety-related messages subjected to input. The messages are broadcasted depending upon the message type and ship's status. For example, static information are basically sent every 6 minutes; while the update rate of dynamic information inversely increases with the ship's speed, from 3 minutes to 2 seconds (IMO, 1998). Standards, recommendations and guidelines regarding to AIS have been adopted by relevant organizations, so more detailed information could be found in documents such as MSC 74(69), Resolution A.917 (22) as amended by Resolution A.956 (23), ITU-R M.1371-1, IEC Standard 61993 Part 2 and *IALA Guidelines on the Automatic Identification System (AIS) Volume 1* etc. Since this research would primarily focus on data resource rather than equipment technology itself, thus technical details on equipment would be not introduced in the paper.

AIS technique is probably one of the most significant developments in maritime navigation since the introduction of radar. AIS data could be collected to help administrative authorities enhance maritime awareness and surveillance. Two popular modes of AIS-data collection will be introduced below.

2.2.2 Shore-based AIS

By means of the SOTDMA and other assistant protocols and through VHF frequencies for AIS (161.975 and 162.025 MHz) (IALA, 2004), the AIS messages could not only be transmitted between ships but also be obtained by coastal receivers. In this way, the traffic picture of ships sailing near coastline could be drawn with the help of computer software. However, messages that could be received are limited by distance from transmitter. The range of coastal AIS receiver is typically 40 NM, 100 NM may be reached under ideal circumstance (European Commission, 2008), thus, unlike LRIT, the contribution for ship monitoring made by conventional AIS mechanism is limited within coastal area. In practice, the shore-based AIS data is always collected to illustrate situational picture of vessel traffic near coastline. However, this is not enough for awareness of shipping because of its naturally global property.

2.2.3 Satellite-based AIS

Satellite-based AIS, as its name suggests, collects vessel data globally using satellite network. Accurately, the reception of AIS signal on satellite base was considered as means of realization of LRIT, but reservations about satellite-based AIS were expressed by IMO because of reasons such as integrity and confidentiality (IMO, 2009; IMO, 2009; IMO, 2004).

Technically, AIS signal could be detected from space by a standard AIS receiver up to 1,000 km, so that satellite-based AIS reception could be realized by optimized antenna and equipment on satellite. A constellation of such satellites could provide necessary data for maritime surveillance (Høye et al, 2008). Research shows that one single satellite can handle up to 900 ships at 1,000 km altitude and that a global constellation could handle up to 1,300 ships with a ship information update rate of 1/hour, and those detection possibilities remain more than 99%. This means that satellite-based AIS mode is possible and basically reliable for commercial development. Having realized the possibility and that awareness of ship's position is needed by many stakeholders such as maritime authorities, shipping companies, etc. Thus endeavors have been made by commercial organizations with the aim to break the restriction of receiving distance, which would meet customers' demand more satisfactorily. In this context, satellite-based AIS data collection technology was rapidly developed. According to information of ORBCOMM, a leading company focused on satellite-AIS, a global network of low-earth orbit (LEO) satellites and accompanying ground infrastructure consisting of 16 ground stations and one network control center has already been established as of March 2015 (the components of satellite-AIS are shown in figure 4). Moreover, 19 AIS-enabled satellites were planned to compose the constellation by the middle of 2015 (Best, 2015).

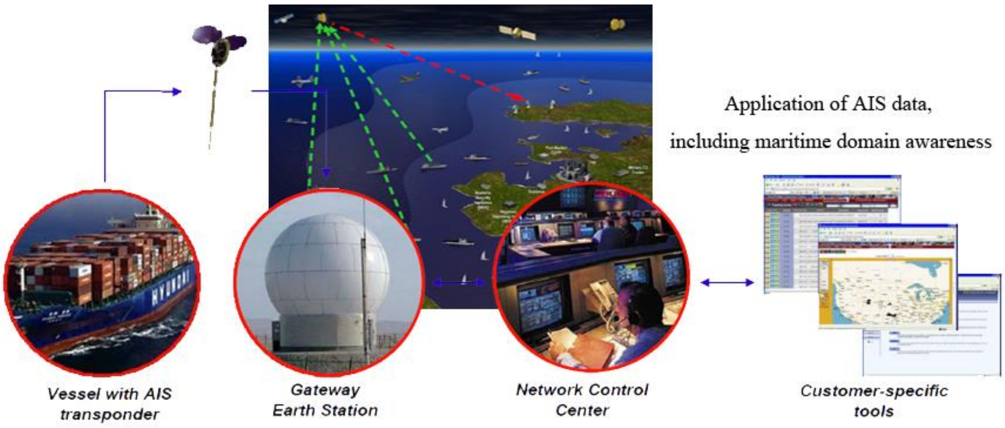

Figure 4: Key components of satellite-based AIS

Source: ORBCOMM (slightly modified by author)

2.3 SAR[1]

Synthetic Aperture Radar (SAR[1]) is a form of radar which is typically fitted on a moving platform such as a satellite or an aircraft. By doing so, SAR[1] uses the motion of its antenna over a target region to break the limitation of antenna size and long distance, and consequently improves resolution of images. Its basic

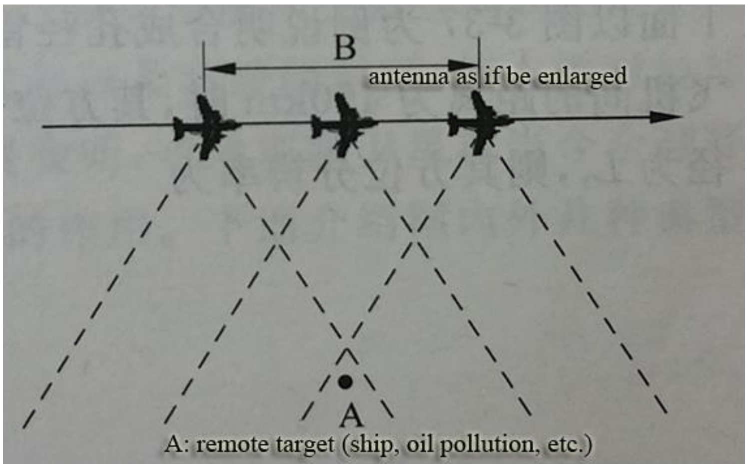

Figure 5: Demonstration of enlargement of SAR's antenna

Source: Su, 2014

principle is demonstrated in figure 5 (after technical processing, effect of an antenna with length "B" aperture could be obtained) (Su, 2014; Dong and Guo, 2005). As a kind of remote sensing technology, SAR[1] is employed for many purposes, such as engineering, land planning and environment surveillance, so far as marine surveillance is concerned, mainly used for the detection of ships and/or oil pollution (Pieralice et al, 2014).

There are two reasons for using satellite-based SAR as a tool of marine surveillance: (a) SAR sensor is an active detection method that is not restricted by conditions of weather or light, meaning that SAR can take high resolution imageries no matter when it's day or night, sunny or cloudy; (b) Being fitted on satellite makes it possible for SAR sensor to obtain contiguous data over large ocean areas in a short period of time. Many researches of SAR application on ship detection have been conducted in the last two decades. Researches prove that classical ship detection measure relies on detection of high-value pixels compared to the local background statistics, or named as Constant False Alarm Rate (CFAR). And based on CFAR method, some improved measures have been generated such as visual attention, Difference of Gauss scale-space and Radiometric-Spatial Analysis. However, to sum up, there are two essential methods of ship detection from SAR imagery: (a) detection of ship herself; and (b) detection of wake of a ship (Pieralice et al, 2014; Amoon et al, 2013; Detsis et al, 2012). The theory of SAR[1] will be further discussed in section 5.2.2.

2.4 VTS

Vessel traffic services (VTS) system is a marine traffic monitoring system typically established by maritime authorities as required by regulation V/12 of *SOLAS* convention. Development of VTS originated from the mid-twentieth century and has been improved several times with the applications of technologies. It should be noted that VTS itself is not a system but a series of services offered by VTS operators of port or maritime authorities, while the physical system of a VTS is basically composed of some sub-systems: (a) VHF radiotelephony communication sub-system; (b) Radar sub-system; (c) Radar data processing sub-system; (d) information transmission sub-system; (e) Management information sub-system; (f) AIS sub-system, etc. (Liu et al, 2006). Such a comprehensive system provides three different levels of services to shipping: (a) information; (b) navigational assistance; and (c) traffic management, with aims to prevent the development of dangerous situation and to essentially enhance maritime safety and efficiency (Nuutinen et al, 2007). The exchange of information in VTS system's operation is demonstrated in figure 6.

However, it should also be noted that VTS system is basically operated for traffic surveillance in port area. The reasons for this situation might be: on the one hand, port area is generally busiest traffic area liable to collision risk more and needs more navigational assistance; on the other hand, it's a result of technology limitation since surveillance of waters beyond port area is obviously also demanded.

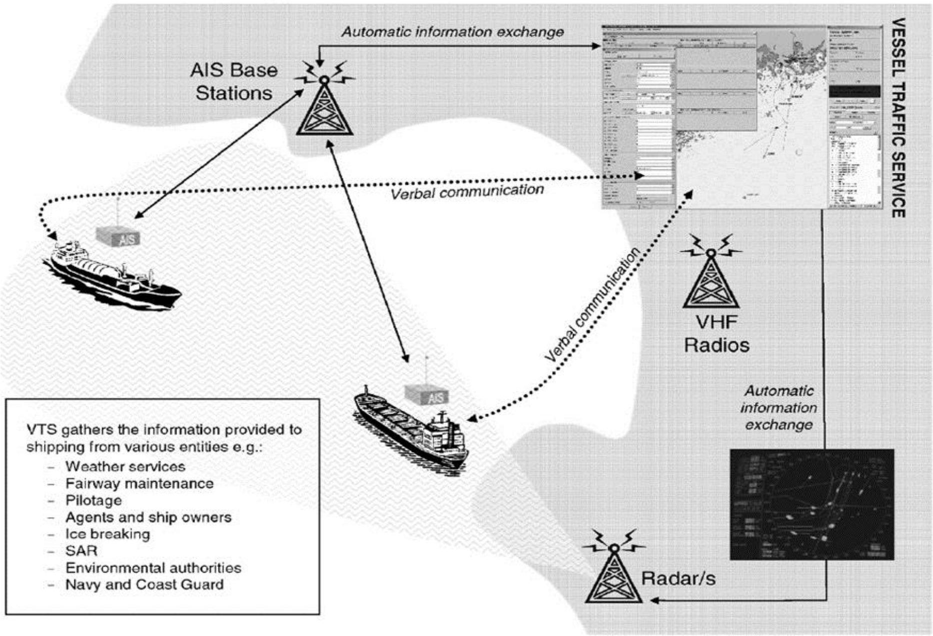

Figure 6: Means of general information exchange in the VTS operations.

Source: Nuutinen et al, 2007

2.5 Ship reporting system

Ship reporting systems may be operated on mandatory or voluntary basis. Mandatory ship reporting is primarily subjected to adoption by the IMO in compliance with Regulation V/8-1 of *SOLAS* Convention and the *Guidelines and criteria for ship reporting systems* adopted by resolution MSC.43 (64). For example, “Off Chengshan Jiao Promontory” amended by MSC94 is a mandatory ship reporting system of China (IMO, 2014). Whilst, many ship reporting systems, aiming to facilitate SAR[2] operation, are operating on voluntary basis. For instance, Automated Mutual-assistance Vessel Rescue System (AMVER) has been operated by US Coast Guard since 1958 (USCG, 2015a), Australian Ship Reporting System (AUSREP) was established in 1973 in a partly mandatory basis, and China Ship Reporting system (*CHISREP*) has been operated in Shanghai, China since 2005. Figure 7 illustrates the reporting area of *CHISREP*.

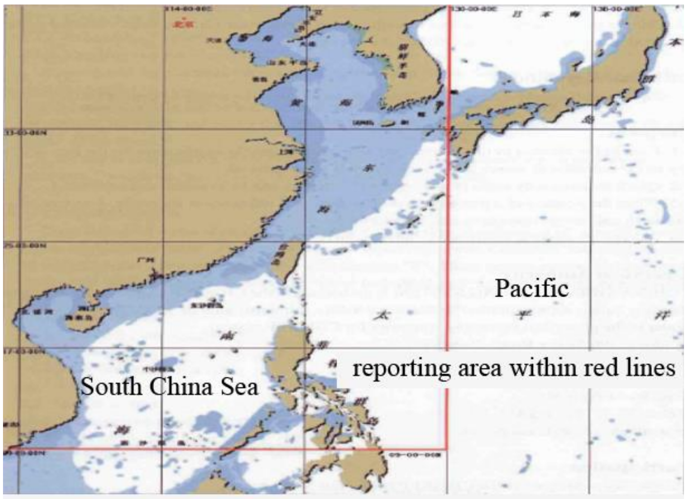

Figure 7: Reporting area of CHISREP

Source: Compiled by author based on information from China MSA

It should be pointed out that different voluntary reporting systems may be with distinct reposting requirements such as message format and reporting manner, which makes them difficult to be integrated smoothly.

2.6 Others

2.6.1 Information collected from spot

In accordance with the principle of radio-relay station, data could be retransmitted from spot to onshore data center through special equipment on patrol vessel or helicopter. The radio-relay station is specifically designed for dedicated purpose. For example, figure 8 shows a radio-relay equipment of fishery authority of China (CARERI, 2012). Maybe another example would be taken to illustrate this point more clearly. AIS message received by a terminal on shipboard could be re-transmitted to other receivers, meaning that the relaying function could be used to extend transmission distance. Of course, the radio-relay transmission depends upon specific equipment and transition station such as patrol vessel at sea.

2.6.2 Others

Besides the abovementioned techniques, VSAT（Very Small Aperture Terminal）, CCTV (Closed Circuit Television), BeiDou satellite system are also capable of capturing or transmitting of marine situational picture. Nevertheless, since they might probably not be fit for long-distance capture or transmission of large amount of data, thus they would not be elaborated on in this paper.

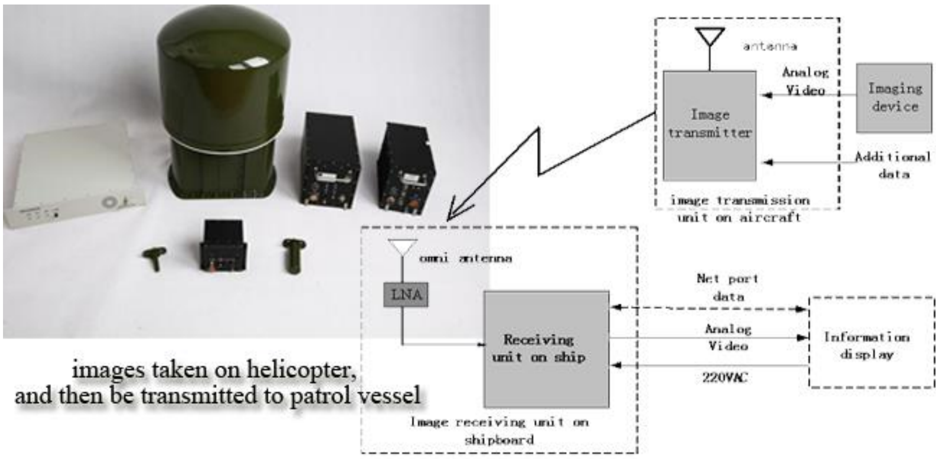

Figure 8: Radio-relay equipment and its schematic diagram

Source: Compiled by author based on information from Chinese Aeronautical Radio Electronics Research Institute

2.7 Chapter summary

In summary, this chapter briefly reviews existing technical methods for maritime surveillance. While, it’s noted that those ship-monitoring technologies were basically generated from different backgrounds with distinct focuses of targets and areas, thus they generally represent different features and independent data standards. In other words, the introduced technologies for monitoring ship's position and/or activity have both advantages and disadvantages of themselves. For example, LRIT is of global coverage but with low reporting frequency; conventional AIS or shore-based AIS transmits near real-time position message but is limited by short coverage and manually input; while as to the space-based sensing measures such as satellite-based AIS and satellite-based SAR[1], as a result of operating by commercial companies (e.g. Inmarsat, Orbcomm), the cost of those data sources are relatively high, and reliability as well as confidentiality of such data are also to be concerned about. Therefore, generally speaking, there is no one sole technology or data source is suitable for achieving all the objectives of maritime domain awareness. Consequently, integration of suitable data sources that could be cross-correlated with each other might be a wise solution, which will be discussed in the following chapters.

Chapter 3 Developing status of maritime surveillance from global perspective

3.1 European Union

The European Union (EU), as a politico-economic union of 28 member states (Wikipedia, 2015), significantly improve the development of both the European and the globe through its institutions e.g. the European Commission (EC). While European Maritime Safety Agency (EMSA), as an agency of EU, plays a leading role on matters related to maritime safety, security and marine pollution prevention. Endeavors for maritime domain awareness have been made by the EU for many years, and some achievements would be introduced below.

3.1.1 CISE

In order to enhance the effectiveness and coast efficiency of surveilling European maritime domain, after assessing situational, legal, beneficial and other related issues, the Common Information Sharing Environment (CISE) program was decided by the EC through the adoption of conclusions as well as communications (EU, 2011). The CISE is defined as "a voluntary collaborative process in the European Union seeking to further enhance and promote relevant information sharing between authorities involved in maritime surveillance" (EMSA, 2014a, pp.9-10). As EU's expectation, CISE will integrate existing surveillance systems and data could be exchange easily so that all authorities concerned would share the information they need for their missions at sea.

The maritime surveillance systems to be integrated include LRIT, shore-based and space-based AIS, and products of EU's precious projects such as SafeSeaNet (Safe

Sea Network: A European Platform for Maritime Data Exchange between maritime transport authorities of Member States), EUROSUR (European border surveillance system), etc. One of the three consensus major benefits of CISE is believed to improve safer, securer and cleaner seas, and the public actors would benefit from it, including coast guards, traffic monitoring, environmental pollution prevention, fisheries, border control, tax and general law enforcement authorities (EU, 2010). A roadmap and six steps towards the roadmap were agreed upon. In 2013, an analysis conducted by Gartner (2013) shows that CISE can be realized over a ten year period for a cost ranging from 83 to 142 m€. The illustration of CISE is shown in figure 9.

Figure 9: Illustration of CISE

Source: European Unit, 2010

3.1.2 GMES

Global Monitoring for Environment and Security (GMES) is an EU's Earth monitoring Program for improving European capacity for Earth Observation. It is a long-term programme, starting from 1998, built on partnerships between the Union, the Member States, the European Space Agency (ESA) and other relevant European stakeholders. The GMES system is characterized by four key features, and its architecture is based on three components: a service component that delivers information in support of environment and security policies, and two observation components (in-situ, and space-based including satellite-based SAR[1]) that provide the data needed for operating the services. It provides services to public policy makers and individuals (Liebig and Aschbacher, 2005; EC, 2005). The infrastructures and components of GMES are illustrated in figure 10.

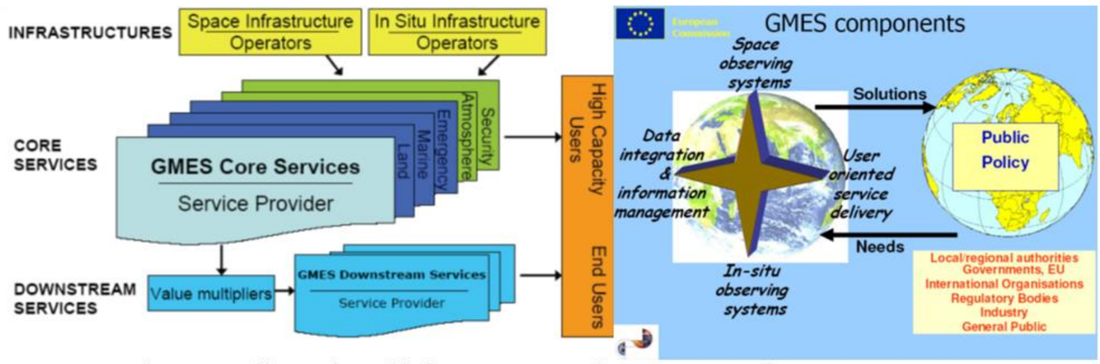

Figure 10: Illustration of infrastructures and components of GMES
Source: Compiled basing on information from European Space Agency (ESA)

3.1.3 CleanSeaNet

The CleanSeaNet program entering into operation in April 2007 is on the basis of satellite-based SAR[1] sensing, aiming to detect possible oil pollution caused by both illegal discharge and accidental spill. The first generation of CleanSeaNet ended its service life in January 2011. In nearly four year's period, CleanSeaNet service was basically operated on the basis of 3 polar orbiting SAR satellites (ENVISAT, RADARSAT-1 and RADARSAT-2) and 5 receiving ground stations, which achieved main outcomes as follows (EMSA, 2014b):

.1 delivering more than 8,000 satellite images;

.2 monitoring over 1,000 million km^2;

.3 detecting 8,866 potential oil spills and half of them were subsequently confirmed; and

.4 providing emergency support for 10 accidental pollutions.

The aforesaid detection outcomes of the whole Europe are demonstrated in figure 11. Gaining benefits from CleanSeaNet 1st generation, the 2nd one has been operating since February 2011.

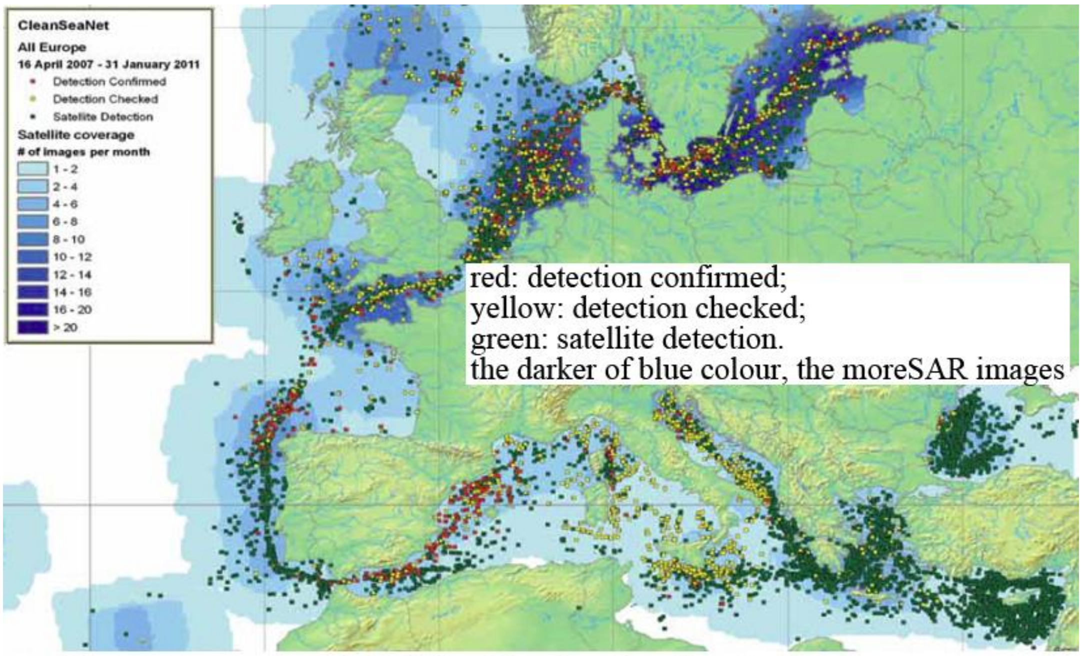

Figure 11: Demonstration of oil spills' detections by CleanSeaNet program
Source: European Maritime Safety Agency (EMSA), 2014

3.2 The United States

The United States Coast Guard (USCG) has safeguarded maritime interests of the USA for many years. One of the reasons for its success might be innovation and application of hi-tech instruments. For instance, a "C4ISR" (Command, Control, Communications, Computers, Intelligence, Surveillance and Reconnaissance) Program has been executing with the intention of improving situational awareness. Through the use of integrated communication systems, C4ISR program further enhances the information-sharing capability of USCG (USCG, 2015b). The Alaska AKDEMO is another example demonstration of marine surveillance whose infrastructure is shown as figure 12.

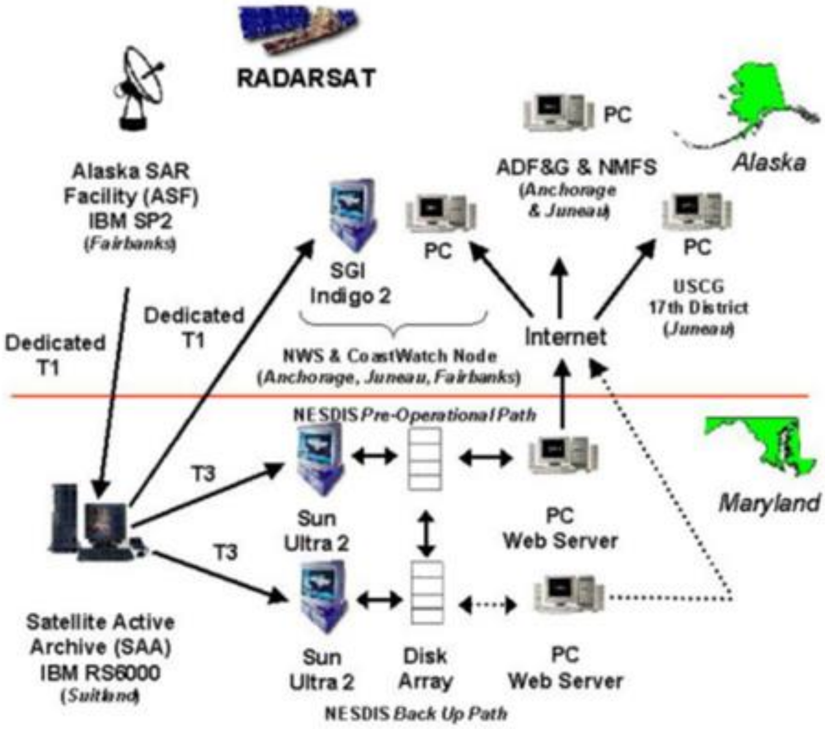

Figure 12: Illustration of infrastructure of AKDEMO program
Source: USCG

3.3 Canada

Just like its neighbor of the United States, Canada also concerns about the issue of maritime surveillance. A good case in point is that, in 2011, delegations of Canada introduced Canadian MDA system twice at meeting of MSC 89 and 10th session of Ad Hoc LRIT Group respectively. The Canadian MDA system was integrated with data sources from interdepartmental sensors including LRIT so as to provide situational information of Canadian marine domain (IMO, 2011a; IMO, 2011b).

3.4 Status quo in China

Since the purpose of this paper is to research on the establishment of Chinese MDA system, the development of marine surveillance as well as the overall status quo of IT systems shall be reviewed too. It’s believed too early to discuss maritime surveillance without introducing the competent authority. China MSA under the Ministry of

Transport takes the responsibilities of maritime safety, security, prevention of pollution from ships, and protection of seafarers' rights. Other official agencies (e.g. the Customs, Ministry of Environment, etc.) are also involved in superintendence of marine affairs.

Although a comprehensive MDA platform for all related authorities is an ideal target to be achieved, the author believes that focus the first step will be reasonable for the ultimate goal could not be achieved in one day. Therefore, as the first step, this paper would merely concentrate on creating MDA system within the scope of China MSA.

3.4.1 Existing platforms for MDA

Despite more and more IT systems have been established in the last two decades and some of them are capable to detect, monitor and/or track activities of vessel, those systems are basically independent from each other. The primary status quo of such systems is summarized as follow:

.1 Chinese LRIT NDC has been operating since July 2009 as required by SOLAS convention. Statistics show that 1,196 ships flying the flag of China and 2,126 ships flying the flag of Hong Kong, China are registered in the NDC's database as of May 2015, subjecting to a search result performed by the author. This implies that huge data (approximately 3.15 million LRIT messages received per year and 878.7 thousands messages sent annually) are available as a result of storage from such large number of vessel and so long period of duration. However, those big data are not used by any system other than LRIT itself.

.2 The first VTS center was established in 1978 in China, and there are already 37 VTS centers operating in ports of China as of November 2014 (Fujian MSA, 2014). While those VTS centers are isolated as several "information islands" within various ports only, moreover, they are products of three different manufactures with distinct and encrypted data formats.

.3 The establishment of Chinese AIS systems started from 2005 and continues to the present. Through nearly ten years' efforts, one national AIS center, 3 district AIS centers and 19 regional AIS centers with totally 121 base stations of shore-based AIS have been built as of 2014, which constitutes Chinese coastal AIS network.

Besides, internal water AIS network composed of 4 district centers and 143 base stations is already established (Wang et al, 2013). A public service platform has been recently provided with only shore-based AIS data, meaning that the information is limited within 40 NM from coastline typically.

.4 Information could be collected by the *CHISREP*, Chinese ship reporting system introduced in chapter 2, become much less than before since it's basically on a voluntary basis.

.5 Commercial IT platforms have been produced during recent years, and several outstanding ones are capable of searching via satellite-based AIS. But most of them do not achieve the expected results because lack of finance and data accuracy, etc.

.6 There is no platform providing information of maritime surveillance dedicated to merchant shipping based on satellite SAR data in China so far.

Figure 13 shows compiled screenshots illustrating the aforementioned platforms.

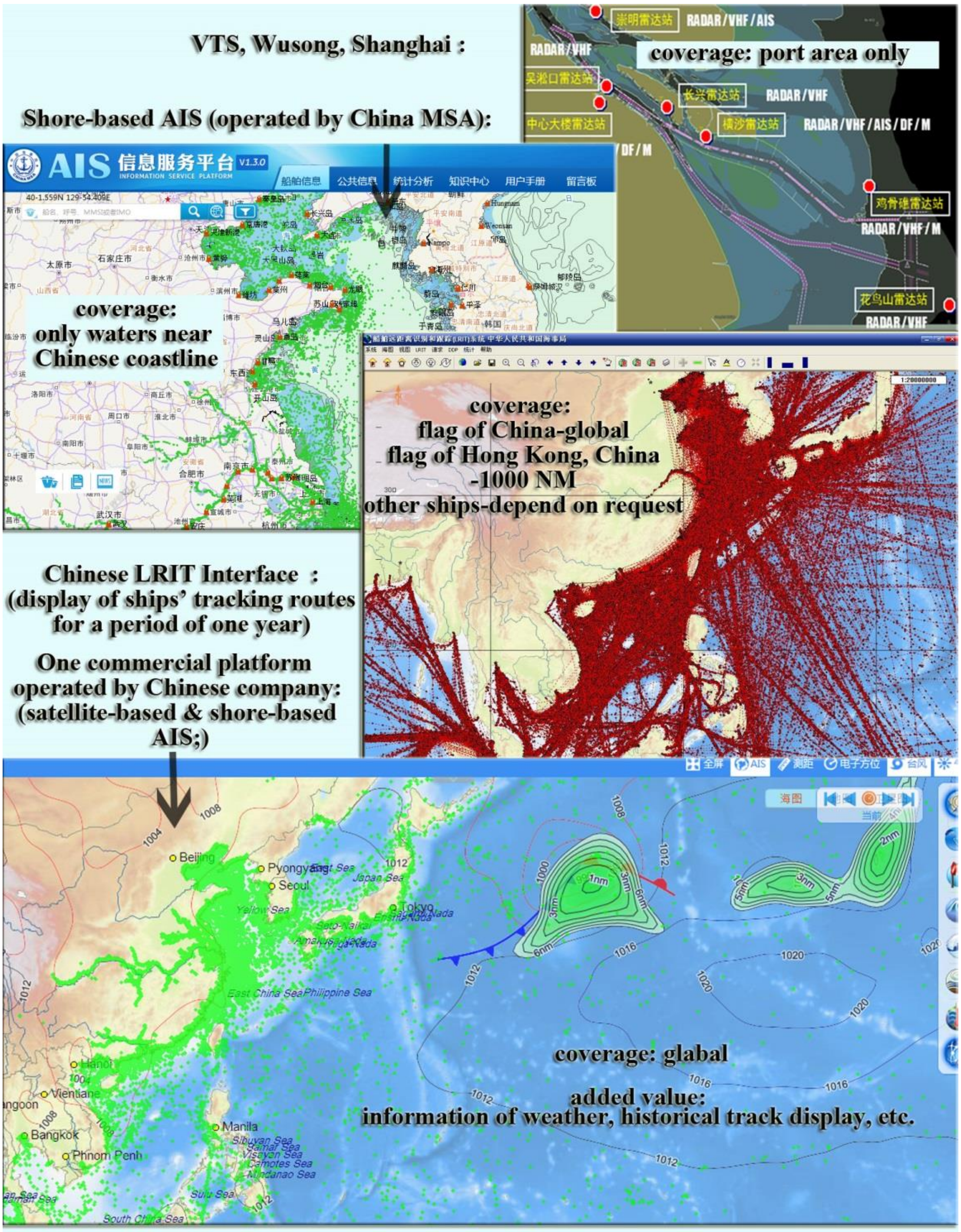

Figure 13: Screenshots of existing platforms related to ship monitoring in China
Source: Compiled by author (screecshots taken on 27-05-2015)

3.4.2 *Top-Down Design* strategy for IT development of China MSA

Information Technology or IT is effectively improving efficiency of human's work and is significantly changing our society. A recent literature view, basing on 152 articles, demonstrates that: "the use of IT across diverse fields and the reliance on IT for high-end, routine operations and common use is growing" (Shaikh and Karjaluoto, 2015, p.542). The importance of IT has been recognized by China MSA too. IT (including a set of systems, technologies, processes, applications, and software) has been developed in full swing in the field of Chinese maritime governance during the last 15 years. Particularly, a *Top-Down Design* strategy for IT development of China MSA has been implemented since 2011.

China MSA pursues to realize "intelligence MSA", or "digitization MSA", with the help of IT. *Top-Down Design* is a strategy for IT development of the overall organization of China MSA including 14 Branch-Bureau and 28 Regional-Bureau. The strategy is a technical roadmap for IT development involving various aspects, such as objectives, infrastructure design, key systems to be developed and their basic features, as well as the general implementation arrangements and requirements. By doing so, the framework of IT of China MSA was basically determined for future years, which means that essential subsystems would be further supported to develop and that the determination is in a stage of general plan rather than detailed blueprint.

According to the design, the future MSA's overall IT system will consist of two primary portals facing internal users and external clients respectively, which will be an integration of 27 existing subsystems including AIS, LRIT, etc. (see Appendix B and Figure 26 for details). The architecture of the system is designed as inter-invocation of hardware resources between individual Bureaus and two primary data centers located in Shanghai and Beijing. The infrastructure, hardware, integration, service invocation and network rely on popular technologies, such as cloud platform, virtual machine, SOA (Service-Oriented Architecture), ESB (Enterprise Service Bus), BPM (Business Process Management), etc. (China MSA, 2011). Figure 14 demonstrates the architecture of *Top-Down Design* and its relationship with MDA data sources.

Figure 14: illustration of the infrastructure of *Top-Down Design* and its relationship with ship monitoring data source (being partly under construction)
Source: Compiled by author based on information from China MSA

Top-Down design strategy has been implemented since 2012, annually consuming budget at a level of ten millions US dollar in the last three years. So far, the framework of Shanghai Data Center with the mode of “cloud platform” has been basically established; Beijing Data Center and other secondary data centers are under optimization construction; ten databases processing essential maritime data (six static information databases and four dynamic information databases) have been created. As shown in figure 14, some of existing technical instruments for ship monitoring have been considered integrating into the overall IT system of China MSA. Nonetheless, it should be noted again, there is no exact plan of integration for various data sources related to ship monitoring. In other words, the *Top-Down design* confirms that the integration of MDA data sources into the comprehensive IT system should be done in the future, but does not describe how to make it.

3.5 Chapter summary

To sum up, this chapter introduces the development status of IT systems for maritime surveillance all around the world and some successful cases in the field in particular. Moreover, the status quo of China, both the existing MDA platforms and the Top-Down Design strategy, is introduced with the purpose of analyzing actions to be taken. Findings of this chapter might be summarized as follows:

.1 There are wide gaps existing between China and worldwide leading cases. For example, the EU has developed MDA platform integrated with multi-data sources. Furthermore, those platforms' performances are expected to be continuously improved under the supports of sustainable developing arrangements, e.g. the CISE program. By contrast, some essential, alternatively called as convention-required, platforms are operating in China. But data of those Chinese platforms isolated from each other, which forms several "information islands" and reduces the usage and efficiency of those independent systems. In other words, expected effect has not been obtained although China MSA's investment on IT has been at a relative high level for years.

.2 It's a consensus that making use of IT could improve working efficiency as well as administrative quality. And the importance of applying IT is realized by China MSA. While, despite that the overall IT system of China MSA is being constructed for optimization under the strategy of *Top-Down Design* and that the necessity of establishing a more effective IT platform for maritime surveillance is confirmed, no specified implementation arrangements or technical instruction has been adopted yet.

.3 The author holds the view that it's a good opportunity to carefully consider in details when to establish Chinese MDA system. On the one hand, China MSA's overall IT system is under reconstruction for years, so that financial support will be probably guaranteed; on the other hand, experiences of operating domestic platforms and learning from successful abroad cases would obviously accelerate development of Chinese MDA system. For instance, integration of multi-data sources, such as shore-based and satellite-based AIS, SAR[1] and LRIT, has been proved to be a feasible and reasonable measure to further improve the effectiveness of MDA.

Chapter 4 Analyses of establishing Chinese MDA

4.1 Necessity and feasibility analyses

In section 1.3, the necessity and feasibility of establishing of China's MDA were discussed solely form legal perspective. It's far from enough for initiating such an important project. Since relevant information has been introduced in the previous chapters, more details are introduced in this chapter.

4.1.1 Necessity analysis

As mentioned in chapter one, with respect to necessity of establishing Chinese MDA platform, first of all, the author would like to remind the facts: As a large Flag State, China has approximately 1,300 vessels or 28.1 million gross tonnage engaged in international voyage out of 220 thousands of registered vessels (China MSA, 2014); as a Port State, China has nearly 3 billion tons cargo-handling capacity per year (as shown in table 1); and as a Coastal State, China has 18,000 km coastline and 3.5 million square kilometers territorial sea. This means that China is definitely an important shipping country and meanwhile China is influenced by shipping in many domains, such as economy, trading, marine environment, ecosystem, society, etc. Thus, shipping activities need to be monitored, supervised, and of course also be served and facilitated as far as practicable.

Secondly, the author would like to share information gained from a specific research conducted in 2013 on the strategy for implementing China's sea power. Some related information is extracted and fundamental resources of China MSA are summarized in table 2 (Shenzhen MSA, 2013).

Table 2: Fundamental resources of China MSA (as of November, 2013)[2]

General information		**Number of patrol vessel (classified by length of vessel, L: m)**							**heli-copter**
Organi-zation structure	**14** Branch Bureaus with **133** sub-branch Bureaus for enforcement of international treaties. and 28 Regional Bureaus governing inner waters only	>100 & ocean-going	>100, non-ocean-going	60<L <100	40<L <60	20<L <40	<20	total	**2**
H.R.	approximately: **23,000**. (exclude Regional Bureau)	**5**	**32**	**55**	**73**	**308**	**455**	**928**	
Sea area	**3.5 million** square kilometers								

Source: Compiled by author based on information from a study report of Shenzhen MSA

The statistic in table 2 presents the awkward situation facing China MSA. Please further think about: how can 3,500,000 square kilometers of Chinese ocean territory could be effectively supervised by China MSA on the basis of only 5 ocean-going vessels and 2 helicopters? The author is of the opinion that it's hard to fully implement China MSA's responsibility without sufficient and effective technical supports, and that a comprehensive MDA system might be such a kind of supports.

Thirdly, the author would like to cite a statement: "Computers have been considered as one of the most important inventions in the 20th century and the future technology trends exclusively emphasize enhancement in human–computer interaction" (Wang and Nelson, 2014, p.82). As discussed previously, existing Chinese platforms for ship monitoring are not adequately integrated, effective or interactive enough. China MSA is endeavoring to optimize IT systems with a view to increasing administrative efficiency. Therefore, it's necessary to consider developing a comprehensive MDA system so as to implement China's Maritime policies more effectively.

[2] Comment by the author: The statistics exclude vessels and helicopters which belong to other agencies but may be under MSA's coordination in emergency situations. In addition, more helicopters and light aircrafts have been or are expected to be served for China MSA after 2013.

Last but not least, compared with EU, USA, Canada, or other countries and/or intergovernmental organizations, capability of routine maritime surveillance of China is still restricted in the coastal area or even port area. This capability obviously could not meet the demand of shipping with loose restriction of geographical scope. For example, several emergency cases, accidents or oil spills happening outside the Chinese coastline, indicated that the demand is strong for MDA beyond the limitation of coastline, territorial sea, contiguous zone and even the EEZ. It's not hard to image how the emergency responses would be facilitated if a MDA platform were provided with detailed, reliable information on scenes at sea, in real time. Hence, to take the responsibility of accident and/or pollution prevention, lifesaving, casualty investigation, etc., China MSA has to improve its capability of MDA.

4.1.2 Feasibility analysis

Although getting a comprehensive overview of activities at sea was a challenge for most countries, but now, with the development of technology and economy, the feasibility of establishment of Chinese MDA system gradually becomes clear with the discussion of previous chapters. The detailed information would not be repeated here, instead, only key features are summarized as follows:

.1 technically speaking, global marine surveillance is possible with the help of advanced technologies, such as remote sensing, radio communication, IT (computing, high capacity of network, processing capability of huge scale of data, etc.);

.2 case studies proved that it's practicable to realize a comprehensive MDA system by means of integrating multi-data sources, such as shore-based and satellite-based AIS, LRIT, SAR[1], etc.; and

.3 assessing from the present conditions of China MSA, establishing MDA system is feasible because: (a) experience has been gained from independent systems for ship monitoring; (b) an overall IT system is under construction for China MSA, providing potential support of hardware, data source and budget.

4.2 Expected benefits

Chinese MDA system, if established, will be expected to bring the following primary benefits:

.1 improving China MSA's performance, in other words, enhancing its performance in maritime safety, security, facility and marine pollution prevention;

.2 sharing reliable and situational sketches of sea with relevant China's authorities such as Customs, immigration office, fishery agency, etc., which will more or less promote their tasks too;

.3 providing appropriate information for stakeholders of shipping, such as ship owners, seafarers, shipping agencies, etc., which will promote their business; and

.4 accelerating new working mode, for instance, "digital cruising" might partly substitute traditional patrol vessel cruising, which will save a lot of human resources and energy resources.

4.3 Expected functions

Since it only serves as tools for the research, the author would not discuss about too much IT details in this section. Therefore regular functions of common software would not be mentioned, instead, only primary functions related to maritime governance are listed as follows:

.1 Display of ships' positions. This is the most essential and important function of a GIS-based MDA platform, providing the locations of ships at least within China's territorial sea. More detailed information of a target vessel could be indicated according to associated databases. An example of assumed interface is illustrated in figure14.

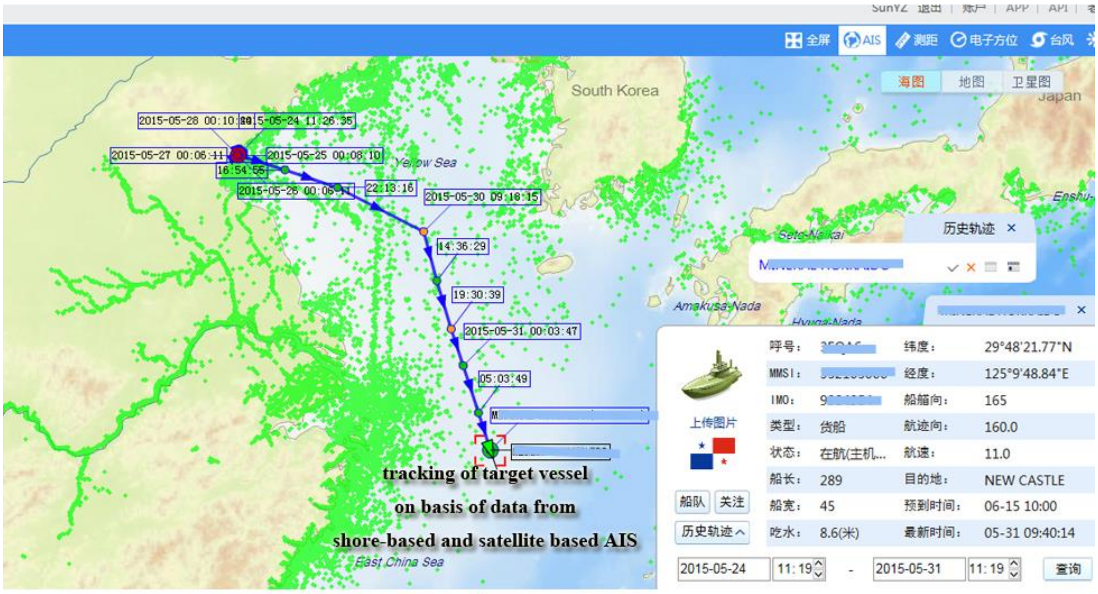

Figure 15: illustration of GIS-based interface of MDA platform (ship identification & tracking)
Source: Compiled by author based on screenshot taken from *myship.com* on 31-05-2015

.2 providing assistance for patrolling. Patrol ships could be marked on the interface of the platform, and, if necessary, advices or instructions could be given by appropriate means.

.3 Digital cruising. With the help of information capturing, data processing and scene simulating, the platform operator or duty officer is supposed to perform digital cruising simulating a patrol vessel navigates at sea. By doing so, violations, close-quarters situations, or even pollutions could be found by MSA officers in office. Figure 15 demonstrates 3D effect of intended digital cruising.

Figure 16: illustration of assumed *digital cruising*
Source: Compiled based on simulator of Shanghai MSA

.4 Anomaly detection for special areas. Here the concept of *Anomaly* is referred the definition by Roy (2008), in the context of MDA as: “Something peculiar (odd, curious, weird, bizarre, atypical) because it is inconsistent with or deviating from what is usual, normal, or expected, or because it is not conforming to rules, laws or customs”. For this function, a user-defined area could be set for drawing particular attentions, and such area is supposed to be defined by means of invoking standard definitions (e.g. territorial sea, etc.) or specifically plotting geographical polygon. The author believes this function will facilitate timely identification of special vessel in special area. For example, special attention could be paid to a highlighted area with high risk of piracy attack, in line with the concept of Information Distribution Facility (IDF) of LRIT (IMO, 2010b).

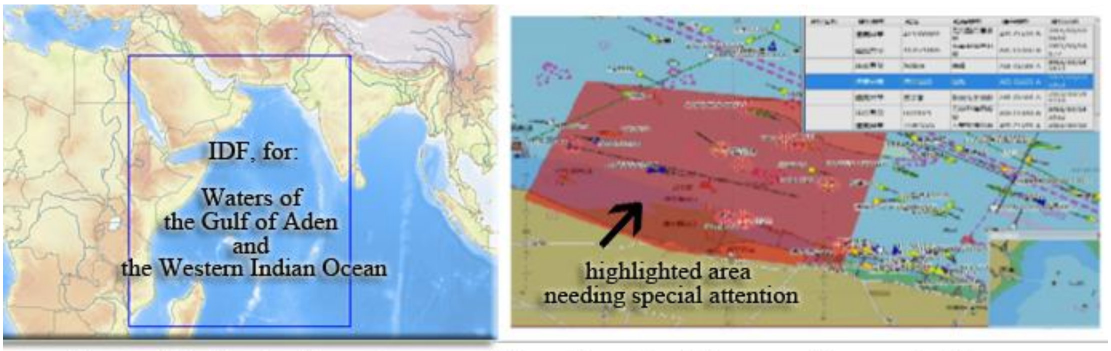

Figure 17: illustration of assumed function of setting area for special focus
(left: IDF, right: user-defined polygon)

Source: Compiled by author based on document of IMO
& screenshot from software of VTS, Shanghai MSA

.5 Oil pollution detection. Guidance by IMO (2009c) suggests that oil pollutant could be detected by means of eyesight observation, photographic and video imagery, and active or passive remote sensing systems. A MDA platform is expected to have function of oil pollution detection as well as targeted ship identification via processing data with various sensors. For example, SAR[1] images of LRIT and/or AIS might detect oil spill in time and lock the responsible vessel. Figure 17 (A) shows a case of oil discharge detection.

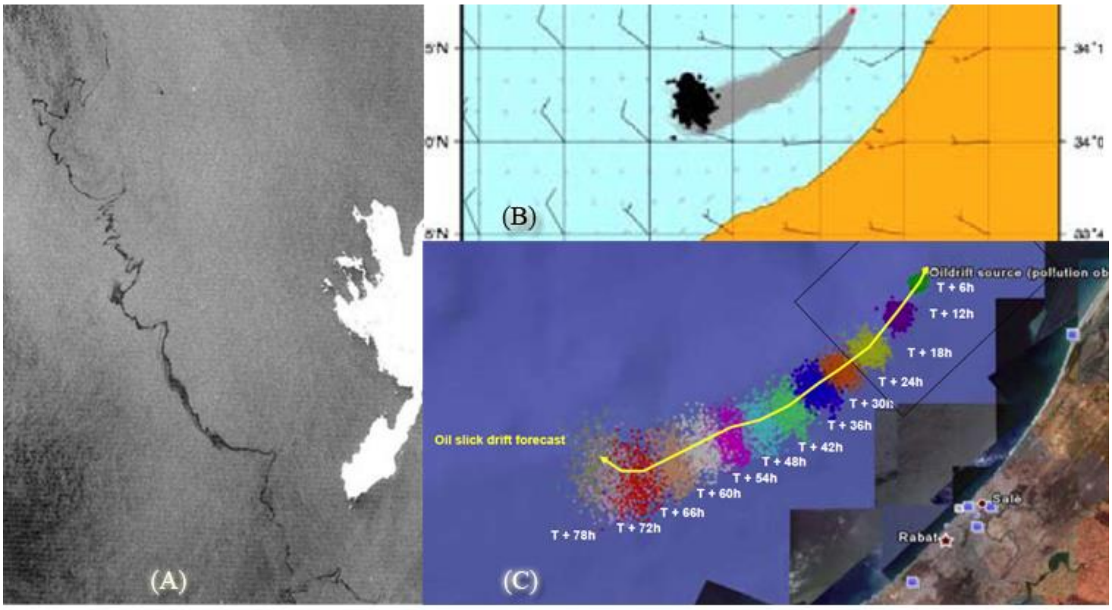

Figure 18: illustration of oil detection and oil drafting modelling
(A: On-going oil discharge captured by satellite SAR on 16 September 2003;
B: mathematical models integrating meteo-oceanic data;
C: synthetic mapping for the modelling of slick drift with)
Source: Compiled in accordance with Guidance document of IMO

.6 Investigation assistance. As the example of oil spill investigation assumed in 4.3.5, a comprehensive MDA system with function of scenario replay and data comparative analysis could contribute to accomplishing MSA's tasks, such as casualty investigation or safety investigation might.

.7 Providing information aids to navigation. Information such as meteorology, oceanography, notices to mariners, etc. could be provided by the MDA system with the aim of enhancing both the administrative decision-making and the services to public.

.8 Pollutant drifting modelling. A MDA system could predict trend of oil pollutant drifting based on reliable meteorological information, detected oil features and data processing support (IMO, 2009c). Figure 17 (B) and (C) illustrate the process of this function.

.9 Statistics and analysis. Searching the records of ships' positons and displaying it on GIS interface. By doing that for a specific period, the navigation routes and ships density could be identified, which is believed to benefit Authorities' decision-makings, such as laying out fairway, traffic separation schemes, or anchorage, etc.

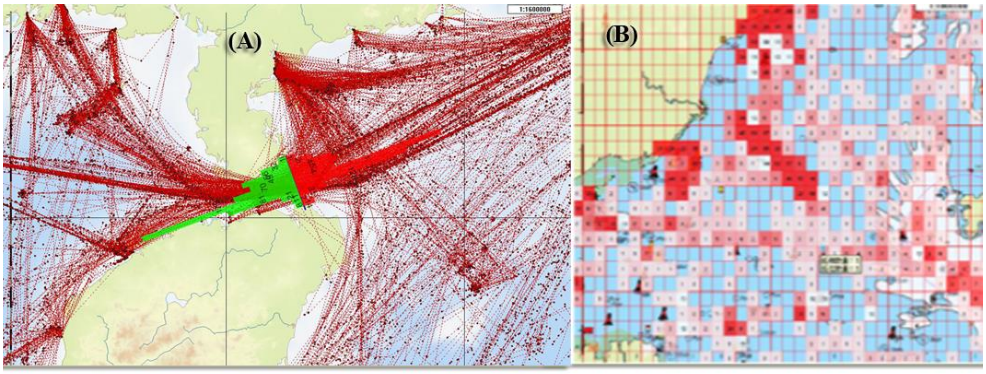

Figure 19: illustration of function of statistic and analysis
(A: tracking of ships' routes and flow of ship course in the area of Qiongzhou Strait;
B: density statistic near Chinese coastal waters)
Source: compiled by the author based on Chinese LRIT software

4.4 Chapter summary

This chapter comprehensively analyzes the necessity, possibility, expected benefits and intended functions of establishing Chinese MDA system. By means of introducing of more information on Chinese status quo, both administrative reality and IT development, necessity of establishing Chinese MDA is substantiated. The author would like to remind the fact that it's hard for China MSA to implement its overall responsibilities of governing and serving vessels navigating away from coastline, and that MDA system might probably improve this situation at least in the field of maritime surveillance. The author believes it's urgent to establish Chinese MDA platform.

The feasibility of establishment of Chinese MDA is also validated through analyzing successful cases abroad and IT development in China. Some potential benefits of MDA are discussed in this chapter. Nine essential functions for a comprehensive MDA system are supposed from perspective of maritime responsibilities and practical tasks in China.

Chapter 5 Introduction on relevant experiments

A comprehensive project should be performed step by step, especially when innovative technology is involved. Conducting experiment is a good choice as preliminary procedure, which would benefit subsequent research.

5.1 Experiments conducted by others

With the purpose of evaluating the capacity of satellite-based AIS, a project named as *PASTA MARE* was conducted by EMSA. Technical theory implies that message collision and receiver saturation are probably the main factors impacting the performance of satellite-based AIS. Message on collision is caused by lacking of synchronization since the SOTDMA protocol was designed only for VHF-range area (please review section 2.2.1 for more details). Receiver saturation is the result of a large amount of messages sending in high traffic density area (Luxspace Sarl, 2010).

However, this issue stayed in theoretical level until the *PASTA MARE* project was conducted with aim of assessing real performance of space borne AIS. The project was conducted in three phases throughout the 2 year study period, carrying out a series of experiments based on shore-based and satellite-based AIS data (provided by commercial company: *Orbcomm, ComDev/ExactEarth* and *LuxSpace*). Final conclusions related to our research are summarized as follows (Luxspace Sarl, 2010):

.1 tracking and tracing vessels by means of satellite-based AIS is feasible;

.2 experiments revealed that the Probability of Detection (PoD) of satellite-based AIS was not high enough and that the PoD's performance on high sea was much better than that in coastal area;

.3 satellite-based AIS hardly meet surveillance requirement of hourly refreshment rate[3], so a combination of shore-based and satellite-based AIS might be capable to satisfy the requirement;

.4 Satellite-based AIS could improve the overall MDA picture but it does not meet all the demands of marine surveillance;

.5 other detection techniques, e.g. SAR[1], are also needed for certain occasions, such as small ship without AIS, switching off power supply with intention or not, not visible by satellite, etc. and

.6 Polling function of LRIT is a powerful tool to obtain high-frequency position messages, which facilitates the observation of vessels closely.

In fact, similar experiments have been conducted. For example, the Australian Maritime Safety Authority (AMSA) performed, based on ORBCOMM's commercial data, a satellite-based AIS performance trial between 25 June and 4 August 2009. This experiment suggested that "AIS via satellite was useful for obtaining greater maritime domain awareness" (IMO, 2009b).

Another experiment was carried out by Kazemi et al (2013) in Sweden as a part of research on using open data for anomaly detection in maritime surveillance domain. The term of *open data* refers to "the idea of making data freely available to use, reuse or redistribute without any restriction", which is mainly available from science and government. It's noted that professor Kazemi and his team members are of the opinion: "Using today's technology, continuous tracking of all maritime activities by a single sensor is insufficient since it cannot monitor everything that happens in the surveillance area" (the author believes this opinion strengthens the conclusion 3 of PASTA MARE project). In this experiment, a dedicated system based on a proposed framework and algorithms was developed. By using open data sources along with

[3] The situation is supposed has been and will be improved as a result of technical development and more satellites being launched as introduced in section 2.2.3.

other traditional sources of data (e.g. AIS), the experimental system was operated to monitor activities of vessels and to identify those with unusual behaviors. Validities of the detection findings were verified by comparing the results of system operated by Swedish Coastguard. After four weeks validation and subsequent analyzing, the experiment concluded that "using open data will improve the efficiency of the surveillance systems by increasing the accuracy and covering unseen aspects of maritime activities".

5.2 Experiment with the author's participation

5.2.1 General information

With the purpose of comparing the performances of different sensors for ship monitoring, Shanghai MSA cooperating with Shanghai Maritime University (SMU) conducted an experiment in November 2013. The author participated in, as a representative on behalf of Shanghai MSA, this research and would like to introduce it. The experiment was composed of two items: (a) detection for fixed-area; (b) detection on passage. The primary objective of experiment item (a) is to verify three different types of SAR[1] sensor and to compare them with LRIT's detection; while item (b) focuses on more sensors including satellite AIS, shipborne AIS terminal and Bei Dou satellite[4]. The main sensors used in the experiment are listed in table 3.

Table 3: Sensors involved for the experiement conducted in November 2013

sensor No.	on board *	on shore	satellite-based		
					SAR
1	Radar	VTS	LRIT	AIS *	RadarSat-2
2	AIS terminal	AIS			TerraSAR-X
3	GPS				Cosmo-Skymed
4	Bei Dou terminal				

remark: * only involved in item (b) of the experiment

Source: Compiled by author

The exact location of item (a) is a square formed by geographic coordinates (30°48′ ~

4 *Bei Dou* is a Chinese satellite navigation system. The primary purpose of this satellite constellation is navigation rather than communication or detection, and on AIS sensor mounted on the satellite. Thus it does not be considered as a ship monitor data source in this paper. However, it should be noted that some Chinese vessels, both merchant vessel and fishing boat, had fitted *BeiDou* terminal on board, so this is considered during the experiment in 2013.

31°20′N and 122°10′E~ 122°47′E) nearby CJK anchorage, as shown in figure 19. Item (b) is conducted, with assistance of MV "Yu Feng"- the training ship of SMU, on a shipping line from Zhang Jia Gang, China to Pusan, Korea, as shown in figure 20.

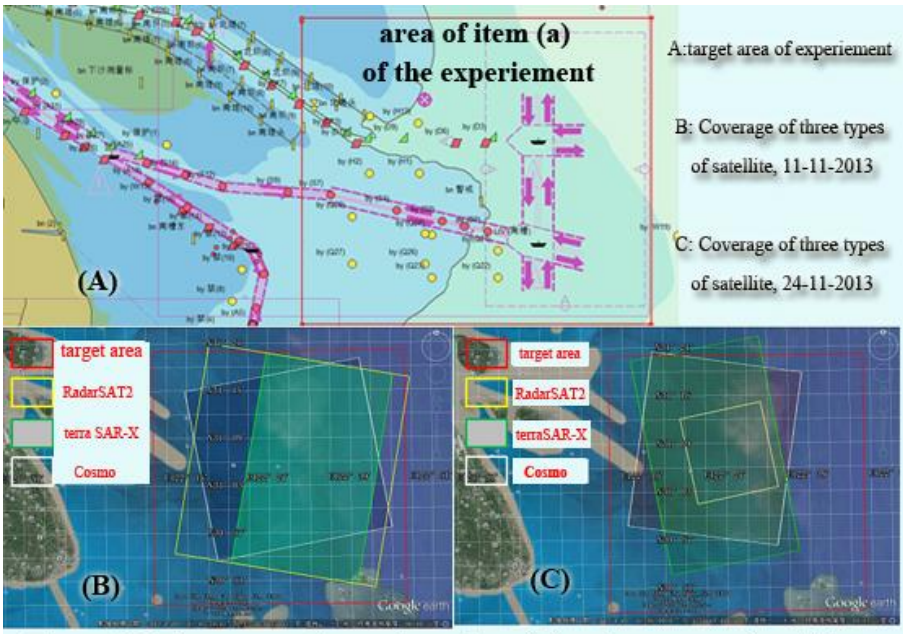

Figure 20: Target area of experiment item (a) and coverage of satellites
Source: Compiled by author based on the experiement

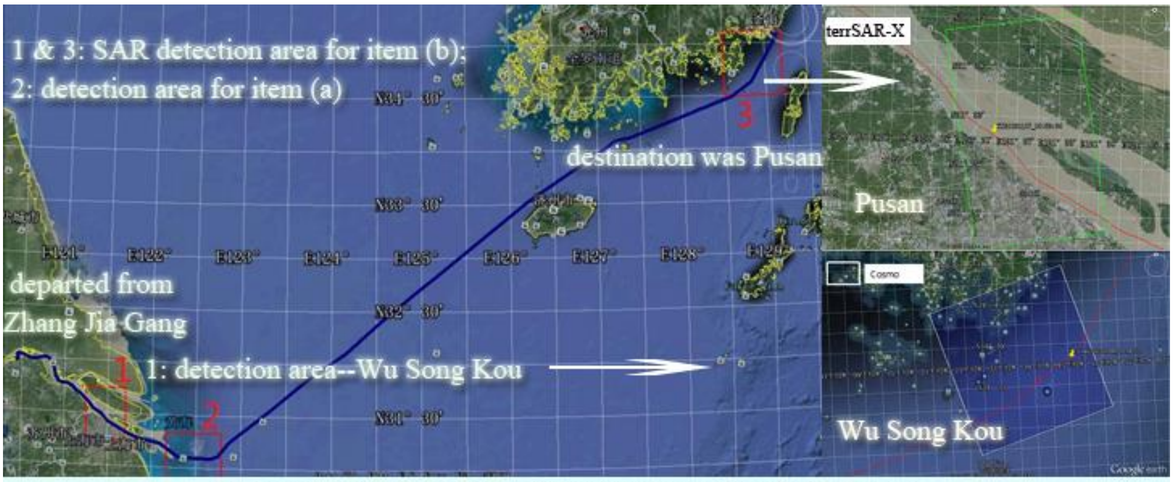

Figure 21: Sailing line of training vessel and trial area
Source: Compiled by author based on the experiement

5.2.2 Data sources and method

The experiment was performed on a basis of different data sources, such as LRIT, AIS, and particularly SAR images. LRIT, VTS, shore-based AIS are data owned and maintained by MSA, so they are readily available; satellite-based AIS data was provided by *China Transport Telecommunications & Information Center (CTTIC)* contracting with *ORBCOMM* company; SAR data was relatively particular because it is purchased from commercial company, so the experimental time was also decided in compliance with the time windows of satellites.

As discussed in section 2.3, there are several distinct algorithms for SAR[1]. In this experiment, an optimized modelling algorithm named *K-distribution CFAR* was chosen since it might eliminate some false alarms generated by sea clutter. The basic mathematic principles of K-distribution CFAR are listed as follows (Wang et al, 2013; Pieralice et al, 2014; Peng and Shi, 2012; Amoon et al, 2013):

Function of relationship between probability density and intensity of image detection:

$$p(x) = \frac{2}{x\Gamma(v)}\left(\frac{Lvx}{\langle x\rangle}\right)^{\frac{L+v}{2}} K_{v-L}\left(2\sqrt{\frac{Lvx}{\langle x\rangle}}\right)$$

$\langle x\rangle$- average value，v- dimension perimeter，L- SAR image number，$\Gamma(\cdot)$- Gamma function，K_{v-L}- (v-L) order modified Bessel function.

To detect ship targets based on K-distribution CFAR: firstly decide sea area as background and calculate the intensity of image detection among the background area, then work out the average value and variance by using the following functions.

$$E(x) = \frac{1}{N}\sum_{i=1}^{N} x_i \qquad Var(x) = \frac{1}{N}\sum_{i=1}^{N} x_i^2 - \left(\frac{1}{N}\sum_{i}^{N} x_i\right)^2$$

x_i- intensity of pixel detected，N- total amount of pixels in background window.

Applying the relationship function to shape parameter, average value and variance as follows:

$$Var(x) = \left[\left(1+\frac{1}{v}\right)\left(1+\frac{1}{L}\right)-1\right]E^2(x)$$

v, the Shape parameter of K-distribution probability density could be calculated. And then, solve the false alarm probability equation

$$1 - P_{fa} = \int_0^{I_c} p(x)dx$$

I_c- threshold of detection could be get. (P_{fa} is false alarm probability, usually be set from $10^{-7}$to 10^{-9}.

Finally, validity judgement for detected pixel X_T could be made according to the value of I_C, with help of standard: $X_T \gtrless I_c$

It could be identified as target pixel when $X_T > I_c$; while it would be recognized as background pixel when $X_T \leq I_c$.

The coordinate system was another factor needed to be decided before conducting experiment, because it would not only influence subsequent calculation for detected targets (as shown in figure 21) but also impact the method of cross-correlation with other data source of ship monitoring. The coordinates of “WGS84” was selected since AIS is also based on this coordinates. Moreover, UTC (Coordinated Universal Time) was used in the experiment.

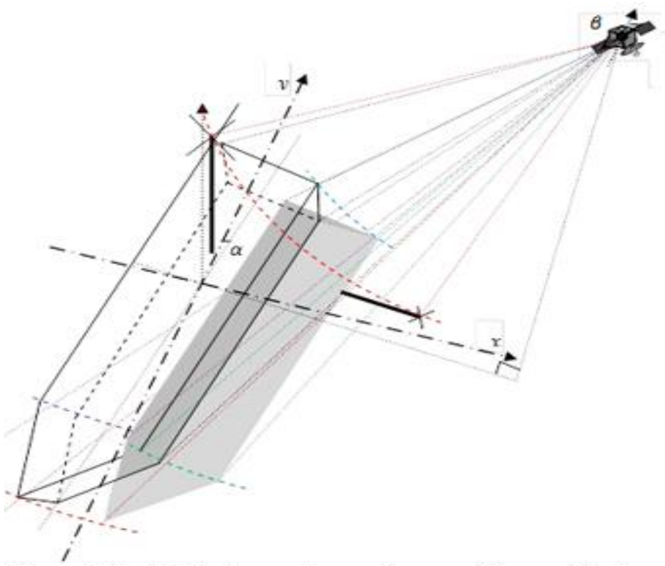

Figure 22: ship’s dimension under specific coordinates
Source: Peng, J. 2012

5.2.3 Result of the experiment

SAR[1] images were got as expected and were compared with other data source of sensors. The detecting result of SAR did not perform as well as a former experiment carried out in the same area with 80% detecting rate (Peng and shi, 2012), however, the author holds the opinion that it was still acceptable and valuable for further research or project. Reception of LRIT data was relatively stable for both item (a) and (b), but only for SOLAS-applied vessel as it required. The performance of satellite-based AIS was not as good as expectation: with regard to item (a), AIS transmitters were probably interfered by other VHF-frequency equipment and occurring message collision with each other, since the ship density in waters of Chinese coastline is very high; as to item (b), less than half of AIS signals of MV "Yu Feng" were detected by satellite, one reason except message collision might be she was out of the visibility scope of satellite. Deviation existed between *Bei Dou* and *GPS*. Besides, cross-correlation and comparison were conducted, and examples of them are illustrated in figure 22 and figure 23. More detailed information is available in Appendix C.

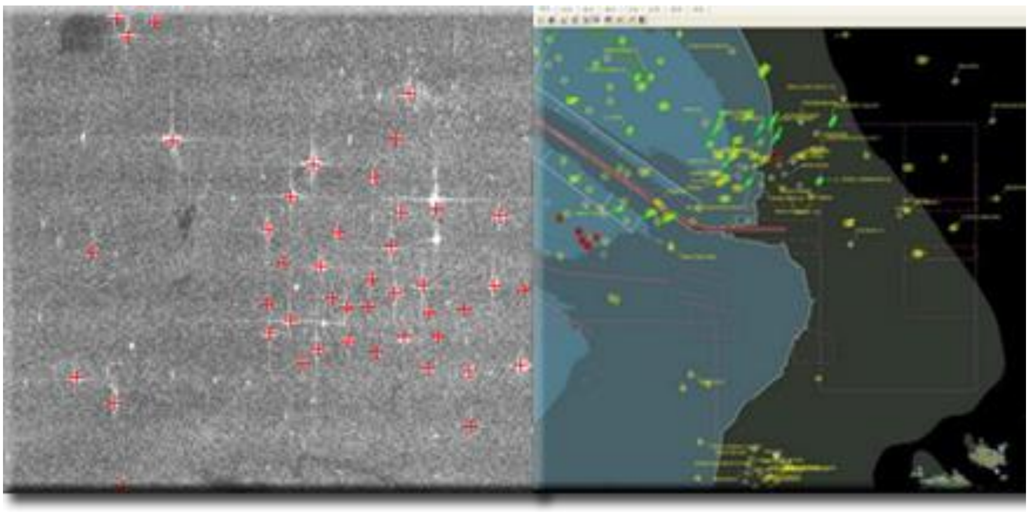

Figure 23: Demonstration of comparison between SAR and VTS
Source: compiled by author based on the experiment report

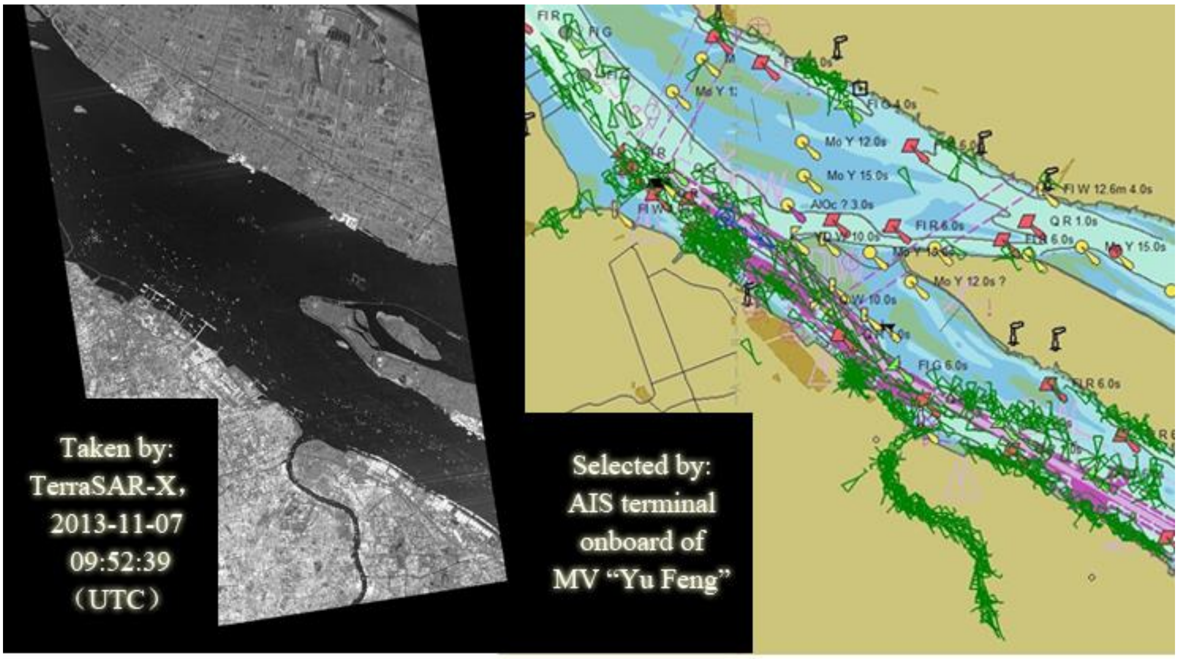

Figure 24: Illustration of comparison of SAR with AIS in item (b)
Source: Compiled by author based on the experimetn report

Result and inspiration of the experiment are summarized as:

.1 SAR[1] is a suitable technique for ship detection, especially for those small ships (LRIT and/or AIS equipment not fitted or working). Nonetheless, SAR[1] could not independently identify those detected targets;

.2 The performance of satellite-based AIS was not good enough to detect all AIS-fitted vessels for the reasons which have been previously discussed or other unrealized ones. However, it should be highlighted that shore-based AIS is a good supplementary data source;

.3 LRIT presents relatively reliable communication capability, especially for those vessels that are large in scale, in good maintenance or new-built ones[5]; and

.4 As mentioned above, VTS, shore-based AIS indicated they are suitable for detection near coastline, but unfortunately, only near coastline.

[5] For some other ships, LRIT function is realized by conventional Inmarsat-C terminals which also engaged for other communications, e.g. GMDSS. It has been approved that the LRIT performances of such shared terminals are significantly worse than those are dedicated used. And some of them are not easy to solve. Anyway, that's another complex issue to be further discussed in this paper, so it would be not debated, and many LRIT-related documents are available in more details

5.3 Chapter summary

This chapter introduces experiments conducted by others, e.g. the *PASTA MARE* project and trial participated by the author. Those experiments are introduced with the intention to verify that:

.1 different sensors for ship detections are of different advantages and disadvantages, such as coverage, updated frequency, reliability, etc. In other words, no one sensor could fulfill all requirements of a comprehensive MDA system;

.2 how potential data sources are decided in the following discussion; and

.3 specific structure of system, method of implementation and algorithm for distinct sensor would impact the performance of a system, so they are needed to be further analyzed for individual system during the establishing process.

Chapter 6 Proposed solutions

Taking into account of discussions in the previous chapters, and especially considering about the *Top-Down Design* Strategy for China MSA's IT development as well as documents of EMSA for construction of its IT platform, some preliminary solutions to China MDA system are proposed in this chapter. It's noted that numerous specified technical specifications would be adopted if such a comprehensive MDA system were established. Thus, some essential technical contents about IT are going to be covered in this chapter with a view to not preparing for a real project but to providing suggestions by the author.

6.1 General principles

(i) As mentioned above, the overall system of China MSA is under construction according to the *Top-Down Design* Strategy at present. Thus the primary principle is that the MDA system should be a subsystem under the overall one, meaning that infrastructure should meet *Top-Down Design* technical requirements. For example, the platform shall be built on SOA architecture through using ESB technology. Moreover, the MSA system should be able to exchange data and to input and/or output services with other subsystems (China MSA, 2011).

(ii) The to-be-established MDA system should reuse the existing systems as many as possible and not impact those keep-operating subsystems, so as to control cost.

(iii) It's important for the Chinese MDA system to follow common standards on process management and interfaces to ensure that other data source, services or processes might be added in future. Thus it should be designed as an extensible and scalable technical platform.

(iv) The author agrees the fact that “Governments for over a decade attempt to publish government data online and make them publicly accessible, readily available, understandable and usable” (Kazemi et al, 2013). So, the system should be designed not only for MSA user but also for public customers.

(v) Data in MDA system might be MSA-owned, depending on purchase or open data as described in section 5.1. Different data sources should be used to the maximum extent, playing individual role according to its characteristics in the MDA platform.

(vi) Knowledge-driven or so called as rule-driven approaches should be adopted in the initial stage of MDA system’s operation, while the primary approach might be replaced by data-driven mode when adequate data is accumulated. In other words, the decision rules of the system might gradually changes from human-dependent mode to big data dependent one.

6.2 Data resources to be integrated

To decide what external information should be integrated as data source for Chinese MDA system, the author holds the view that some essential factors should be taken into account:

.1 data’s features to meet the demands of intended functions, such as coverage, update frequency, probability of detection, reliability, and vessels applied to;

.2 availability of the data (readily available, dependence on purchase or importing from other platforms);

.3 data’s content and format; and

.4 other elements needed to be considered, e.g. commercial confidentiality and/or sensitivity of the data.

Bearing in mind the above considerations, the author list features of some potential data resources are listed in table 4. In addition, more detailed information is attached in Appendix D.

Table 4: Essential features of potential data resources for Chinese MDA system

data source	update frequency	content & format	extraction means	coverage/applicability	reliability	availibility
shore-based AIS	2s – 3min	static and dynamic information of vessel; text message-standard data format	could be derectly imported from database of MSA	cover A1 sea area, terminal fitted ships	high, except high density area	readily available
satellite-based AIS	depends on geographical position and capability of commercial provider, etc.	primary danymic and static information ; standard data format	subjected to contract	nearly golbal coverage	medium, (lower than shore-based AIS)	to be purchased
LRIT	6 hours basically, less intervals subjected to request	identification, positions, time of transmision standard data format	LRIT data center	applies to vessels required as SOLAS, data of foreign vessels subjected to requests	high for most ships; medium for non-dedicated Inmarsat-C terminals	readily available
VTS	about 1 min	basically danymic information. encrypted data	extracted from dedicated VTS system	port area,	high	readily available
SAR	subjected to contract	dynamic data; imagery format	subjected to contract, but data needs conversion and further processing	nearly golbal coverage	high under most circumstances	to be purchased
Integrated administration system / ship registration system	N/A	ship particulars, static data in detail, part of dynamic information. standard data format	could be derectly imported from database of MSA	detail information for: all vessels flying the flag of China, other ships which have been visited in China. Basic data for vessels other than above from Lloyd's database etc.	high	readily available
CHISREP	depends on voyage status	voyage information, basically dynamic data	could be derectly imported from database of MSA	for ships sailing into reporting lines	low (actually, small amount of data)	readily available
additional services	depends on different provider	oceanographic and meteorological data, standard format	some of them are open data	nearly golbal coverage and all vessels	high or medium	could be collected on free basis

Source: Compiled by author based on cellected information, experiment and experience

Based on the above analyses and discussions of previous chapters (including the introduction of individual technique's characteristics, the demand for maritime surveillance with near-seamless-coverage and near-real-time-awareness, and experiences gained from leading cases as well as participated experiment), the author suggests "core" data to be integrated into Chinese MDA, including:

.1 ship position, i.e. information of latitude and longitude and the time stamp of the transmission;

.2 ship identification, by means of IMO number (shall be set as primary key for relational database), MMSI numbers, as well as Name, Call Sign and Flag of ship;

.3 ship and cargo detailed information (the availability might depend on the flag and voyage of the vessel);

.4 ship detection information derived from SAR images;

.5 oil pollution information detected by SAR image and/or other instruments; and

.6 oceanographic and meteorological information.

Accordingly, data sources would be extracted from other IT system, external provider or open data resources might include but not limited to: shore-based AIS, LRIT, VTS, satellite-based AIS, SAR, integrated administration system and open data resources (e.g. oceanographic and meteorological information).

6.3 Data fusion

As analyzed above, to establish a comprehensive MDA system, key data from different sensors are needed. Moreover, Detsis et al (2012) believe that one of largest problem with comprehensive maritime surveillance is that sensors are not globally standardized with regard to sharing information. Therefore, the process of data fusion becomes an important step to achieve an effective MDA system. Data fusion "aims to process multiple sets of data gathered from multiple sources, in order to build a holistic view of the environment" (Nilsson et al, 2012, p.60). In order to provide the most up-to-date and reliable maritime traffic picture, a MDA system has to fuse ship monitoring information abstracted from sensors (e.g. AIS, LRIT, VTS, etc.) and combine them with data from existing databases (e.g. ship registration system, as discussed in the previous section) in a consistent manner. A lot of researches have been done with the intention to develop and improve data fusion models. Notwithstanding some technical difficulties might be encountered in designing distinct measures for data fusion, it has been proved that it's possible to achieve the goal of data fusion by implementing a series of processes (such as detection, association, correlation, estimation, combination, user-refinement, optimization, etc.) based on mathematics, algorithm and modeling (Peng et al, 2010; Nilsson et al, 2012; Gómez-Romero et al, 2015).

Since data fusion is a systemic and complex technology supported by a series of fundamental theories, it's beyond the scope of this paper. Moreover, recalling that a practical case of experiment and corresponding data fusion has been introduced in section 5.2, we will spare no specific discussion on data fusion technology. Alternatively, some basic opinions on data fusion would be expressed. With regard to the demand of Chinese MDA system, the author consider that the selected data sources in previous section should be integrated into the system as far as possible, and that some key points for the integration might be (Peng et al, 2010; Nilsson et al, 2012):

.1 three primary procedures for data fusion might be grouped as data collection, data modelling and data analysis;

.2 efforts should be made to harmonizing coordinate system, time to be stamped, identification verifying, position correction, information correlation, and so on;

.3 data sources selected to be integrated do not mean they should be always used everywhere, in contrast, some of data sources might be only ordered when necessary. For instance, surveillance of EEZ might need only combination of satellite-based AIS and LRIT, or coupled with low solution image of SAR[1] ordinarily, but high solution image of SAR[1] must be purchased to provide high level information service in emergency; and

.4 it's better to continuously improve method and/or modelling of MDA system's data fusion, and system operators as well as experts of MSA are conductive to this process.

An example structure of Chinese MDA system data fusion is demonstrated in figure 24. In addition, a schematic view of the user-fusion model is shown in figure 25, which illustrates different levels of data fusion processes and its relationship with user's optimization.

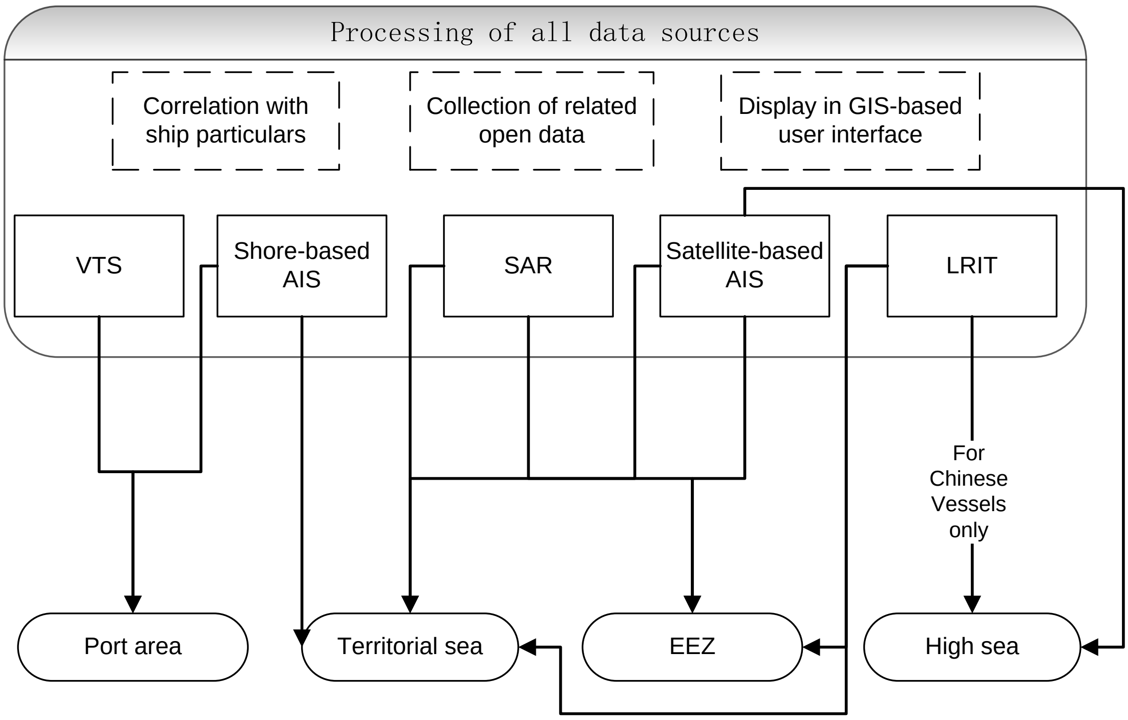

Figure 25:Demonstration of data used for monitoring different areas in Chinese MDA
Source: compiled by author

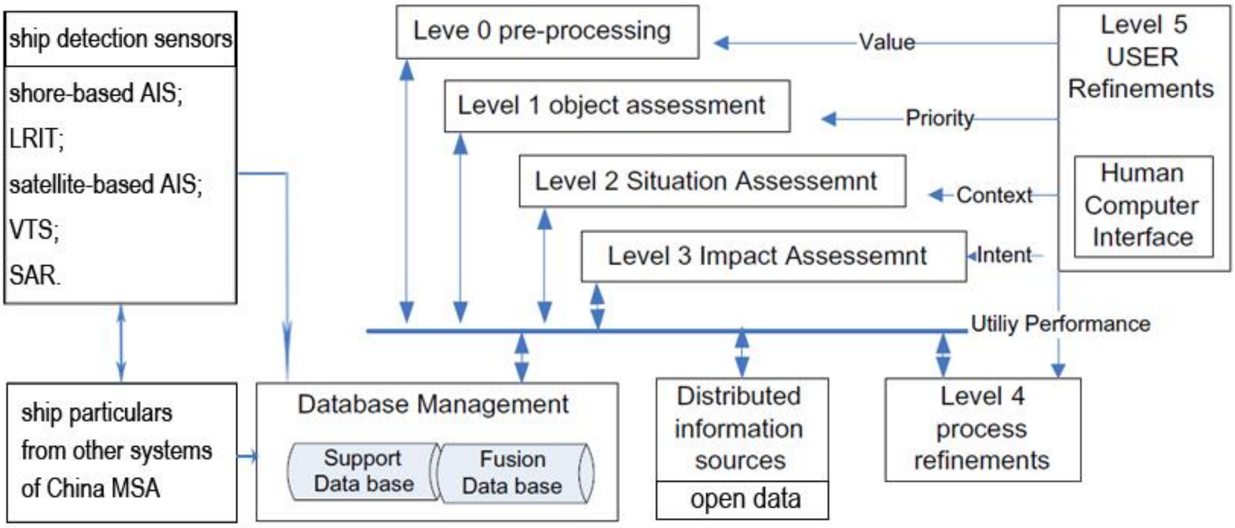

Figure 26: Schematic view of the user-fusion model for illustration of Chinese MDA's data fusion
Source: Compiled according to a research conducted by Nilsson et al.

6.4 System design

Considering the principal design for Chinese MDA system, the author believes two essential elements should be reviewed, i.e. the infrastructure of China MSA's *Top-Down design* and the basic functions of MDA platform. As to the *Top-Down design*, the author hopes it has been basically understood after reading the introduction in section 3.4.2 as well as figure 14. With regard to the second element, nine intended functions have been described in section 4.3 from a perspective of application. Since this section focuses on system design, primary functions of a MDA platform need to be discussed below in terms of IT.

The basic technical functionalities of Chinese MDA system might include (EMSA, 2010):

.1 Data Exchange: data could be provided by or transmitted to other operational applications under China MSA's overall IT system as well as potential external systems;

.2 Data Management and Access: Chinese MDA system should be able to identify each type of data and its provider and to store and manage both independent and integrated data;

.3 Processing of data, including consolidation, correlation, fusion and enrichment of different data sources, as briefly discussed in the former section;

.4 Dissemination: the processed data is distributed to the users, via system-to-system interfaces and visually using the integrated portal of China MSA; and

.5 Federated services: the platform shall allow the management of the applications in a rationalized and effective way. Such horizontal services may include but are not limited to: (i) user management and access control; (ii) data management; (iii) service management; (iv) security; (v) application monitoring; and (vi) logging. And it's noted that such federated services are basically subject to the unified design and construction of overall IT system of China MSA.

The proposed Chinese MDA system shall be in compliance with *Top-Down design* strategy of China MSA, meaning that it should be developed under SOA architecture. The relationship between Chinese MDA platform and the overall IT system is illustrated in figure 26.

As discussed in previous chapters, MDA system, if to be established, would not be an independent system but a subsystem interacting with other applications and/or databases. This means that there is no need to consider too much of some elements for conventional IT system development, such as hardware, storage, security, etc. Instead, development of Chinese MDA system should concentrate on data and services which would input from or output to other components. In order to interpret this idea clearly, figure 27 is compiled and provided below, demonstrating the working principle of data processing module as an example.

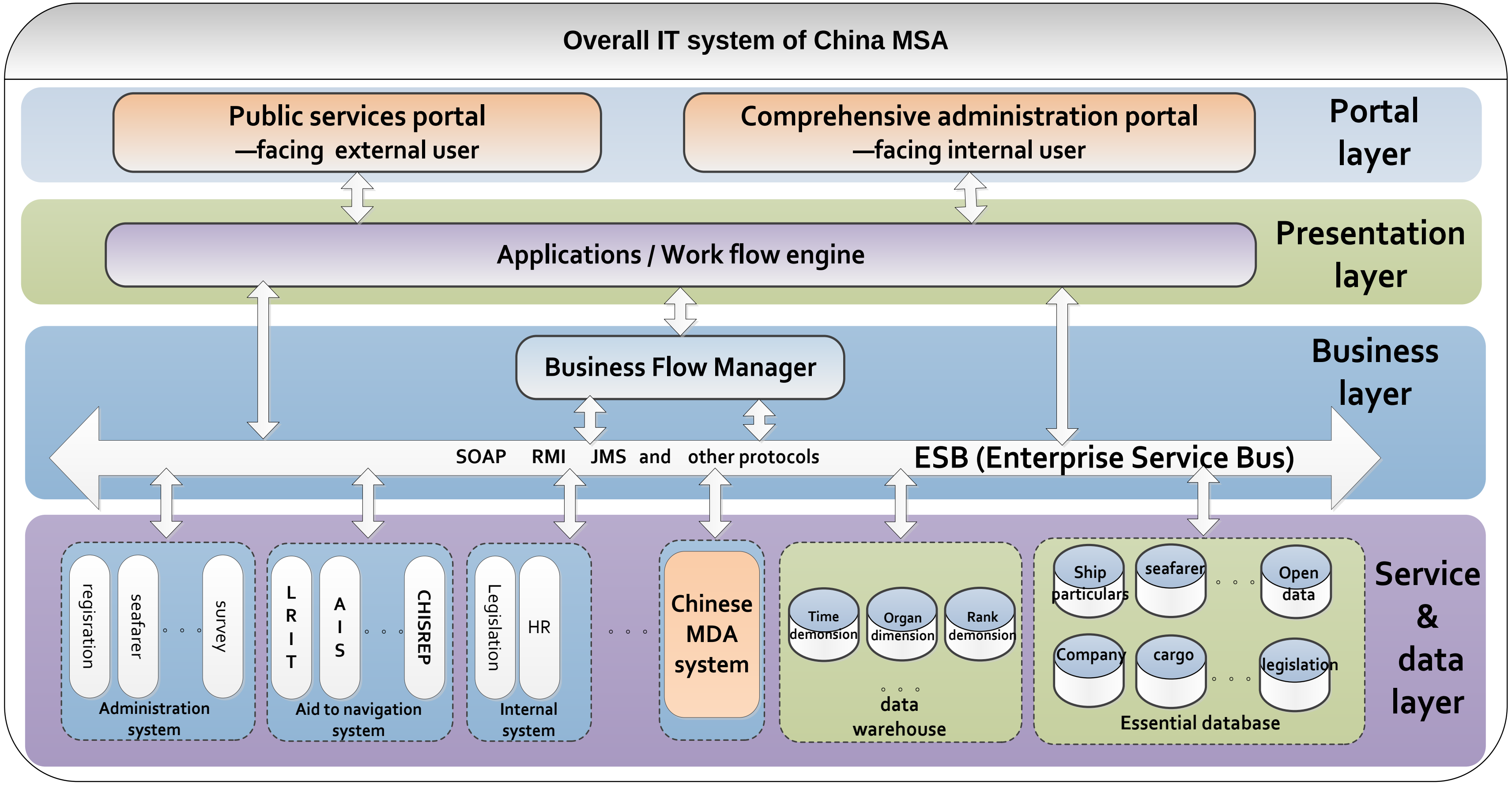

Figure 27: Illustration of relationship between Chinese MDA platform and overall IT system
Source: compiled by author taking account of *Top-Down design* strategy

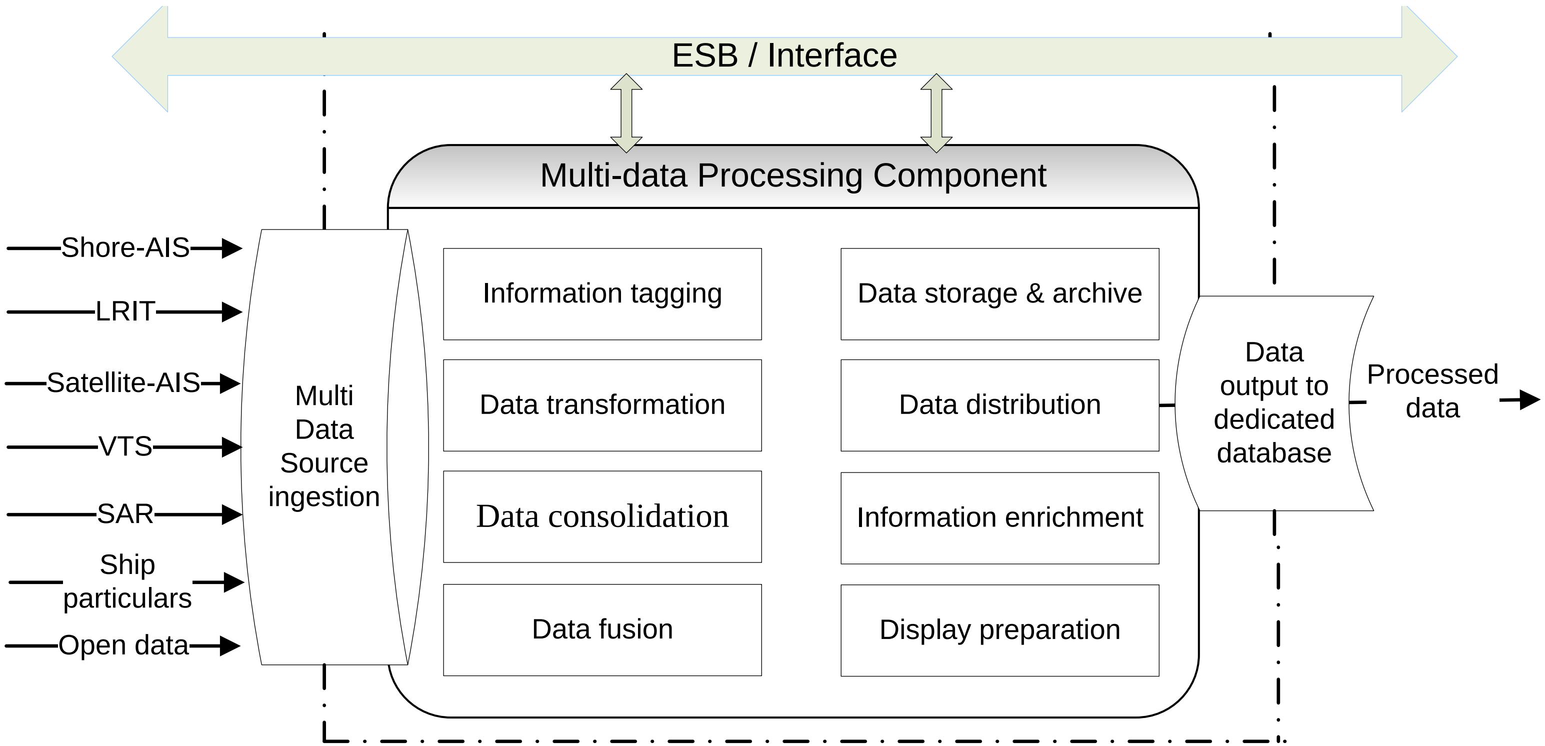

Figure 28: Demonstration of data processing component for MDA platform
Source: compiled by author referring document of EMSA

6.5 Chapter summary

In summary, this chapter proposes solution for developing Chinese MDA system taking into account of analyses of previous chapters and IT strategy of China MSA. Six general principles for establishing Chinese MDA platform are suggested. By means of analyzing demands of MDA's function and comparing data features of potential resources, the research identifies seven essential data source for MDA system in this chapter. Furthermore, based on the author's experience, knowledge and learning gained from other researches, fundamental principles and suggested instances are provided for processes of data fusion and system design, and some graphical interpretations are presented so as to further explain ideas of the author.

Chapter 7 Conclusion

It's been a consensus that shipping is an important industry with long history. While along with the development of technologies and the growing consciousness of marine conservation, significant changes are gradually taking place in this traditional sector. Technical innovations not only occurred in marine transporting but also presented in the patterns of maritime administration. This paper concentrates on improving the effectiveness of China's maritime surveillance with the help of modern technologies. In order to conduct an all-around and objective research, the following contents are discussed.

(i) Necessity: By reviewing relevant international conventions, such as *UNCLOS, SOALS, MARPOL*, as well as Chinese domestic laws related to marine affairs, it's proved that establishing MDA system is not only supported by current legislations but also encouraged as a means to fully implement obligations of Contracting Government. The status quo of China's maritime administration is illustrated via listing statistics of ship registration, maritime trade, marine territory and available resources of China MSA, which implies that it's urgent for China to create a comprehensive mechanism for realizing effective marine surveillance. In other words, it's hard to fulfill China MSA's responsibilities outside the coastal area on a basis of existing resources, i.e. number of staff, patrolling vessel, helicopter, etc. For example, how could 3.5 million km^2 of ocean territory is effectively supervised by only a few of ocean-going vessels and helicopters? And how could timely response be made to non-innocent passage, marine accident or oil spill under the condition of few-awareness at sea? Thus, the author believes establishing MDA system is one of the efficient measures to deal with the difficult situation at present.

(ii) Feasibility: Besides the possibility in term of legislation, other aspects for establishment of Chinese MDA system are also analyzed in the paper. First of all, from perspective of technology, it's possible to obtain a complete recognized maritime picture with the help of communication and information techniques such as SAR[1] remote sensing, satellite-based AIS, etc. Secondly, with respect to existing cases, some typical projects which have been done or are under construction, verifying the feasibility of a comprehensive MDA system. Last but not least, it's achievable to develop such a MDA platform under current conditions of China MSA, for some independent marine detection systems, e.g. LRIT, shore-based AIS, have been operating in China. On the other hand, an overall IT system of China MSA is under construction by guidance of *Top-Down design* strategy, which provides necessary resources such as hardware, data, and budget.

(iii) Proposed solutions: As the key point of this paper, some primary solutions to establishment Chinese MDA system are proposed on the fundament of knowledge and understandings learned from researches, projects and experiments performed by others, as well as the experience gained from a former experiments participated by the author. Those solutions cover essential processes of platform development. i.e.: general principles of developing Chinese MDA system; primary functions of the system, from the perspectives of both practical applications and technical implementation; selected data sources for Chinese MDA platform are suggested; principle and method of data fusion are suggested, and general design of MDA, as a component of overall IT system, is also proposed in this paper.

In conclusion, numerous vessels are navigating on the waters under the jurisdiction of China, so it's necessary to be aware of activities and statuses of those ships, although there might be long distance away from coastline and in dynamic situation. However, by taking advantage of monitoring from multi-sensors and integrating of data from multi-sources, it’s definitely possible to be aware of situational pictures at sea. It should be noted that the solutions to establishment MDA system are not proposed as a subsequent project specification; instead, they are proposed with intention to draw more attentions to considering the establishment of Chinese MDA system and to illustrate the feasibility of establishing such a system as well as the conformity with IT development strategy of China MSA.

Appendix A

Relevant provisions of conventions and laws supporting maritime surveillance

Convention/ Law	Article	Apply to	Sea area	Characteristics of maritime surveillance
UNCLOS	• Article 17 • Article 18 • Article 19 • Article 21 • Article 22 • Article 24 • Article 25	All ships	Within Territorial Sea	To provide, guarantee and identify the right of innocent passage; To set up sea lanes and traffic separation schemes, etc.
	• Article 56		EEZ	Sovereign right and jurisdiction right
	• Article 96	Government Ship	High sea	immunity
	• Article 110 • Article 111	War ship or Government ship		Right of visit; Right of hot pursuit.
SOLAS	Chapter V • Article 11 • Article 12	Governmental Authorities; applicable ships	Waters under jurisdiction	Ship reporting system; Vessel traffic services (VTS).
	• Article 19-1	Applicable ships (basically international voyage)	all	Requirement related to LRIT
	• Article 19.2	Applicable ships (basically international voyage)	all	Requirement related to AIS
SAR[2] Convention	Chapter V, etc.	Governmental Authorities; applicable ships	Waters under jurisdiction	Ship reporting system

MARPOL	Annex I • Article 15 • Article 34; Annex II • Article 13; Annex III • Article 7 • Article 34 Annex IV • Article 11; Annex V • Article 3 • Article 4 • Article 5 • Article 6; Annex VI • Chapter 3	Applicable ships	Waters under jurisdiction	Prescribe specific discharge standards and marine environmental protection requirements, and also empower authorities of Member States to enact superintendence such as pollution detection, ship's activity monitoring, marine environmental protection.
Law of the People's Republic of China on the Territorial Sea and the Contiguous Zone	• Article 6 • Article 8 • Article 9 • Article 10 • Article 11	Foreign ships	Within Territorial Sea	right of innocent passage; necessary actions could be taken in order to prevent and stop non-innocent passage; sanctions against violations; To set up sea lanes and traffic separation schemes, etc.
	• Article 13	Government authorities	in the contiguous zone	Exercise control measures
	• Article 14	Ships served for military purpose or government	In the territorial sea, contiguous zone, or outside the aforesaid area	Enact the right of hot pursuit subjected to prescribed conditions
Law on the Exclusive Economic Zone and the Continental Shelf of the People's Republic of	• Article 3 • Article 4 • Article 8 • Article 10 • Article 12	Government authorities	Economic Zone and the Continental Shelf	Sovereign right and jurisdiction; Right of visit; Right of hot pursuit, etc.
	• Article 7 • Article 9	Organization or individual		Activities should be subjected to approval and under governance of

China				competent authorities
Maritime Traffic Safety Law	• Article 14	Ship and her owner and/or operator	Waters under jurisdiction	Empower competent authorities (MSA) to promulgate special regulations with a view to the governance of vessel traffic
Marine Environment Protection Law	• Article 5 • Article 19 • Article 67 • Article 71 • Article 72	ships	Waters under jurisdiction	Give rights to competent authorities (MSA) to supervise, investigate and inspect vessels; Set obligation to competent authorities (MSA) to monitor marine pollution from ship and response report of pollution

Source: Compiled by author based on provisions of relevant conventions and laws[6].

[6]: Detailed information is listed in Reference.

Appendix B

Existing independent IT systems being used by China MSA				
No.	**Name**	**Basic function**	**Structure**	**Usage status**
Category A: Maritime administration systems				
1	ship registration system	Maintenance of ship name, management of registration procedures, identification card, issuing certificate, etc.	Browser/server (B/S) Distributed deployment	About 100 registry departments within Branch Bureaus. 162 registry departments within Regional Bureaus
2	Ship identification number management system	Whole processes management for Ship identification number	B/S Centralized deployment	Ship owner; Departments of Branch Bureaus and Regional Bureaus.
3	Integrated administration system	Approval for entry and departure of port, Flag State inspection, pollution prevention operation, etc.	B/S Distributed deployment	964 sites within Branch Bureaus. 1806 registry departments within Regional Bureaus
4	PSC implementation system	Whole process management of PSC	B/S Deployed in Liaoning MSA	Authorized PSC offices
5	Ship survey management	Whole process management of survey	B/S & Client/server(C/S)	620 authorized survey agencies
6	Management for surveyor system	Registered surveyor's examination, certification, etc.	B/S Deployed in China MSA	Five pilot sites
7	Seafarers management system (sea-going)	Training, examination, certification, maintenance, etc.	B/S Centralized deployment	56 authorized authorities/agencies
8	Seafarers management system (inner waters)	Training, examination, certification, maintenance, etc.	B/S Distributed deployment	Regional Bureaus

9	Seafarers examination system	Examination, questions	Local area network	Examination sites
10	Seafarers passport management system	Issue seafarers' passports	B/S Centralized deployment	Branch Bureaus
11	Information services web for seafarers	Publishing information	B/S Centralized deployment	Seafarers
12	Recruitment for seafarers web	Recruitment information service	B/S Centralized deployment	Seafarers
13	Management of pollution prevention system	Approval for pollution prevention operation, on spot inspection, emergency response management	B/S Distributed deployment	Branch Bureaus
14	Cargo and passenger management system	Declaration of cargo/passenger, safety inspection, etc.	B/S Distributed deployment	Branch Bureaus
15	Ship card management system	Processing management of ship card	B/S Centralized deployment	Registration offices
16	Maritime administrative charging system	Fee charging operation, receipt management, account settling, etc.	B/S & C/S, Distributed deployment	Branch Bureaus
17	Command assistance under emergency system	Decision-making support, safety status monitoring, information analysis	B/S & C/S, Distributed deployment	MRCCs
18	Navigation condition manage system	Approval of project on/under water, promulgating notice to mariners	C/S	Branch Bureaus
19	Internal website	Web portal of China MSA (internal network)	B/S Centralized deployment	Employees of China MSA
20	External website	Web portal of China MSA (external network)	B/S Centralized deployment	The public
Category B: Aids to navigation / Maritime surveillance systems				

21	LRIT system	LRIT service and corresponding management	C/S Centralized deployment	LRIT NDC of China, Several authorized users
22	AIS system	Ship detection and replay historical record	B/S, 4 regional center deployed	AIS data center and Other users
23	CHISREP	Reporting ship voyage information	Shanghai MSA	MSA
Category C: internal administrative systems				
24	Legislation system	Legal issues management	B/S Distributed deployment	Branch Bureaus
25	Human resource system	Information maintain, search, etc.	B/S Distributed deployment	Branch Bureaus
26	Project arrangement system	Project management	B/S Distributed deployment	Branch Bureaus
Category D: other system				
27	Maritime comprehensive statistics system	Statistics and analyzing of maritime business	B/S Centralized deployment	Branch Bureaus

Source: compiled by author by taking account of Top-Down design of China MSA

Appendix C

Details of experiment carried out by the author in cooperation with Dr. Wang S. Z. and Dr. Peng J. et al in November 2013. The source of figures and tables in this appendix are all from reports of the experiment.

Item (a): Area Detection

1. Experiment period

Collecting data twice: 11-11-2013, 24-11-2013

2. Area to be detected by distinct SAR1 mounted on satellites

Chose the period that satellites RadarSAT2、TerraSAR-X、Cosmo-Skymed passing the target area at nearly same time, as shown in figure C-1, figure C-2, table C-1 and table C-2.

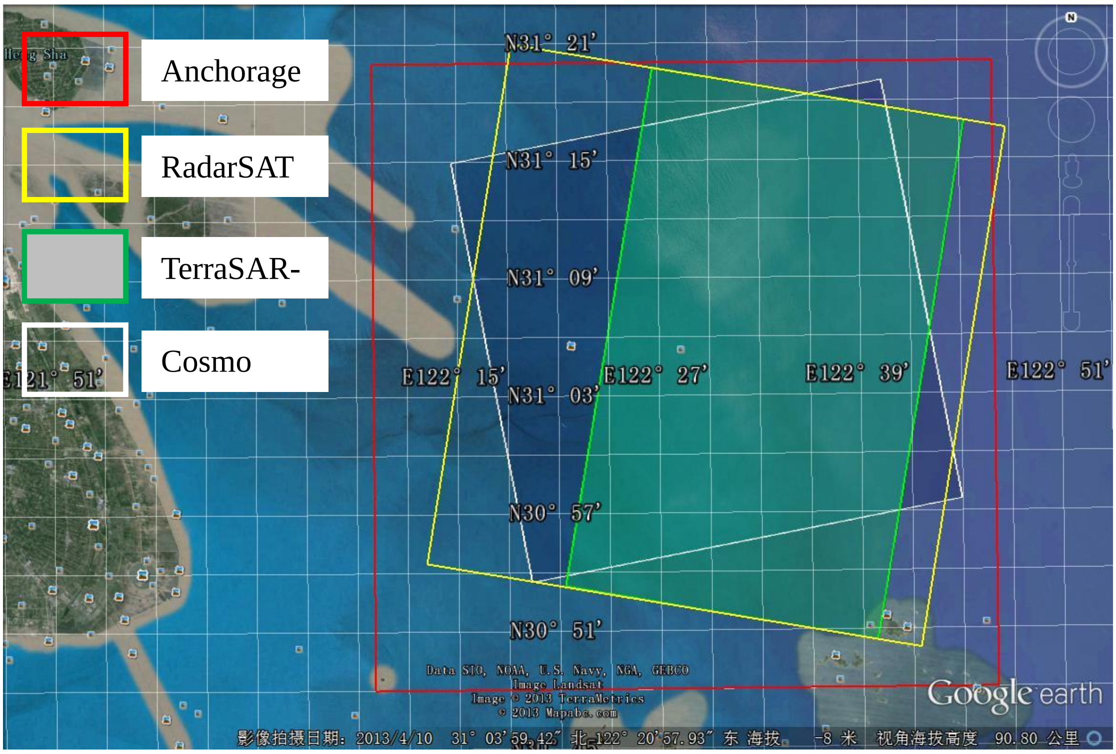

Figure C-1: Illustration of satellites passing on 11-11-2013

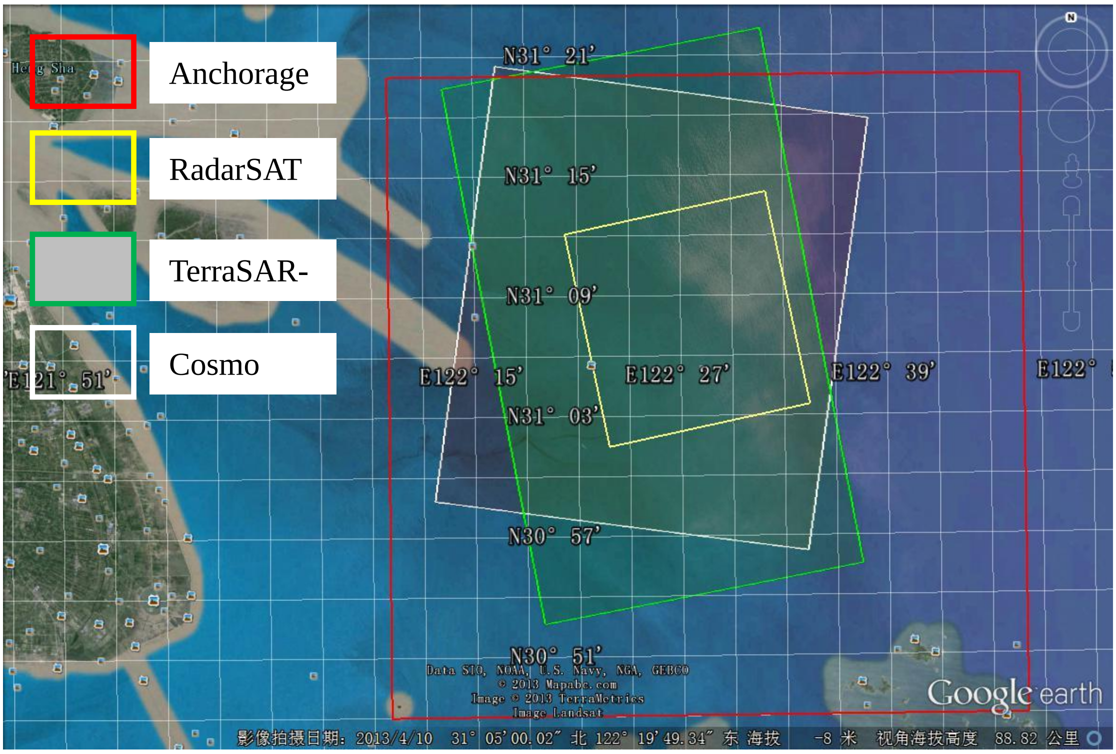

Figure C-2: Illustration of satellites passing on 24-11-2013

Table C-1: Parameters of related satellites, 11-11-2013 (coordinates: WGS84)

No.	Satellite	Mode	Strip_ID	period	Shooting time (s)	grade	Resolution ratio	incident angle	Detection area （NW, NE, SW, SE）	coverage (km)
1	RadarSAT2	Fine	30860	2013-11-11 21:43:15:69	7.5	SSG	8m	43.61	31°21'N/122°18'E, 31°17'N/122°48'E, 30°54'N/122°13'E, 30°50'N/122°42'E	50×50
2	TerraSAR-X	SM	149/ Strip_009R	2013-11-11 21:53:44.73	10	EEC	3m	35.287	31°20’N/122°27’E, 31°17’N/122°45’E, 30°53’N/122°21’E, 30°50’N/122°40’E	30×50
3	COSMO -SkyMed-1	Himage	34791	2013-11-11 21:36:13.06	5.822	EC	3m	32.276	31°15’N/122°15’E, 31°19’N/122°40’E, 30°54’N/122°19’E, 30°58’N/122°45’E	40 ×40

Table C-2: Parameters of related satellites, 24-11-2013 (coordinates: WGS84)

No.	Satellite	Mode	Strip_ID	period	Shooting time (s)	grade	Resolution ratio	incident angle	Detection area （NW, NE, SW, SE）	coverage (km)
1	RadarSAT2	Ultra fine	31039	2013-11-24 09:45:40.12	3	SSG	3m	27.09	31°12'N/122°20'E, 31°14'N/122°32'E, 31°02'N/122°23'E, 31°04'N/122°34'E	20×20
2	TerraSAR-X	SM	5	2013-11-24 09:44:15.73	10	EEC	3m	31.020	31°19’N/122°13’E, 31°22’N/122°32’E, 30°53’N/122°19’E, 30°56’N/122°37’E	30×50
3	Cosmo-SkyMed -4	Himage	16505	2013-11-24 09:28:40.90	5.93	EC	3m	53.940	31°21’N/122°16’E，31°18’N/122°38’E，30°59’N/122°13’E，30°56’N/122°34’E	40 ×40

3. Experimental data

3.1 meteorology (24-11-2013)

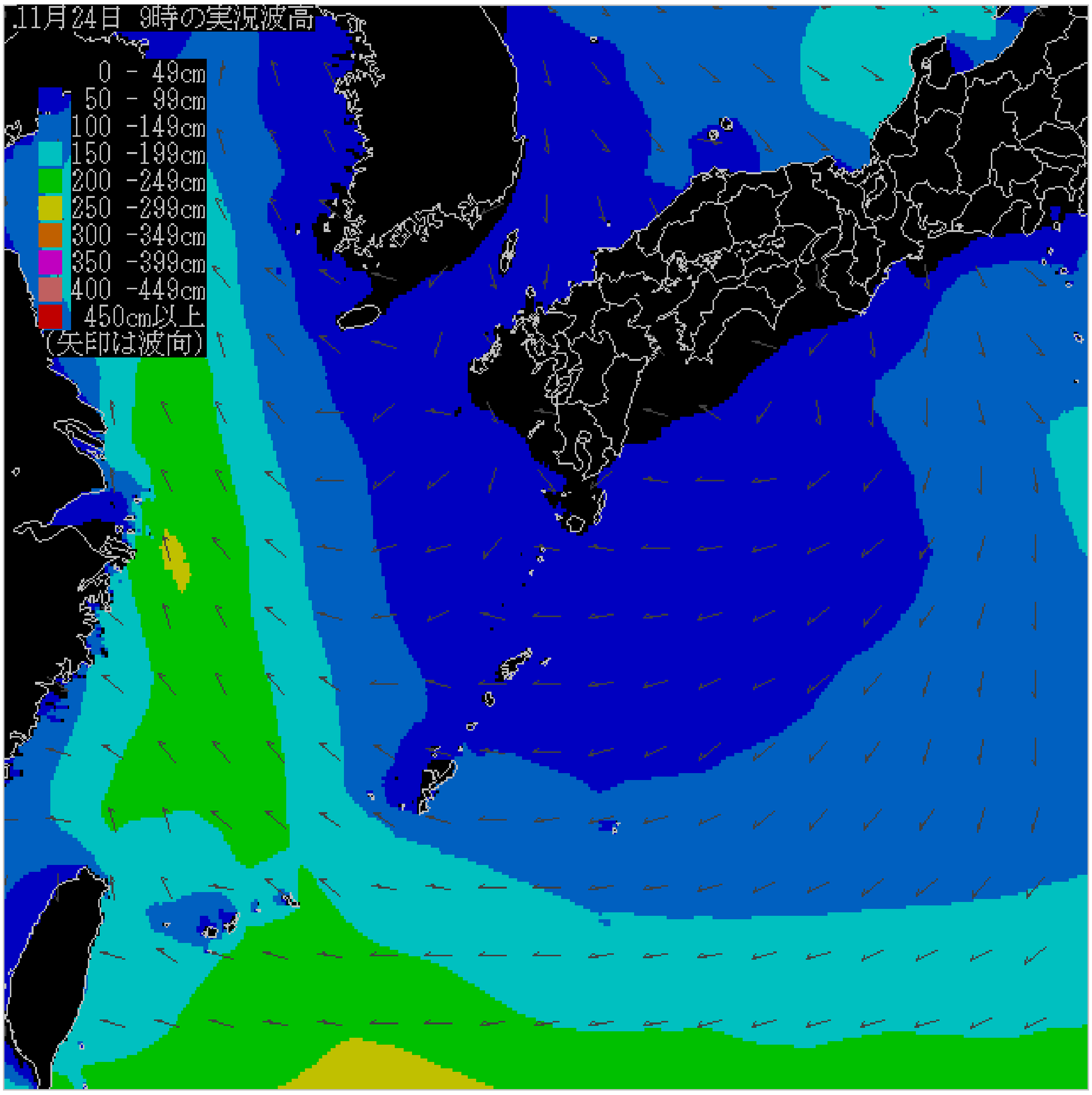

Figure C-3: Illustration of wave at 2013-11-24 09:00（UTC）

3.2 remote sensing (SAR[1] images)

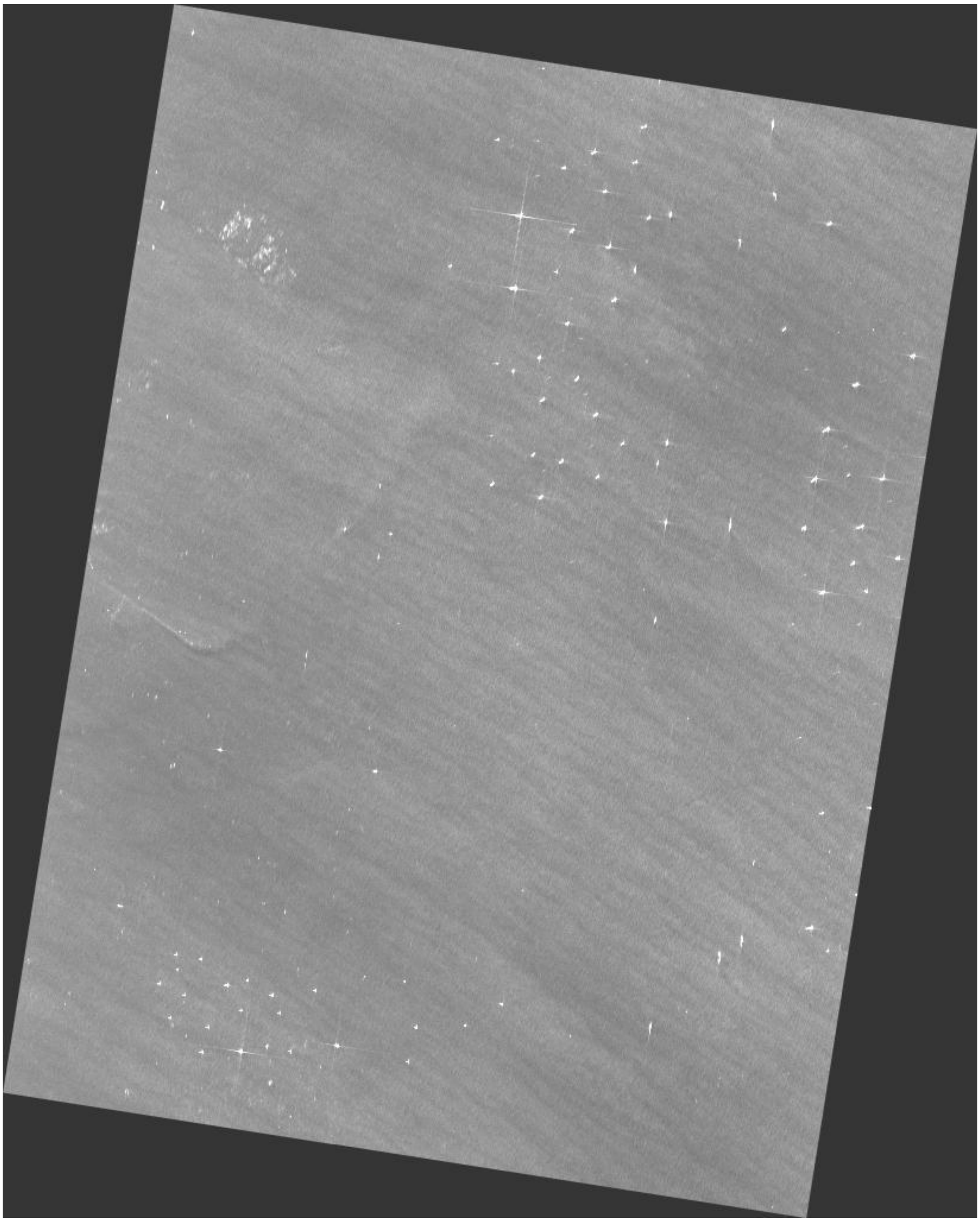

Figure C-4: SAR image of Cosmo-Skymed-4,2013-11-24 09:28:46-09:28:54（UTC）

Figure C-5: SAR image of RadarSAT-2,2013-11-24 09:45:40.12（UTC）

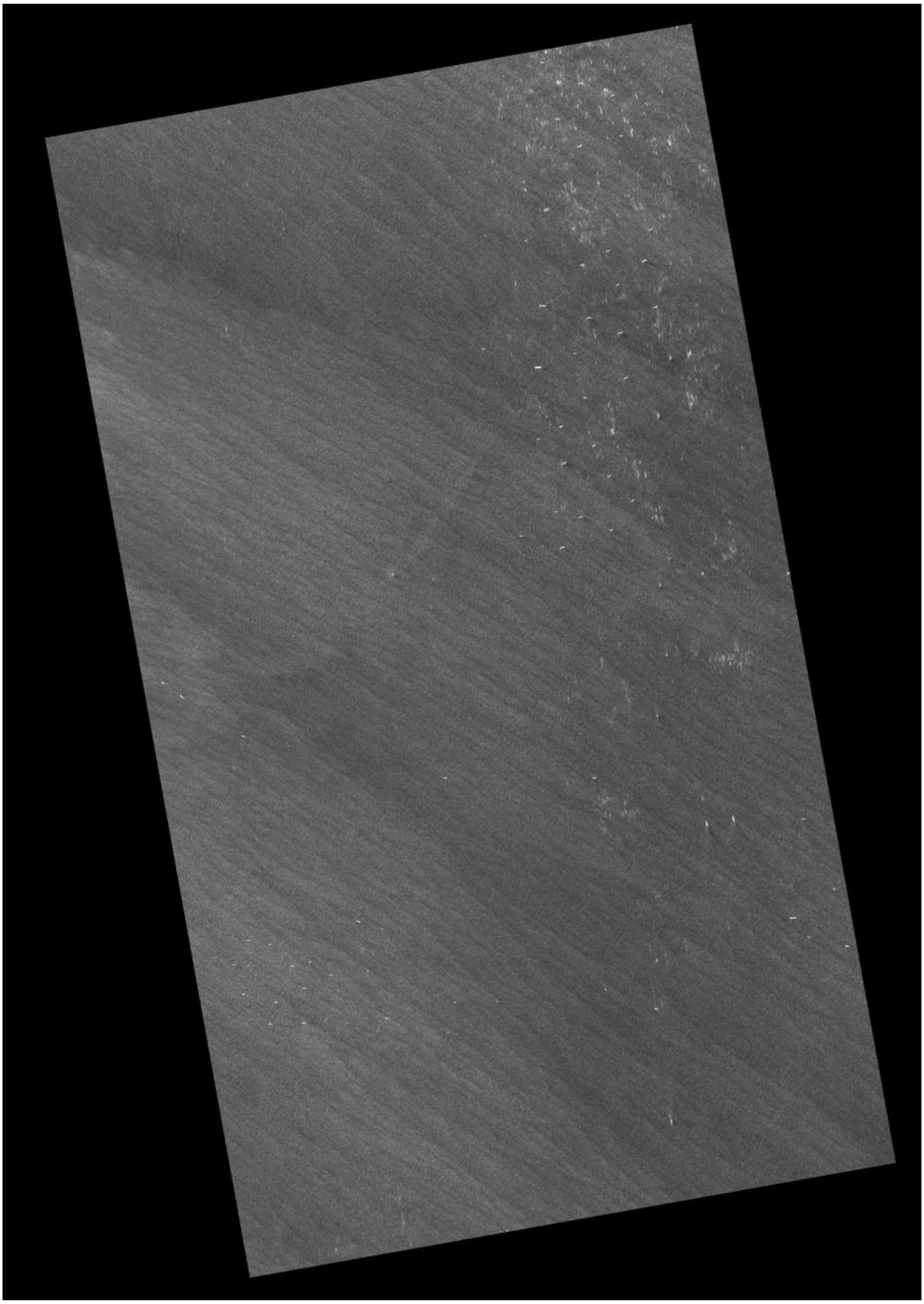

Figure C-6: SAR image of TerraSAR-X,2013-11-24 09:44:15.73（UTC）

3.3 LRIT

Table C-3: ships detected by LRIT（2013-11-24 08:00~10:00UTC）

IMO	SHIP_NAME	SHIP_FLAG	UTC_TO_LRIT_TIME_STAMP(TIME)	LONGITUDE	LALTITUDE
8404381	XIANHU	CHN	2013-11-24T08:42:00.000Z	122.7758	31.01
9672569	JIN HAI LAN	CHN	2013-11-24T08:50:00.000Z	122.5639	30.76528
9643752	ZHONG YU 1	CHN	2013-11-24T09:22:00.000Z	122.6358	31.02194
9198111	OOCL SHANGHAI	HKG	2013-11-24T09:24:00.000Z	122.6153	30.7825
9332729	GLORY FORTUNE	HKG	2013-11-24T09:26:00.000Z	122.6919	31.09389
9216975	RUI NING 1	CHN	2013-11-24T09:46:00.000Z	122.4825	31.28778
9101792	SITC PYEONGTAEK	HKG	2013-11-24T09:52:00.000Z	122.5292	30.90111

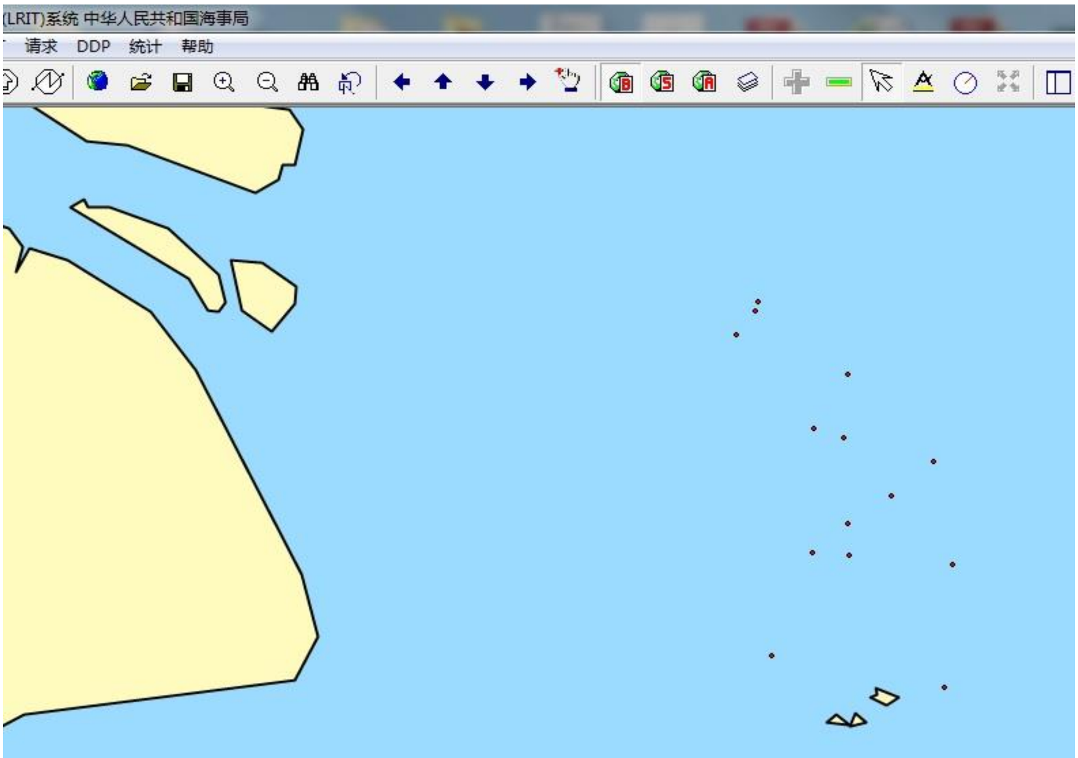

Figure C-7: Historical replay of LRIT , 2013-11-24 06:00~12:00（UTC）

Item (b) Detection on Passage

1. Factors of trial ship and her voyage

Ship name: MV “Yu Feng”

IMO：8822038

Call Sign：BPQX

MMSI：412049010

Experimental period：from 7 November 2013 to 9 November 2013

Voyage:：from Zhang Jia Gang, China to Pusan, Korea.

2. Experiment plan

（1）Wu Song Kou, as shown in figure C-8.

（2）Pusan, as shown in figure C-9.

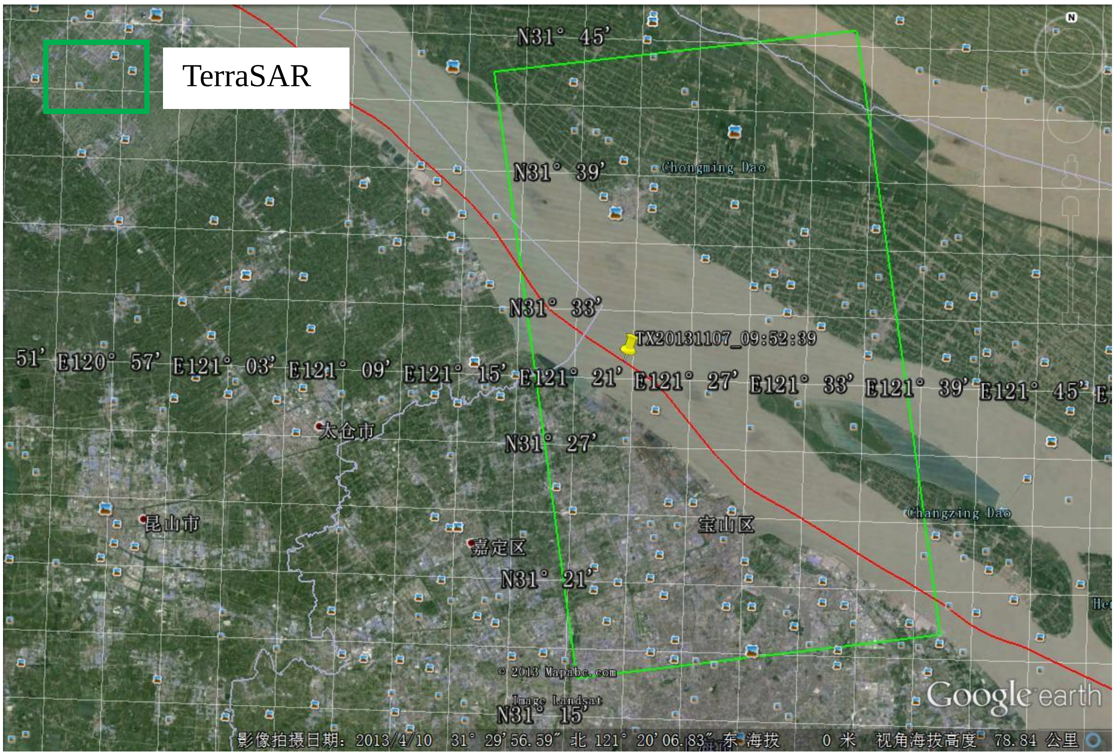

Figure C-8: Detection area of TerraSAR-X，2013-11-07，09:52:39（UTC）, Wu Song Kou, MV “Yu Feng”: 31°30'44.82"N, 121°23'33.42"E（2013-11-07 09:52:39UTC）

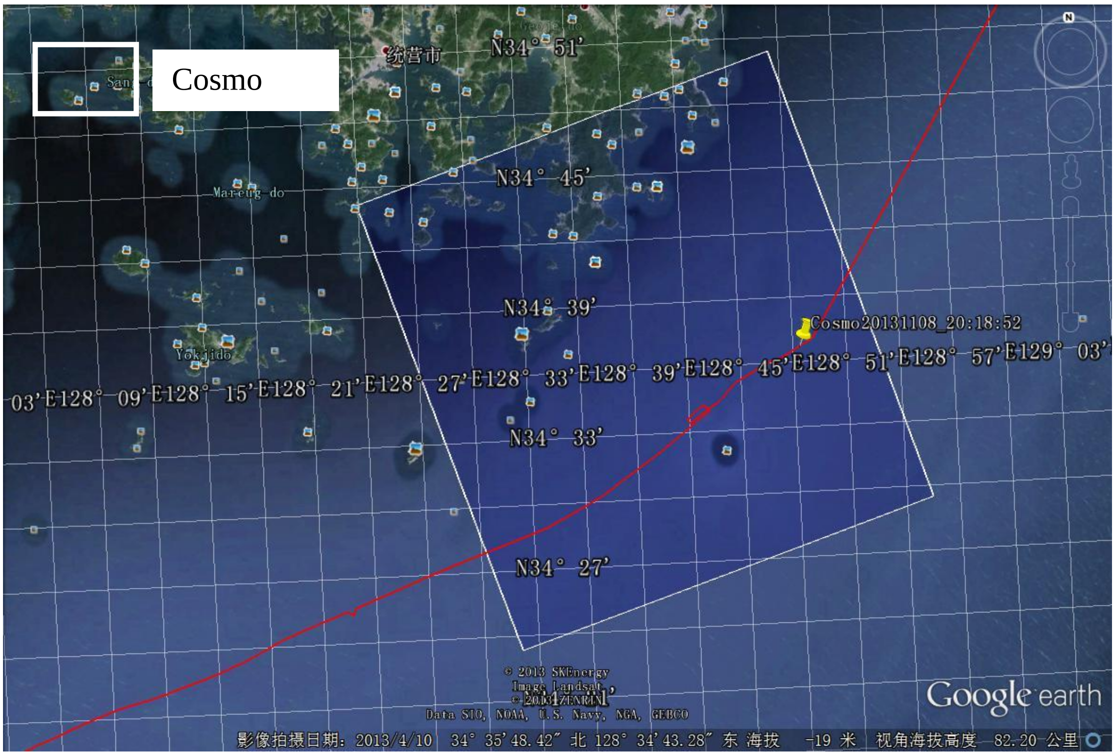

Figure C-9: Detection area of Cosmo-Skymed-4, 2013-11-08，20:18:51（UTC）, Pusan, MV “Yu Feng”: 34°36'42.78"N, 128°48'22.50"E（2013-11-08 20:18:52UTC）

Table C-4: Parameters of related satellites, 2013-11-07~2013-11-08 (coordinates: WGS84)

No.	Satellite	Mode	Strip_ID	period	Shooting time (s)	grade	Resolution ratio	incident angle	Detection area （NW, NE, SW, SE）	coverage (km)
1	TerraSAR-X	SM	81/ Strip012R	20131107 09:52:39	10	EEC	3m	35.287	31°43’N/121°16’E, 31°46’N/121°35’E, 31°17’N/121°22’E, 31°19’N/121°40’E	30×50
2	COSMO -SkyMed-4	Himage	16275	2013-11-08 20:18:52.57	5.822	EC	3m	32.276	34°44’N/128°24’E, 34°50’N/128°47’E, 34°23’N/128°32’E, 34°29’N/128°55’E	40 40

3. Experimental data

3.1 meteorology (7 Nov 2013~8 Nov 2013)

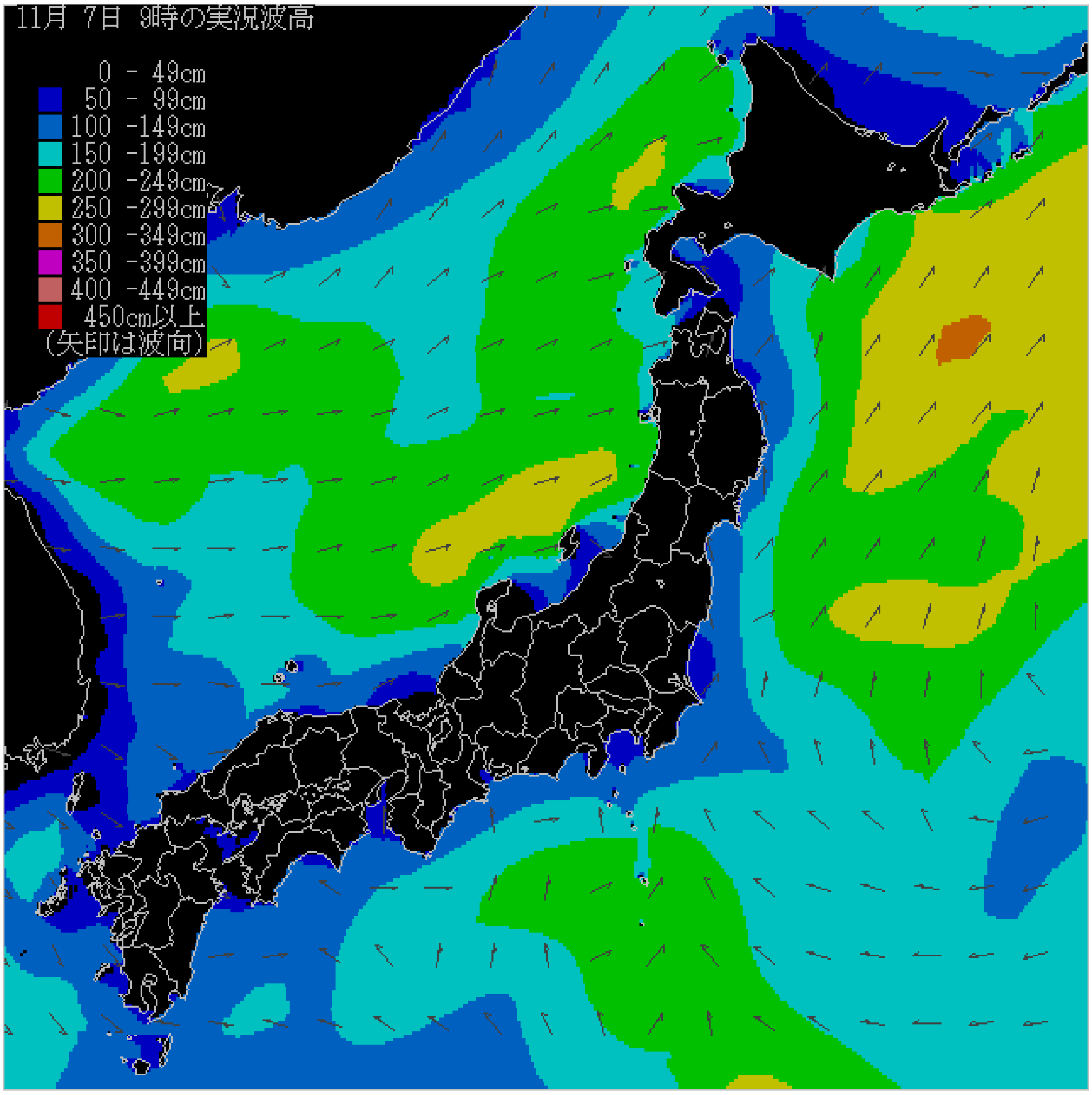

Figure C-10: Illustration of wave at 7-11 2013-11-07 09:00（UTC）

3.2 Remote sensing

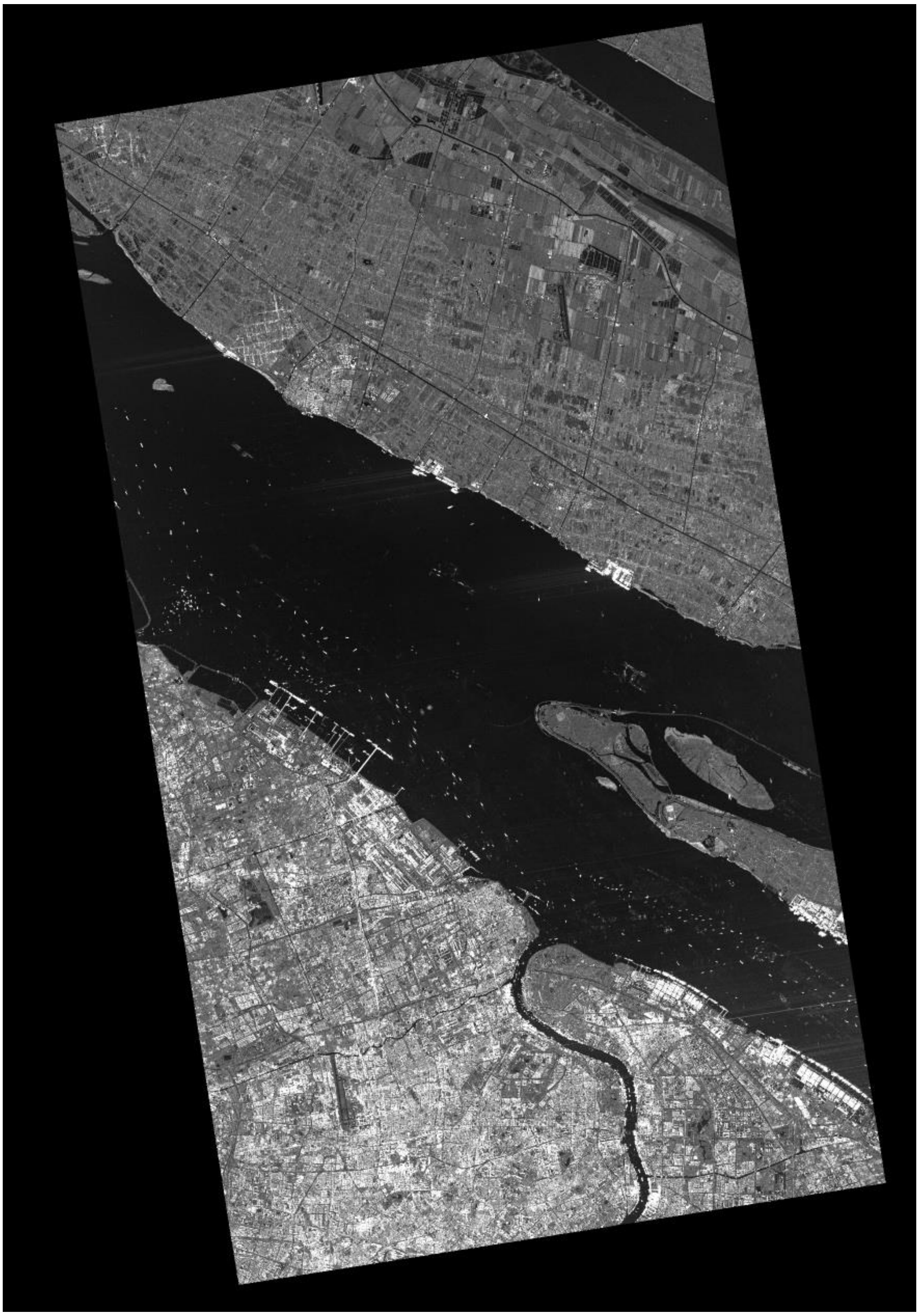

Figure C-11: Image from satellite SAR of TerraSAR-X, 2013-11-07 09:52:39（UTC）,Wu Song Kou

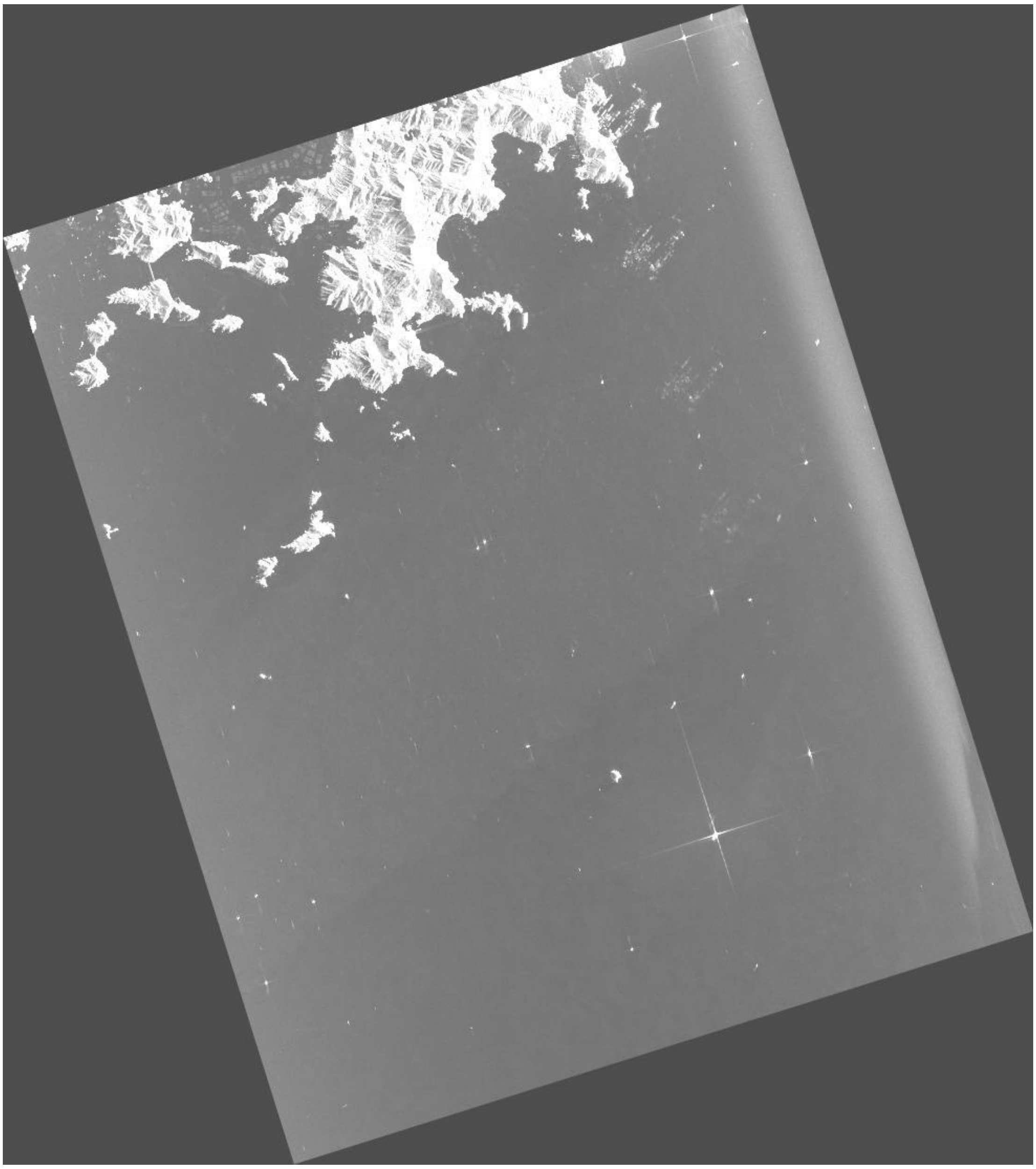

Figure C-12: Image from satellite SAR Cosmo-Skymed-4，2013-11-08 20:18:52.57（UTC）, Pusan, Korea.

3.3 Screenshot of AIS on “Yu Feng”, (blue one is signal of MV/“Yu Feng”)

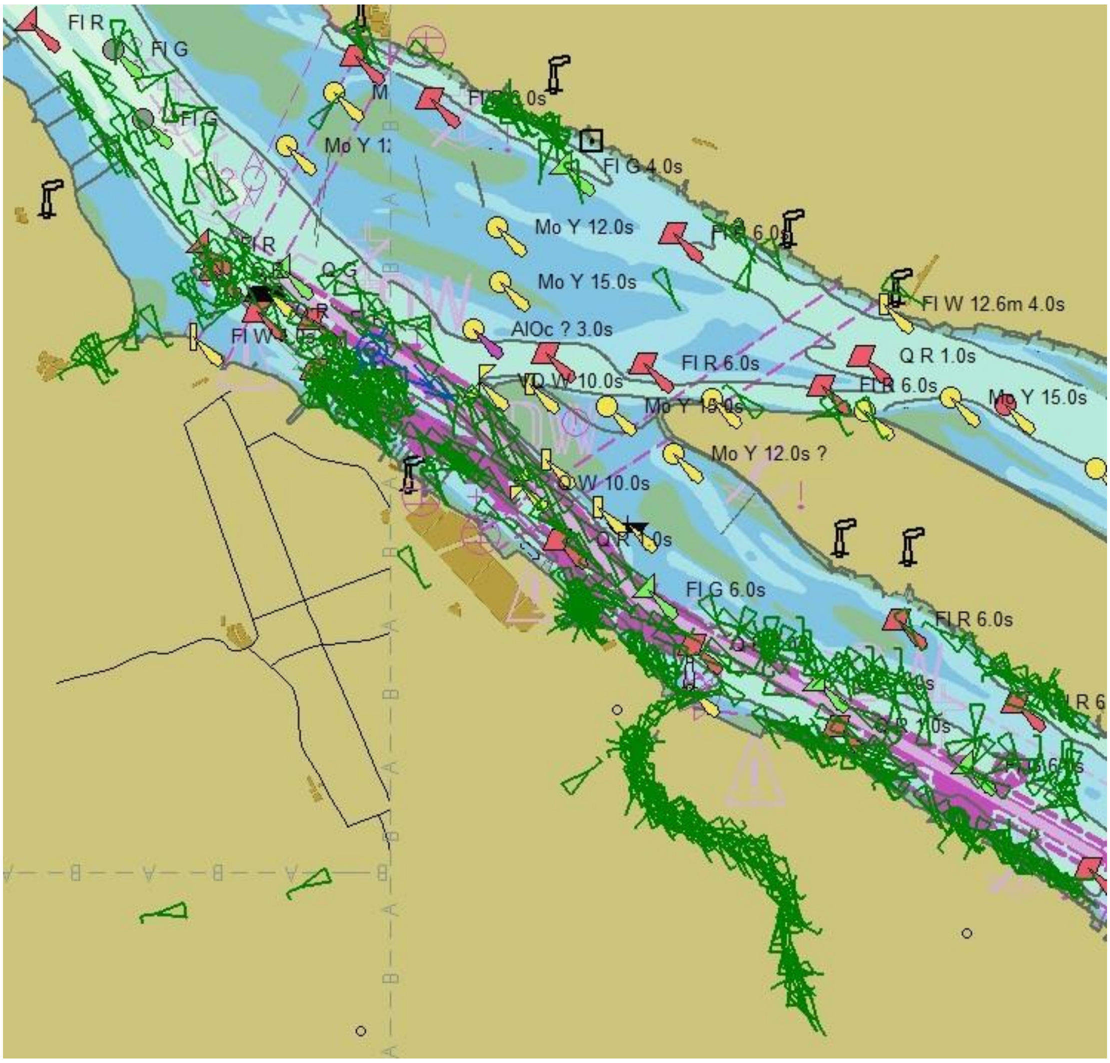

Figure C-13: Screenshot of AIS on “Yu Feng”, 2013-11-07 09:52:39（UTC）, Wu Song Kou area,

Figure C-14: Screenshot of AIS onboard of “Yu Feng” on the waters of Pusan, 2013-11-08 20:18:52.57（UTC）

3.4 Tracking by GPS onboard of MV/ Yu Feng

Figure C-15: tracking of MV/Yu Feng, 2013-11-07~2013-11-09

3.5Tracking of MV/ Yu Feng by LRIT system of China NDC

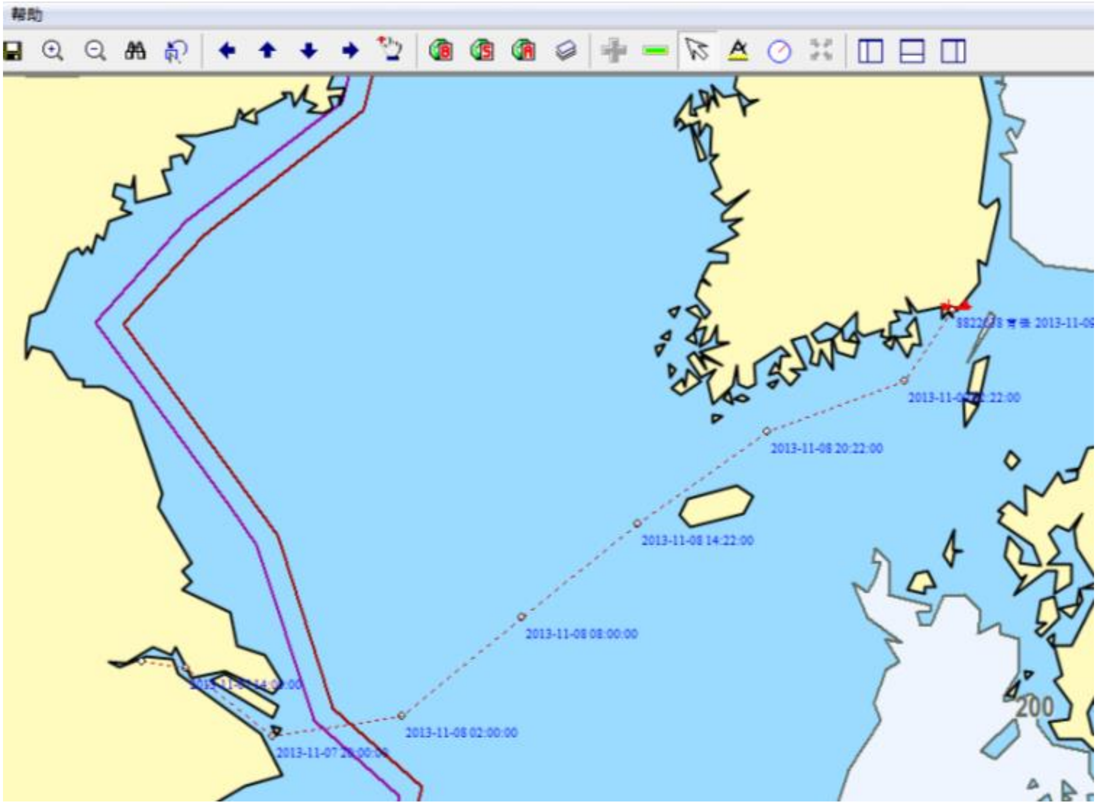

Figure C-16: Tracking of MV/Yu Feng by LRIT, 2013-11-07~2013-11-09

Table C-5: Position reports of MV/Yu Feng in LRIT, 2013-11-07~2013-11-09

IMO	SHIP_NAME	SHIP_FLAG	UTC_TO_LRIT_TIME_STAMP(TIME)	LONGITUDE	LATITUDE
8822038	YU FENG	CHN	2013-11-07T06:00:00.000Z	120.8792	31.90667
8822038	YU FENG	CHN	2013-11-07T12:00:00.000Z	121.8067	31.28778
8822038	YU FENG	CHN	2013-11-07T18:00:00.000Z	123.1972	31.46861
8822038	YU FENG	CHN	2013-11-08T00:00:00.000Z	124.4825	32.36444
8822038	YU FENG	CHN	2013-11-08T06:22:00.000Z	125.7206	33.20917
8822038	YU FENG	CHN	2013-11-08T12:22:00.000Z	127.1039	34.03
8822038	YU FENG	CHN	2013-11-08T18:22:00.000Z	128.5644	34.48333
8822038	YU FENG	CHN	2013-11-09T00:21:19.000Z	129.0833	35.10306

3.6 Tracking of MV/Yu Feng by satellite-based AIS

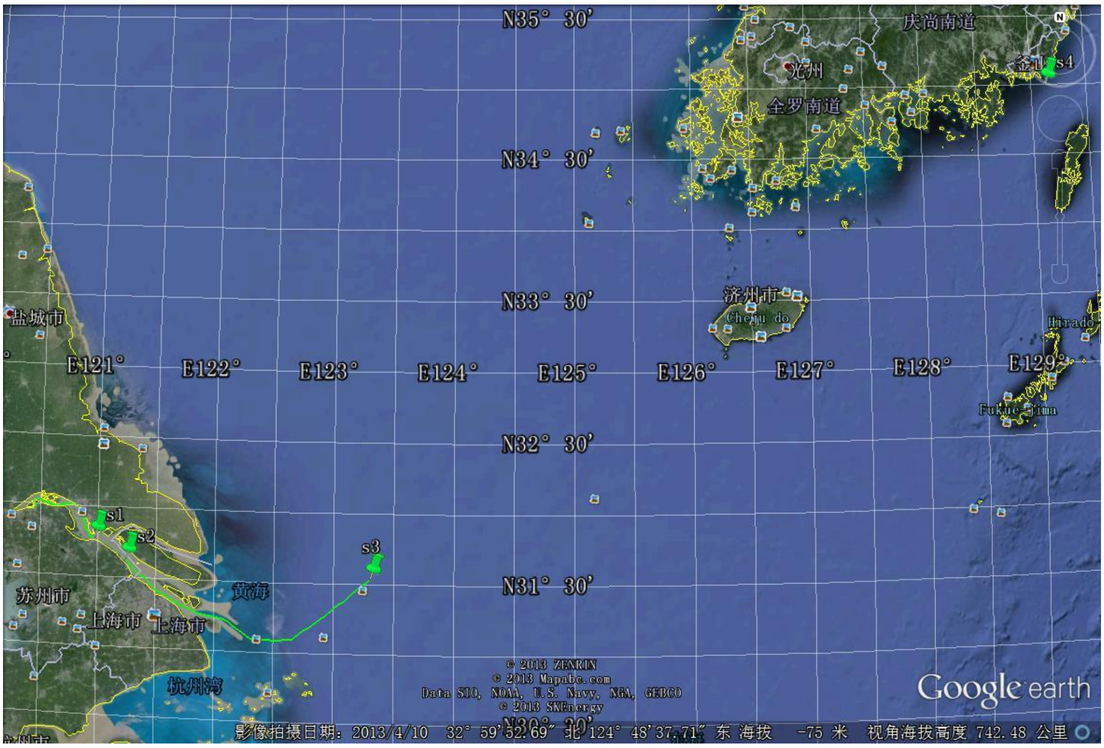

Figure C-17: Tracking of MV/Yu Feng by satellite-based AIS,

2013-11-07~2013-11-09

3.7 Tracking of MV/Yu Feng by Bei Dou satellite

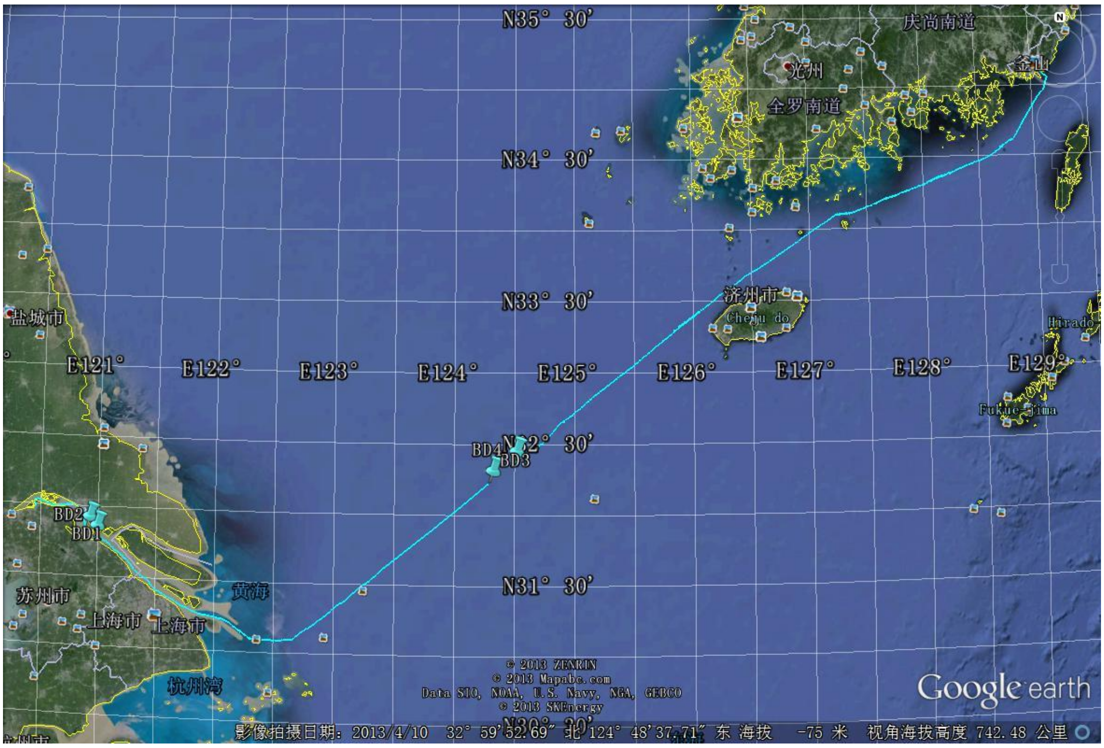

Figure C-18: Tracking of MV/Yu Feng by Bei Dou satellite, 2013-11-07~2013-11-09

Appendix D

Detailed information of different data sources

Table D-1: Intervals of AIS reporting, Class-A shipborne mobile equipment reporting intervals

Ship's dynamic conditions	Nominal reporting interval
Ship at anchor or moored and not moving faster than 3 knots	3 min
Ship at anchor or moored and moving faster than 3 knots	10 s
Ship 0-14 knots	10s
Ship 0-14 knots and changing course	3 1/3 s
Ship 14-23 knots	6 s
Ship 14-23 knots and changing course	2s
Ship > 23 knots	2s
Ship > 23 knots and changing course	2s

Source: IALA, 2004

Table D-2: Intervals of AIS reporting, equipment other than Class A shipborne mobile equipment reporting intervals

Platform.s condition	Nominal reporting interval
Class B shipborne mobile equipment not moving at faster than 2 knots	3 min
Class B shipborne mobile equipment moving at 2-14 knots	30s
Class B shipborne mobile equipment moving at 14-23 knots	15s
Class B shipborne mobile equipment moving > at 23 knots	5s
Search and rescue aircraft (airborne mobile equipment)	10s

Aids to navigation	3 min
AIS base station	10s

Source: IALA, 2004

Table D-3: Dynamic and static information of AIS (shore-based)

information		Static information	
content	description	content	Range of value
Message ID	Identifier for this message (1, 2 or 3)	Message ID	5
Repeat Indicator	0-3. Used by the repeater to indicate how many times the message has been repeated; default = 0; 3 = do not repeat again.	Repeat Indicator	0-3
User ID	MMSI number (Unit serial number as substitute)	User ID	
Navigation status	0 = underway using engine; 1 = at anchor; 2 = not under command; 3 = restricted maneuverability; 4 = constrained by draught; 5 = moored; 6 = aground; 7 = engaged in fishing; 8 = underway sailing; 9 = (reserved for HSC category); 10 = (reserved for WIG category); 15=Default	AIS version indicator	0-3
Rate of turn(ROT)	±708 degrees/min. (-128 indicates not available which is the default)	IMO number	1-999999999
SOG	Speed Over Ground in 1/10 knot steps (0 -102.2 knots) 1023 = not available; 1022 = 102.2 knots or higher	Call sign	
Position accuracy	1 = High (<10m. Differential mode of e.g. DGNSS receiver); 0 = Low (> 10m; Autonomous mode of e.g. GNSS receiver or other electronic position fixing device); default = 0	Name	

Longitude	Longitude in 1/10 000 minute (±180 degrees, East = positive, West = negative); 181 degrees = not available = default	Type of ship and cargo type	
Latitude	Latitude in 1/10 000 minute (±90 degrees, North = positive, South = negative); 91 degrees = not available = default	Dimension/reference for position	
COG	Course Over Ground in 1/10 degree (0 – 3599); 3600 = not available = default	Type of electronic position fixing device	0-15
True heading	Degrees (0-359) (511 indicates not available = default	ETA	
Time stamp	UTC second when the report was generated (0-59,) or 60 - if time stamp is not available which should also be the default) or 61 - if the electronic position fixing system is in manual input mode; or 62 -if the positioning systems is in estimated [dead reckoning] mode, or 63 - if the positioning system is inoperative.	Maximum present static draught	0-255
Regional Application	Reserved for definition by a competent regional authority. Shall be set to 0, if not used for regional application.	Destination	
RAIM Flag	(Receiver Autonomous Integrity Monitoring) flag of electronic position fixing device; 0= RAIM not in use = default; 1 = RAIM in use.	Spare	

Source: IALA, 2004

Table D-4: Essential data for VTS[7]

Data item	Format & range of value
TrackID	Text, 1-999999999
Time	
Latitude	
Longitude	
Course	
Speed	
Draught	
Call sign	
Ship Name	
Info	

Table D-5: data of LRIT

Content	Value range
IMO number	Text, 1-999999999
Position	
Report Time	

Table D-6: SAR[1] **data**

Content	Value range
Track Id	Text, 1-999999999
Position	
Report Time	

[7] Since VTS is a relatively high-integrated system and different VTS manufactures use different data format, so only list some essential data meeting MDA's demands are listed in this part. More detailed information is available from IALA or VTS manufactures.

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[8] The author of this paper did participate the referenced research in 2013.