8-30-2023

The research on weather routing market and e-Navigation service in China

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RESEARCH ON WEATHER ROUTING MARKET AND E-NAVIGATION SERVICE IN CHINA

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A dissertation submitted to the World Maritime University in partial fulfillment of the requirements for the award of the degree of Master of Science in Maritime Affairs

2023

Declaration

I certify that all the material in this dissertation 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 dissertation reflect my own personal views, and are not necessarily endorsed by the University.

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NB The supervisor's signature is not required

Acknowledgements

I would like to thank the following people who have offered me great help during the whole period of MSEM project. Without them I would not have the chance to meet all these lovely people, I would not be able to live in this beautiful campus in Dalian, I would not acquire rich knowledge. Coincidentally, today is May 20th, a day of love and gratitude, I would like to take this opportunity to express my gratitude and love to them.

I am sincerely grateful to China MSA for offering me this splendid opportunity to study in Dalian. Many thanks to my superior leaders for releasing me from my regular work to complete my postgraduate study with undivided attention.

Thank the World Maritime University, for input throughout this MSc programme.

Thank my supervisor Prof. BAI CHUNJIANG for his wise suggestions and instructions to my dissertation. Thank Prof. ZHAO JIAN, Mrs. ZHAO LU and Mr. GUO LEI for their enthusiasm for the project, for their support, encouragement and patience.

Thank all the professor who presented the lectures, for their contributions to teach and share their knowledge and experience.

Thank my colleagues, classmates and all the related people for helping me convey my questionnaires. And thank all those lovely people from all aspect of marmite industry who were so generous with their time in completing the questionnaire surveys.

Thank the authors of the references cited in this paper and the reviewers who took time out of their busy schedule to put forward valuable suggestions for revision.

And finally, thank my family for all the support you have shown me through the entire culmination. I love you all!

Abstract

Title of Dissertation: **Research on Weather Routing Market and e-Navigation Service in China**

Degree: **Master of Science**

The dissertation is a study of the development and application of weather routing service in China. It summarizes the current background and historical development process of weather routing at home and abroad. In this study, research has been conducted on the weather routing supply side, policies side and market side. It analyzed and summarized the profiles of weather routing providers, policy direction of Chinese weather routing, and predicts the future development trends of weather routing.

A questionnaire survey was conducted on the weather routing user side, and based on the analysis of user feedback, the experience and feelings of first-line users of weather routing services and products were collected in this research, which formed user-based suggestions for the development of weather routing services and products.

A Chinese e-Navigation testbed on meteorological services has been investigated and evaluated in this research. Compared to the requirements of users and international industry, constructive suggestions were provided for the development of this testbed.

This dissertation finally outputs the reasons for the monopoly of China's weather routing market and provides corresponding countermeasures. Several

recommendations for the future development of China's e-Navigation weather routing services also be illustrated.

KEYWORDS: Weather routing, Meteorological service, Meteorological policy, Weather routing provider and user, Market, e-Navigation

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LIST OF ABBREVIATIONS

AtoNs	Aids to Navigations
BDS	BeiDou Navigation Satellite System
CAGR	Compound Annual Growth Rate
CAS	Chinese Academy of Sciences
CHINA MSA	China Maritime Safety Administration
CII	Carbon Intensity Indicator
CMA	China Meteorological Administration
CO2	Carbon Dioxide
DCS	Data Collection System
EEDI	Energy Efficiency Design Index
EEXI	Energy Efficiency Existing Ship Index
GIS	Geographic Information System
GMDSS	Global Maritime Distress and Safety System
IMO	International Maritime Organization
IPCC	The Intergovernmental Panel on Climate Change
MOST	Ministry of Science and Technology
MS	Maritime Services
MSC	Maritime Safety Committee
NERC	National Development and Reform Commission
NMC	National Meteorological Center
NPC	National People's Congress National People's Congress of the People's Republic of China
SEEMP	Ship Energy Efficiency Management Plan
SOLAS	Convention on the Safety of Life at Sea
UN	United Nations
UNCTAD	United Nations Conference on Trade and Development

CHAPTER 1 INTRODUCTION

1.1. Research background

1.1.1 International background of climate change

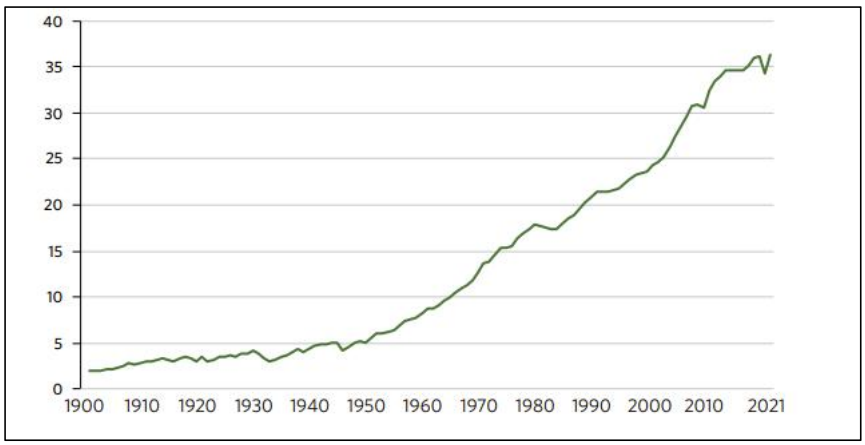
Currently, humanity is facing an unprecedented global climate change challenge. The Intergovernmental Panel on Climate Change (IPCC) has repeatedly confirmed in its series of reports that human activities are the main cause of global climate change (Intergovernmental Panel on Climate Change [IPCC], 2023). Moreover, with climate change, humans are also suffering from various disasters, and the frequency of extreme weather is increasing. According to IPCC data, from 1880 to 2012, global temperature rose by 0.85°C, and for every 1°C increase in temperature, crop yields will decrease by about 5%. From 1981 to 2002, due to climate warming, global maize, wheat, and other major crop yields decreased by 40 million tons per year (IPCC, 2008). Climate change also affects the marine environment. From 1901 to 2010, due to global warming and sea ice melting, the global ocean area expanded, and the average sea level rose by 19 cm. Since 1979, the Arctic sea ice area has been shrinking at a rate of 1.07 million square kilometers per decade.

Since 1990, global carbon dioxide (CO2) emissions have increased by nearly 50%. During the decade from 2000 to 2010, the growth rate of emissions was higher than that in the previous three decades (United Nations [UN], 2022). This data strongly

support the close connection between global warming and human activities.

Figure 1

CO_2 Emission from Industrial Activities and Fossil Fuel Between 1900-2021 (gigatons of CO2)



Note. From *The Sustainable development goals report 2022* (p. 52), by United Nations, 2015, United Nations (https://unstats.un.org/sdgs/report/2022/). Copyright 2022 by United Nations.

Recognizing the hazards of climate change, the human society has begun to take a series of measures to control human activities and reduce carbon dioxide emissions.

On the occasion of the 70th anniversary of the establishment of the United Nations (UN), more than 150 world leaders held a historic Sustainable Development Summit at the UN Headquarters in New York from September 25th to 27th, 2015. At this summit, the 193 UN member states formally adopted the United Nations General Assembly Resolution 70/1 *Transforming Our World: The 2030 Agenda for*

Sustainable Development (UN, 2015), which includes a declaration, 17 sustainable development goals, and 169 specific targets, providing direction for the UN and its members' efforts and actions for the next 15 years. The 17 sustainable development goals encompass the three major aspects of economy, society, and environment. The 13th goal, "Take urgent action to combat climate change and its impacts" (UN, 2015, p.23), reflects the international community's concern about the climate challenge. The world is calling for more significant policy adjustments and technological innovations to promote global climate recovery and sustainable development.

1.1.2 Actions by the IMO

Against the backdrop of such a global situation, the International Maritime Organization (IMO) has also been taking proactive actions to address the issue of climate change. In 2018, the IMO adopted the *Initial IMO Strategy on Reduction of GHG emissions from ships*, which aims to reduce the total annual greenhouse gas emissions from international shipping to below 50% of the 2008 levels by 2050; to reduce carbon intensity by 40% from the 2008 levels by 2030, and to strive to reduce carbon intensity by 70% from the 2008 levels by 2050 (International Maritime Organization [IMO], 2018).

However, in fact, the IMO, which has the important responsibility of protecting the marine environment, began to take actions in the field of greenhouse gas emissions as early as 2011. In that year, Annex VI to Chapter 4 of the MARPOL Convention, "Regulations on energy efficiency for ships" (IMO, 2011), was adopted, establishing standards for the Energy Efficiency Design Index (EEDI) for newly built ships and the Ship Energy Efficiency Management Plan (SEEMP) for all ships, in order to improve ship efficiency and control greenhouse gas emissions from ships. With the

entry into force of Annex VI to the MARPOL Convention Chapter 4, the IMO subsequently proposed a series of measures and means, as shown in Table 1 below:

Table 1

Timeline of IMO Greenhouse Gas Reduction Measures

No.	Effective Date	Name
1	2013	EEDI, Energy Efficiency Design Index
2	2013	SEEMP, Ship Energy Efficiency Management Plan
3	2019	SEEMP II/ DCS, Data Collection System
4	2023	EEXI, Energy Efficiency Existing Ship Index
5	2023	CII, Carbon Intensity Indicator

1.1.3 Overview of weather routing

The aforementioned measures have always revolved around one idea: to reduce emissions by improving the efficiency of ships. In particular, the SEEMP involves an important tool for helping shipping companies improve the operational efficiency of their ships, which is Weather Routing. Weather Routing is a means of optimizing traffic routes based on predicted weather conditions and is commonly used in navigation, aviation, and road transportation. In the field of shipping, Weather Routing plays a role in avoiding adverse weather conditions to ensure the safety of ships, reducing the impact of adverse weather conditions on ships by optimizing their routes, reducing greenhouse gas emissions, and improving ship efficiency to protect the environment. Another important application of weather routing is that charterers can use it to specify and optimize ship routes, ensuring that ships can meet contract requirements for speed and fuel consumption during the charter period.

Currently, many companies in different countries and regions around the world

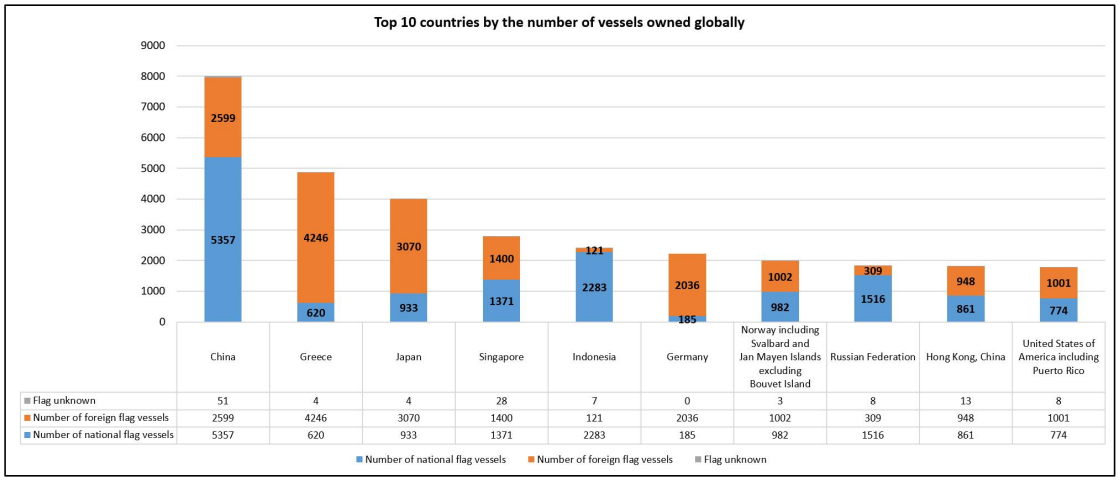
provide weather routing services for maritime transportation. According to market research and information disclosed on the official website of *Expert Market Research* (Expert Market Research, 2022), the top ten companies in the global meteorological forecasting service industry are AccuWeather Inc., IBM Corporation, Fugro Group, StormGeo AS, ENAV S.p.A., DTN LLC, Infoplaza Marine Weather, Met Office, Weather Routing Inc., and Precision Weather Service. Based on their basic company information, it can be determined that the main companies engaged in weather routing are StormGeo AS (Norway), DTN LLC (Switzerland), Infoplaza Marine Weather (Netherlands), and Weather Routing Inc. (USA). In addition, according to research conducted by Chinese scholars in the *Acta Meteorologica Sinica*, "*Overview and development situation of marine weather routing service for ships"* (Zhang et al., 2020), other two major ship weather routing companies internationally include Weathernews (Japan) and True North Marine (Canada). These weather routing companies mentioned above are the leaders in the global maritime weather routing field, mainly located in Europe, America, and Japan.

As of the end of 2021, there were 16,000 companies in China that cover the field of meteorology in their business scope, of which over 3,000 operate normally and over 400 are of a certain scale (Cai, 2022). Representative enterprises and institutions in the field of weather routing in China include the National Meteorological Center (NMC), the Huayang Maritime Center, the China Huayun Group, Huafeng-AccuWeather, and Shanghai Haiyang Weather Routing Technology Co., Ltd., Due to the late start of China's ocean weather routing, the domestic and foreign markets for ocean weather routing have been monopolized by developed foreign countries. According to the data from *Review of Maritime Transport 2022* published by the United Nations Conference on Trade and Development (UNCTAD) in 2022, China had a total of 8,007 ships with a gross tonnage of 1,000 or more, ranking first

in the world (United Nations Conference on Trade and Development [UNCTAD], 2022).

Figure 2

TOP 10 Countries by the Number of Gross Tonnage of 1,000 or More Vessels Owned Globally



Note. Adapted from *Review of Maritime Transport 2022* (p. 40), by United Nations, 2022, United Nations (https://unctad.org/rmt2022). Copyright 2022 by United Nations.

As the country with the largest number of ships in the world, China did not have a company or organization with enough strength to provide oceanic weather routing services for its own fleet for a long time. Therefore, providing reliable oceanic weather routing services for its own country's ships (referred to as *National weather routing service for national ships* by the domestic industry) has been a dream of China's meteorological industry to break the monopoly of foreign companies.

In order to change the status quo and promote the continuous improvement of China's meteorological services, in April 2022, the Chinese State Council issued the *Meteorological High-quality Development Plan (2022-2035)*, which pointed out the need to improve the economic and high-quality development level of meteorological services, clearly defined the implementation of *Strong Maritime Nation Plan* and implementation of *Strong Transportation Network Plan*, and required the strengthening of the ability of global ocean weather routing services and the development of global trade logistics meteorological services. (The State Council of the People's Republic of China [State Council], 2022).

1.2 Main research content and key issues to be solved

Considering the above background, this paper will focus on three aspects.

1.2.1 Research on the supply side of weather routing services, the policy side of Chinese meteorological service, and the overview of the weather routing market

For this issue, the differences of the most important participants in weather routing service in China and abroad will be compared, and the current situation and policies of China's weather routing market will be studied. After that, corresponding research conclusions will be provided.

1.2.2 Research on the user side of weather routing

In order to understand frontline users' needs and the current usage of weather routing products in China and abroad, the study will conduct a questionnaire survey of

frontline users of weather routing services, then analyzes the information collected from the survey, and draws corresponding conclusions to provide suggestions for the development of Chinese weather routing services and products.

1.2.3 Research on the application of meteorological services in the Chinese e-Navigation project

Based on the construction of relevant Chinese maritime e-Navigation projects, the author research on the application of meteorological services in the Chinese e-Navigation project, and proposing ideas and suggestions for the development of the Chinese e-Navigation project from meteorological services to weather routing services.

1.3 Research significance

Based on the background of China's strong promotion of high-quality development of weather routing, this study focuses on how weather routing can serve the construction of a strong maritime and transportation country. It reviews the development of weather routing at home and abroad and puts forward constructive opinions and suggestions for the development of weather routing business in China. Meanwhile, this study conducts research based on frontline weather routing users, providing valuable reference information for the development of weather routing products. Finally, starting from the field of maritime safety and navigation services in China, this study analyzes and studies the meteorological service cases in the e-Navigation project constructed by China Maritime Safety Administration (CHINA MSA). It provides useful measures for the development of weather routing services in the subsequent e-Navigation project and will play a positive role in promoting the

transformation and upgrading of China's maritime safety and navigation services.

1.4 Research methods

As mentioned in the main research content section, this article mainly conducts research in three aspects, each of which uses different research methods. The specific research methods and operational information are introduced below.

1.4.1 Literature review method

In the research process of the supply side of weather routing services, Chinese policies related to weather routing, and an overview of the weather routing market, the author used a large number of literature review research methods to collect information on international and domestic weather routing service providers, updating the latest status of weather routing service providers at home and abroad. In terms of research on Chinese weather routing policies, the author collected and sorted out the legal regulations and policy documents related to weather routing in China in the past five years, helping to form an understanding of the future development trends of weather routing services in China. The research on the overview of the weather routing market was mainly summarized through public media reports and relevant academic documents to provide a general understanding of the current market situation.

1.4.2 Comparative analysis method

In the process of studying the supply side of weather routing services and the overview of the weather routing market, in addition to using the literature review

method to collect information, the author also organizes the collected information, summarizes and analyzes the characteristics of international and Chinese meteorological weather routing providers and compares them, so as to more intuitively show the differences in weather routing services and markets between China and foreign countries.

1.4.3 Questionnaire survey method

During the research into the weather routing user end, the author uses a survey questionnaire method to conduct a survey questionnaire with 25 specific questions, which was distributed to users at the forefront of weather routing services, such as crew members, ship owners, ship management companies, and charterers, to conduct user information and demand research. The received questionnaires were analyzed to summarize first-hand information about the users of weather routing service.

1.4.4 Case study method

When studying the application of meteorological services in the China e-Navigation project, the author analyzed and studied a meteorological service testbed based on the China e-Navigation project as a typical case, introduced its basic information and construction architecture, and tested the implementation of its functions, finally providing ideas and suggestions for the subsequent construction of the testbed in accordance with the international standards of weather routing services.

CHAPTER 2 DEVELOPMENT PROCESS OF WEATHER ROUTING

2.1 Concept of weather routing

There are various definitions of weather routing both in China and world-wide, but it can be defined as a service that predicts weather and sea conditions along the initial planned route for a period of time in the future, and based on the ship characteristics to provide advice for route optimization to avoid adverse weather and sea conditions based on the forecast information, in order to ensure the safety of the ship, improve navigation efficiency, and reduce fuel consumption (Wang, H. & Bai, C. J., 2006).

2.2 General history of weather routing

Weather routing has a long history. From the moment when humans faced the ocean and used ships for maritime activities, weather and sea conditions have become important factors to consider. During the Yin and Zhou Dynasties in China (approximately from 1300 BC to 771 BC), people knew how to set sails using wind power for navigation. Historical records show that in the Qin Dynasty, people knew how to take advantage of high tides to set out for the sea, and they even began to learn to use monsoons for long-distance navigation (WEI, 2015). At that time, navigators relied on their rich experience and understanding of the weather to

determine the ship's route and ensure safe navigation, which became the earliest form of weather routing technics.

In the late 15th century, Western navigators began to use the northeast trade winds for trade, which were named after them. From the 17th to the 18th century, Western navigators continuously collected environmental data during navigation and began to carry out systematic and scientific meteorological statistics and forecasting. In the 19th century, climate atlas for long-distance voyages began to be compiled to help navigators design different routes for different seasons. In 1938, the U.S. Weather Bureau published the *Atlas of climatic charts of the oceans* covering the whole world (Weather China, 2013).

With the application of radio technology in the 1920s and 1930s, weather forecasting became possible to be directly delivered to ocean-going vessels. In the 1950s and 1960s, large computers were applied to weather analysis, which made weather forecasts sent to ocean-going vessels more accurate and also gave rise to the first commercial weather routing services. In the 1970s and 1980s, with the application of satellite technology, ships were able to receive weather information globally, which further improved the efficiency and reliability of weather routing services. Nowadays, with a series of technological changes, weather routing services continue to advance, and electronic and visual weather routing shipborne terminals and software have been developed, providing users with increasingly sophisticated services.

2.3 Modern weather routing technology development history

Since the beginning of the 20th century, meteorological information services including weather routing have been developing rapidly with the outbreak of the

second and third industrial revolutions, accompanied by advancements in communication, radio, semiconductors, electronic information, aerospace, and artificial intelligence. Humans began to use electricity on a large scale to improve productivity and started using communication technologies such as telegraphs and radios. The use of satellites and computers greatly enhanced human capabilities in data analysis and processing, resulting in significant improvements in the timeliness and accuracy of weather routing. This section will introduce the development of modern weather routing technology from two aspects: the development of modern meteorological technology (meteorological observation, data collection, communication) and weather routing algorithms (data processing).

2.3.1 Development of modern meteorological technology

2.3.1.1 Communication technology

The emergence of the first telephone in 1876 revolutionized traditional communication methods, and its application in meteorology in Europe in 1900 enabled the transmission of weather warnings through cables; only two years later, Marconi achieved the broadcast of weather forecasts to ships at sea through wireless telegraphy, and in 1905, SS New York received the first telegraphy weather report at sea; in 1921, the University of Wisconsin achieved the world's first radiotelephone broadcast of weather forecasts, and by 1928, the teletype machine had replaced telegraph and telephone services as the main way to deliver weather information; facsimile began to be used for the transmission of meteorological charts in 1948, and today, long-range wireless and satellite communication equipment has become widely used on ocean-going vessels, becoming the main channel for transmitting meteorological information.

2.3.1.2 Meteorological observation technology

The advancement of technology has also propelled the upgrade of meteorological observation technology. In 1937, the United States began to attempt using radio meteorographs to replace aircrafts for aerial meteorological observations. In 1954, the first dedicated meteorological radar (AN/CPS-9) was put into use. Meteorological observation technology was also influenced by the aerospace field. In 1960, the world's first meteorological satellite, TIROS I, was successfully launched. Due to the success of meteorological observation satellites, meteorological observation ships began to be gradually phased out, and humans entered the era of using satellites for meteorological observation and forecasting.

2.3.1.3 Electronic information technology

The impact of electronic information technology on meteorological services cannot be ignored. In 1948, Princeton's Institute for Advanced Studies began researching into the use of computers for weather forecasting. In 1955, the US Weather Bureau became the first to use computers for regular weather forecasts, and computer algorithm models for weather forecasting have rapidly developed since then. In 1990, the US began using supercomputers in meteorological services to run more complex models and obtain more accurate forecasts (National Weather Service, n.d.).

2.3.2 Development of Weather Routing Algorithm

With the development of electronic information technology, data processing has become an important factor affecting the accuracy of weather routing. Since the

1950s, new algorithms have emerged constantly, driving the advancement of weather routing technology. However, these algorithms can generally be categorized into three types: traditional algorithms, intelligent heuristic algorithms, and machine learning algorithms.

2.3.2.1 Traditional algorithms

Traditional algorithms mainly include isochronous the line method, the dynamic programming method, the variational method and Dijkstra algorithm, a branch of the greedy algorithm.

The **isochronous line method** refers to the line connecting points where a vessel has traveled the same distance within a certain period of time. This method enables navigators to find the shortest route more conveniently, accurately, and quickly. James formally applied this method in the field of ship weather routing in 1957 (James, 1957). With the advancement of computer technology, the isochronous line method has been implemented on computers. Hagiwara et al. utilized computers for route optimization, making route planning and subsequent modifications more convenient and efficient (Hagiwara & Spaans, 1987).

The basic idea of **dynamic programming** is to break down the original problem into sub-problems and obtain the optimal solution to the original problem by solving the optimal solution to the sub-problems. The prefix point grid method proposed by De Wit in weather routing provides meteorological route optimization for ships with fixed speeds (de Wit, 1990).

In ship route optimization and meteorological navigation, the **variational method**

can define optimization objectives as the shortest distance or minimum fuel consumption to calculate the optimal route. Bijlsma et al. have used this method to optimize ship routes with minimum fuel consumption (Bijlsma, 2008).

2.3.2.2 Intelligent heuristic algorithms

In contrast to traditional algorithms, intelligent heuristic algorithms are inspired by biological evolution and swarm intelligence in nature, simulating these principles and processes to develop a set of algorithms based on heuristic search and optimization ideas. Common intelligent heuristic algorithms include A* algorithm, ant colony algorithm, genetic algorithm, simulated annealing algorithm etc.

The **A* algorithm** was invented by Peter E. Hart et al. in 1968 (Hart et al., 1968). In China, Lu Yanshuang et al. used the A* algorithm for global route planning of unmanned ships (Lu, 2010), and in 2015, Park et al. provided an effective solution for ship weather routing using the A* algorithm (Park & Kim, 2015).

The **ant colony algorithm** was inspired by the way ants search for food in nature and was proposed by Italian scholar Marco Dorigo in 1992 (Dorigo et al., 1992). In China, Zhang et al. optimized the multi-objective ant colony algorithm for ship weather routing (Zhang et al., 2021).

The **simulated annealing algorithm** was first proposed and applied by American physicist Kirkpatrick in 1983 (Kirkpatrick et al., 1983). This algorithm simulates the process of finding the optimal solution to a problem as a high-temperature object gradually cools down and its internal particles reach a stable state. In China, Li Yuan-kui et al. applied the simulated annealing algorithm to design the fastest and

most fuel-efficient routes for wind-assisted ships (Li, 2014).

2.3.2.3 Machine learning techniques

Unlike intelligent heuristic algorithms, machine learning techniques are not based on natural phenomena or rules but on statistical analysis of data to extract useful patterns and knowledge. Wang et al. developed a ship energy efficiency optimization model using wavelet neural networks (Wang et al., 2016); Du et al. used artificial neural network technology to predict energy consumption of ships under different environmental and technical conditions (Du et al., 2019).

CHAPTER 3 RESEARCH ON THE SUPPLY SIDE OF WEATHER ROUTING AND THE POLICY SIDE IN CHINA

3.1 Overview of weather routing service providers

This section will select representative Chinese and foreign weather routing service providers based on information from Expert Market Research and the content mentioned in the Acta Meteorologica Sinica, summarize and sort out the providers' characteristics and information, and conduct a comparative analysis of the two sides.

There are seven foreign weather routing service providers: AccuWeather Inc (USA), StormGeo AS (Norway), DTN LLC (USA), Infoplaza Marine Weather (Netherlands), Weather Routing Inc. (USA), Weathernews (Japan), and True North Marine (Canada). And four domestic weather routing service providers: National Meteorological Center (NMC), the Huayang Maritime Center, the China Huayun Group, and Shanghai Haiyang Weather Routing Technology Co., Ltd. The specific information and feature summary are as follows.

3.1.1 Overview of international weather routing service providers

3.1.1.1 AccuWeather Inc

AccuWeather Inc was founded in 1962 and is headquartered in the United States. It is a privately owned global commercial meteorological services company founded by Dr. Joel N. Myers, with over 450 employees and forecast services covering 3.5 million locations globally, serving a population of 1.5 billion people. The company mainly serves industries such as manufacturing, transportation, energy, retail, insurance, health, forensic appraisal, and financial services. In 2015, the company established a joint venture with China Meteorological Administration's commercial weather media company, Huafeng Media Group, and exclusively released weather information in China. (AccuWeather, 2022)

3.1.1.2 StormGeo AS

StormGeo AS was established in Norway in 1997 and is a private weather service company founded by meteorologist Siri Kalvig. The company has over 550 employees located in 18 countries worldwide. The company's main service areas include shipping, oil and gas, renewable energy, aviation, media, and data science, with over 3,000 customers. In 2014, the company acquired Applied Weather Technology (AWT), located in California, USA, officially entering the field of maritime weather routing. In 2021, the company was acquired by the Swedish industrial manufacturing company Alfa Laval (StormGeo AS, 2023).

3.1.1.3 DTN

DTN, a private meteorological service company founded in the United States in 1984, mainly serves industries such as agriculture, aviation, marine weather, mining, smelting, sports, transportation, and renewable energy, with a total of two million users in various industries. However, the maritime industry is not its main service

sector. (DTN, 2023)

3.1.1.4 Infoplaza Marine Weather

Infoplaza Marine Weather is a private meteorological service company founded in the Netherlands in 2009, providing services in land, marine, media, and mobile businesses with over 100 employees and 20 million monthly active users worldwide.

3.1.1.5 Weather Routing Inc.

Weather Routing Inc was founded in the United States in 1961, and is a private commercial company that specializes in weather routing for ships. Their main services include commercial shipping, cruises, yachts and fishing boats, energy, etc. They have around 50 employees. (Weather Routing Inc, 2023)

3.1.1.6 Weathernews Inc.

Founded in 1986 in Japan, Weathernews Inc. is a privately held company specializing in weather routing for the maritime industry. It was formerly a subsidiary of Oceanroutes, a US-based weather routing company, and acquired Oceanroutes in 1993. In 2003, Weathernews Shanghai was established in China. The company's main services cover shipping, offshore energy, offshore construction, maritime logistics, fisheries, aviation, highways, railways, manufacturing, agriculture, and more. With over 1,120 employees and offices in 21 countries worldwide, the company's annual sales exceed 148 million US dollars (Weathernews, n.d.).

3.1.1.7 True North Marine

True North Marine is a private enterprise in the field of ship weather routing, established in Canada in 2013. The company specializes in ship weather routing services, ship operation monitoring services, and voyage performance analysis services, mainly serving bulk carriers. The company has a total of 36 employees and has offices in China, India, and Greece. (True North Marine, 2023)

3.1.2 Weather routing service providers in China

3.1.2.1 National Meteorological Center (NMC)

National Meteorological Center (NMC) was established in 1950 as a public institution directly under the China Meteorological Administration (CMA) and is responsible for providing national and global public meteorological services. The company's services mainly cover aviation, hydrology, agriculture, finance, marine navigation, atmospheric science, disaster assessment, and ecological meteorology. The company has a total of 364 employees, 8 meteorological satellites, 2,423 ground meteorological stations, and more than 60,000 automatic weather stations. In the field of marine navigation, it successfully developed China's independent ocean weather routing system in 2019, breaking the monopoly of foreign companies in the Chinese weather routing market. (National Meteorological Center [NMC], 2020)

3.1.2.2 Huayang Maritime Center Co., Ltd

Established in 1995, this state-owned enterprise mainly engages in shipping operation, ship management, crew dispatch, software development, information system integration, and website operation. The company has more than 800

employees and a crew of 4,000. After strategic cooperation with the National Meteorological Center, the company successfully developed the Chinese weather routing service products in 2019. (Huayang Maritime Center, n.d.)

3.1.2.3 China Huayun Group Co., Ltd.

Established in 1992 as a state-owned enterprise by the China Meteorological Administration, the company mainly engages in meteorological detection, satellite remote sensing, meteorological radar, information and meteorological services, agriculture, and artificial weather modification. It is the largest supplier of meteorological detection products and system solutions in the Asian region with the most comprehensive categories. However, marine weather routing is not the company's main business. (China Huayun Group, n.d.)

3.1.2.4 Shanghai Haiyang Weather Routing Technology Co., Ltd

Established in 2001, its predecessor, the Sino-American joint venture Shanghai Haiyang Oceanroutes Co., Ltd. (established in 1985), is the earliest domestic company engaged in ship weather routing services. The company's main businesses include smart maritime traffic, intelligent shipping, and global weather routing. It has provided weather routing services for nearly 10,000 voyages to date. (Shanghai Haiyang Weather Routing Technology, n.d.)

3.2 Research into China's weather routing policies

3.2.1 Laws and regulations

3.2.1.1 Meteorology Law of the People's Republic of China

China's first comprehensive administrative law on meteorology was the *Regulations of the People's Republic of China on Meteorological Services* promulgated by the State Council in 1994. Subsequently, the Standing Committee of the National People's Congress National People's Congress of the People's Republic of China (NPC) passed the first law on meteorology, the *Meteorology Law of the People's Republic of China* in 1999. This law was revised three times in 2009, 2014, and 2016. The relevant provisions of these laws and regulations on the marketization of China's weather routing are summarized in Table 2:

Table 2

Provisions of Laws and Regulations on the Marketization of China's Weather Routing

Laws and Regulations	Content			
Regulations of the People's Republic of China on Meteorological Services [a]	**Chapter I General Provisions, Article 5**: The meteorological services falling under the public interests meteorological service shall be provided free of charge; those belonging to the specialized meteorological services may be provided with charges.	**Chapter I General Provisions, Article 6**: The State encourages citizens, legal persons and other organizations to engage in the researches of the meteorological observations and weather forecast techniques according to these Regulations. Their legitimate rights shall be protected by the State.	**Chapter I General Provisions, Article 7**: Any foreign organization or individual who intends to carry out meteorological activities in the territory of the People's Republic of China and other sea areas under the jurisdiction of the People's Republic of China shall be subject to the approval of the competent meteorological agency under the State Council jointly with the competent departments concerned, and abide by the pertinent laws and regulations of the People's Republic of China.	**Chapter II Meteorological Observation, Article 13** The weather data obtained by any foreign organization or individual from its independent observation or from its joint observation with any department or individual of the People's Republic of China within the territory of the People's Republic of China and other sea areas under the jurisdiction of the People's Republic of China shall be owned by the People's Republic of China. The provider of the observation data shall have a right to use it.
Meteorology Law of the People's Republic of China [b]	**Chapter I General Provisions, Article 3** On condition that unpaid	**Chapter I General Provisions, Article 7** The State encourages and	**Chapter I General Provisions, Article 8** Meteorological activities that	**Chapter III Meteorological Observation, Article 16** Organizations or individuals that

	public welfare meteorological services are guaranteed, meteorological offices and stations may provide paid meteorological services in accordance with law.	supports…strengthens international cooperation and exchange in the field of meteorology and develops the meteorological information industry, all in order to improve meteorological work.	organizations and individuals of other countries wish to conduct in the territory of the People's Republic of China and the sea areas under the jurisdiction of the People's Republic of China shall be subject to approval by the competent meteorological department under the State Council in conjunction with relevant departments.	engage in meteorological observation shall, in accordance with relevant State regulations, report the observed meteorological data to the competent meteorological department.
Meteorology Law of the People's Republic of China (2009 Amendment) [c]	As above	As above	As above	As above
Meteorology Law of the People's Republic of China (2014 Amendment) [d]	As above	As above	As above	As above
Meteorology Law of the People's Republic of China (2016 Revision) [e]	As above	As above	As above	As above

Note. [a] State Council (1994, pp. 2-4). [b] *Meteorology Law of the People's Republic of China*. [c] *Meteorology Law of the People's Republic of China (2009 Amendment)*. [c] *Meteorology Law of the People's Republic of China (2014 Amendment)*. [e] *Meteorology Law of the People's Republic of China (2016 Revision)*.

From the perspective of the above laws and regulations, China has actually been encouraging domestic and foreign organizations and individuals to carry out meteorological activities in China since 1994. However, these permissions are also accompanied by two major restrictions that still work till this day: first, all foreign organizations and individuals wishing to carry out meteorological activities in China must obtain the approval of China's meteorological regulatory authority; second, any non-official organizations and individuals that are engaged in meteorological detection must submit the data obtained to the Chinese meteorological regulatory authority concerned. Therefore, the Chinese weather routing market is actually a limited open market.

Due to the existence of the first limitation, service providers in China's meteorological service market have the ability to select overseas competitors by virtue of their close relationships with Chinese regulatory authorities, making this right the most favorable moat and commercial barrier for Chinese meteorological service enterprises to respond to international challenges.

From the perspective of the second limitation, only organizations and departments within the Chinese Meteorological Administration system may have access to the most comprehensive meteorological data resources in China, giving official meteorological institutions and state-owned enterprises under them an absolute advantage in facing challenges from other domestic commercial and private enterprises in terms of meteorological data. This has to some extent restrained the development of domestic private commercial meteorological service providers, resulting in insufficient domestic market competition and activity.

3.2.1.2 Meteorological Data Sharing Management Regulation

In 2001, the China Meteorological Administration (CMA) issued the *Meteorological Data Sharing Management Regulation*, which made specific provisions on how organizations and individuals can obtain and use official meteorological data. Chapter III Article 13 specifies that users shall not transfer for remuneration or free of charge the meteorological data obtained from various levels of meteorological authorities, including new data formed by converting the units, media, or brightness of the meteorological data, and new data formed by substantial processing of the meteorological data.

Article 14 stipulates that users may not directly distribute or provide to external users databases, products, or services containing meteorological data obtained from various levels of meteorological authorities, nor may they indirectly use them as a basis for generating such databases, products, or services. Users who obtain meteorological data from meteorological authorities at all levels may distribute them internally and store them on a local area network for use by the unit, but they may not be connected to the Internet or wide area network (CMA, 2001).

This regulation clearly limits the use of meteorological data obtained by various users from meteorological authorities to internal use only, and prohibits external distribution or use in altered forms, with a series of punishment measures for violations. Even though the 2015 *Measures for the Administration of Meteorological Information Service* published by CMA encourage legal meteorological information services (CMA, 2015), there is no policy relaxation regarding the use of meteorological data.

Therefore, other organizations, private commercial meteorological service companies,

or individuals in China's non-meteorological authority systems do not have a competitive advantage in terms of meteorological data and information when conducting meteorological service activities. However, this does not mean that these non-official entities do not have any way to carry out relevant businesses. It is possible to cooperate with relevant meteorological agencies and provide external and public services.

3.2.2 Development plan

In this section, the author collected and studied important development plans related to weather routing from the official website of CMA since 2021. The author conducted a systematic and data-driven analysis of these plans, especially regarding the relevant quotas of weather routing in the Chinese market. As a result, the author was able to make an educated guess about the future development form and market environment of weather routing in China.

3.2.2.1 14th Five-Year Plan for Meteorological Support in Transportation

In 2021, the CMA, the Ministry of Public Security, the Ministry of Transport, the National Railway Administration, and the State Post Bureau jointly issued the **Five-Year Plan** (FYP) for meteorological support in transportation. The targets for maritime transportation set by the plan indicate that efforts should be made to realize the co-construction, co-sharing, and joint use of shore-based, sea-based, and ship-based meteorological facilities and marine information, and to further enhance the capability of offshore weather routing services and highlight their role in international maritime services.

The plan includes implementation measures such as developing and optimizing domestically-owned intellectual property rights for meteorological forecast and risk warning technologies in sea navigation, improving the capability of providing weather services for shipping enterprises, industry management departments, and insurance companies, and developing optimization algorithms for offshore navigation routes, improving the global weather routing system and mobile platform, and developing a multi-source data service platform for offshore navigation.

To implement the above measures, the plan proposes projects such as developing global weather routing technology for ships and establishing a global weather routing system (CMA, 2021a). It is noteworthy that the plan document is primarily sent to subordinate maritime authorities and navigation services departments of CHINA MSA, implying that relevant units have the obligation and responsibility to implement the plan's requirements.

3.2.2.2 14th Five-Year Plan of National Meteorological Development

In 2021, CMA and the National Development and Reform Commission (NERC) jointly issued the *14th Five-Year Plan of National Meteorological Development.* The plan clearly states that in the construction of a strong maritime country, it is necessary to establish marine meteorological services, strengthen meteorological support for shipping navigation, and establish a global oceanic weather routing business with independent technology. The plan also emphasizes the promotion of cross-departmental interconnection and sharing of marine meteorological resources, laying the foundation for more in-depth cooperation between meteorological authorities and maritime authorities and navigation services departments (CMA, 2021b).

3.2.2.3 Outline for High-quality Meteorological Development (2022-2035)

In 2022, the State Council issued the *Outline for High-quality Meteorological Development (2022-2035)*. The outline provides a medium- to long-term development plan spanning 12 years, and supporting the construction of a maritime power and a transportation power will continue to be an important part of meteorological services for a long time in the future. It also mentions the need to strengthen the global oceanic weather routing service capabilities and provide meteorological support for global trade logistics once again (State Council, 2022). The plan also calls for the improvement of relevant systems and policies to promote and regulate the orderly development of the meteorological industry and stimulate the vitality of the meteorological market, but does not provide specific measures for this requirement.

3.2.2.4 China's Meteorological Science and Technology Development Plan (2021-2035)

China Meteorological Science and Technology Development Plan (2021-2035) was jointly released by CMA, Ministry of Science and Technology (MOST), and Chinese Academy of Sciences (CAS) in 2022, which sets out the development targets for meteorological science and technology in 2025 and 2035 respectively, requiring the professional meteorological service technology to reach or approach the international advanced level and achieve global service by 2025, and become a meteorological service power with international competitiveness by 2035; the plan provides 9 key areas and 46 priority development directions for China's meteorological science and technology development, and once again includes providing ocean weather routing

for ships as one of the priority development directions; in the field of meteorological science and technology innovation, the plan specifically mentions the need to cultivate meteorological science and technology enterprises with global competitiveness, and provide entrepreneurial platforms and services for meteorological science and technology (CMA, 2022).

3.2.3 Research on the future policy trends of China's weather routing

Analyzing and summarizing the key terms from the important planning documents mentioned above will help provide a more intuitive understanding of the approximate direction of the Chinese government's weather routing development for the next 5-10 years. The table of key term statistics is shown below.

Table 3

The Number of Occurrences of Each Key Term in Different Development Plans

Development Plan	**Overall length**	**Maritime (Ocean or sea)**	**Highway (or Road)**	**Railway**	**Waterway (or Water transportation)**	**Navigation**	**Market**	**Business (or Enterprise)**	**Independent**
14th Five-Year Plan for Meteorological Support in Transportation	8300	27	33	34	19	8	0	5	2
14th Five-Year Plan of National Meteorological Development	27000	26	1	7	0	2	2	6	5
Outline for High-quality Meteorological Development (2022-2035)	6700	15	0	2	0	1	1	0	4
China's Meteorological Science and Technology Development Plan (2021-2035)	23000	21	1	0	0	4	3	7	14

From the table, it can be seen that compared with highways, railways, and inland waterway transportation, the ocean will be a more important field for application and development in China's meteorological services in the next 5-10 years. Although the proportion of ship navigation and weather routing in the maritime field is not high, it is mentioned in all the listed planning documents enough to reflect the importance of this work. In terms of promoting business and enterprise, the government mentions it less frequently and lacks specific implementation measures. In contrast, the frequency of keywords such as promoting the development and application of independent products and services is significantly higher.

Therefore, based on relevant information on above mentioned Chinese laws, regulations, and development plans, the author predicts that the following trends will emerge in China's weather routing in the next 5-10 years:

First, increase the development and application of self-developed products and services, gradually narrowing the gap with international peers in technology and services, and significantly enhancing competitiveness.

Second, Chinese weather routing products and services will gradually participate in the competition in the international weather routing market, and market share will be effectively increased.

Third, the meteorological authorities will further strengthen horizontal cooperation with other government functional departments in the field of meteorological services.

Fourth, domestic market players will still be mainly government-backed institutions and state-owned enterprises, with private enterprises playing a supporting role.

Market vitality and competition may not show significant improvement.

3.3 Overview of Chinese and foreign weather routing markets

3.3.1 Overview of global weather routing markets

After decades of development, the international meteorological services market has become very mature. Driven by the uncertainty of weather brought about by global climate change, it is expected that meteorological services will continue to maintain a good growth momentum in the future. According to EMR's research and analysis, the global meteorological forecasting system market is expected to maintain a compound annual growth rate of 5.6% (CAGR 5.6%) between 2022 and 2027, and is expected to reach 3.85 billion US dollars in 2027 (EMR, 2021). In the professional meteorological services market, the service objects are extensive, including agriculture, energy, manufacturing, transportation, retail, financial services, insurance, health, judicial appraisal and other fields, which can almost penetrate into all aspects of global economic development. Although ship weather routing is a branch of the transportation industry and its market size is expected to be much smaller than the overall meteorological service market, many developed countries in Europe and America have already begun to apply weather routing technology to the field of long-distance shipping as early as the 20s and 30s of the last century, and it has a history of nearly a hundred years.

According to research data from Thalis P.V. Zis in 2020, the use of a weather routing service provider's license costs $15,000 per vessel, with subsequent subscription fees of approximately $30,000 per year (Zis, T.P.V. et al.， 2020), totaling about $45,000

per year in weather routing services for a single vessel. Based on the calculation of approximately 55,000 vessels with a gross tonnage of over 1,000 globally according to UNCTAD (2022), the rough estimate of the upper limit of the global weather routing market size in 2022 is around $2.475 billion per year.

Table 4

Ownership of the World Fleet, Ranked by Carrying Capacity in Dead-weight Tons, 2022, National- and foreign-flagged Fleet

	Country or territory of ownership	Number of vessels			Deadweight tonnage				
		National flag	Foreign flag	Total	National flag	Foreign flag	Total	Foreign flag as a % of total	Total as a % of world
1	Greece	620	4 246	4 870	55 715 512	328 703 344	384 430 215	85.51	17.63
2	China	5 357	2 599	8 007	113 035 546	163 977 083	277 843 335	59.19	12.74
3	Japan	933	3 070	4 007	35 970 817	200 656 470	236 638 365	84.8	10.85
4	Singapore	1 371	1 400	2 799	67 869 137	68 312 248	136 243 709	50.16	6.25
5	Hong Kong, China	861	948	1 822	72 061 117	39 473 538	111 587 729	35.39	5.12
6	Republic of Korea	804	867	1 680	14 767 539	77 501 218	92 302 014	84	4.23
7	Germany	185	2 036	2 221	6 976 526	72 616 389	79 592 915	91.23	3.65
8	Bermuda	2	505	507	26 137	63 381 136	63 407 273	99.96	2.91
9	Norway including Svalbard and Jan Mayen Islands excluding Bouvet Island	982	1 002	1 987	18 980 244	40 945 002	59 931 039	68.33	2.75
10	United Kingdom of Great Britain and Northern Ireland including Channel Islands and Isle of Man	363	1 014	1 380	9 376 891	49 222 876	58 746 865	84	2.69
11	United States of America including Puerto Rico	774	1 001	1 783	10 193 014	44 123 048	55 113 272	81.23	2.53
12	China, Taiwan Province of	150	856	1 014	6 590 724	48 326 874	54 974 072	88	2.52
13	Denmark	414	430	844	20 484 167	20 152 955	40 637 122	49.59	1.86
14	Monaco	0	393	393	0	38 011 632	38 011 632	100	1.74
15	Switzerland	17	480	497	911 905	29 975 783	30 887 688	97.05	1.42
16	Türkiye	406	1 175	1 583	5 768 553	24 653 060	30 433 830	81.04	1.4
17	Belgium	99	244	343	9 141 427	20 304 520	29 445 947	68.96	1.35
18	Indonesia	2 283	121	2 411	24 763 544	4 050 071	29 065 796	14.06	1.33
19	United Arab Emirates	124	954	1 087	631 741	26 597 771	27 363 741	97.68	1.26
20	India	874	197	1 076	16 165 552	9 302 885	25 979 620	36.53	1.19
21	Russian Federation	1 516	309	1 833	9 250 551	15 044 248	24 317 936	61.92	1.12
22	Iran (Islamic Republic of)	244	10	255	18 608 833	830 667	19 441 051	4.27	0.89
23	Netherlands	665	524	1 189	5 392 304	12 519 434	17 911 737	69.9	0.82
24	Saudi Arabia	160	108	269	13 619 108	3 738 256	17 358 885	21.54	0.8
25	France, Metropolitan	173	252	425	4 356 779	10 978 404	15 335 183	71.59	0.7
26	Italy	453	177	630	9 040 908	6 237 878	15 278 786	40.83	0.7
27	Viet Nam	959	167	1 133	11 358 301	3 562 368	14 934 404	23.88	0.69
28	Brazil	295	84	384	4 672 784	9 077 925	13 773 954	66.02	0.63
29	Cyprus	124	227	353	4 435 287	9 272 007	13 758 739	67.64	0.63
30	Canada	207	174	383	2 491 394	7 342 722	9 835 479	74.67	0.45
31	Oman	4	64	69	5 558	9 326 443	9 332 147	99.94	0.43
32	Malaysia	453	163	629	6 597 645	2 344 395	8 985 167	26.22	0.41
33	Nigeria	203	73	282	3 521 990	3 976 535	7 520 054	53.03	0.34
34	Qatar	53	74	127	733 693	6 475 247	7 208 940	89.82	0.33
35	Kuwait	44	7	51	4 805 336	446 848	5 252 184	8.51	0.24
	Subtotal, top 35 shipowners	**22 172**	**25 951**	**48 323**	**588 320 562**	**1 471 461 279**	**2 062 880 823**	**71.44**	**94.63**
	Rest of the world unknown	*3 173*	*2 558*	*6 714*	*33 495 841*	*56 785 576*	*117 177 484*	*48.46*	*5.37*
	World	**25 345**	**28 509**	**55 037**	**621 816 403**	**1 528 246 855**	**2 180 058 307**	**71.08**	**100**

Note. From *Review of Maritime Transport 2022* (p. 40), by United Nations, 2022, United Nations (https://unctad.org/rmt2022). Copyright 2022 by United Nations.

3.3.2 Overview of China's weather routing market

In contrast to the international meteorological service market, China's meteorological service has always put public welfare services first and its main task is to provide free public meteorological services. In addition to the restrictions on the use of meteorological data, the commercial market for meteorological services in China has been monopolized by government-backed organizations, and the market is not mature, lacks market competitiveness and vitality, which further leads to significant gaps between the capabilities of the main providers of commercial meteorological services in China in terms of technology, services, innovation, and market operations compared to developed countries such as Europe and America.

In the field of ship weather routing, China started relatively late and only began to try to develop weather systems in the 1980s and 1990s. During the research and development process, it was once constrained by technology and stalled, resulting in a significant gap between China and mature weather routing service companies in Europe and America.

However, international shipping, due to its natural outward-looking nature, is not restricted by domestic meteorological laws and regulations, which has exposed China's ocean-going vessel weather routing field to fierce global market competition from the beginning, resulting in the long-term monopoly of China's ocean-going vessel weather routing by foreign providers. According to the same charge standard of investing $45,000 per vessel in weather routing, according to the latest data from UNCTAD in 2022, there are 8,000 ships with a gross tonnage of over 1,000 in China, so China's upper limit of the weather routing market in 2022 is roughly $360 million,

equivalent to about RMB 2.5 billion per year.

3.3.3 Comparison of market performance of Chinese and international representative weather routing companies

3.3.3.1 International weather routing service companies

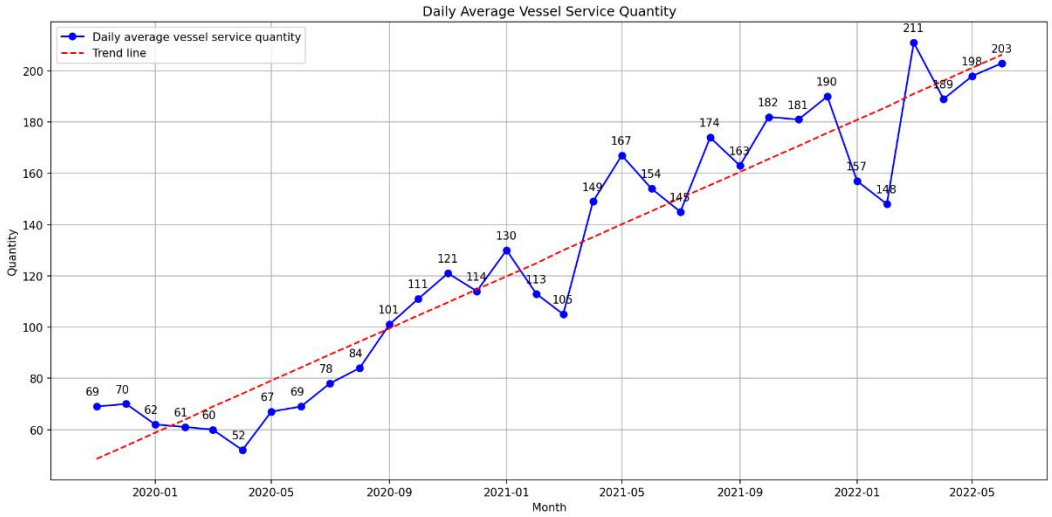
According to the data available on their official websites, the representative international weather routing service companies are StormGeo AS (AWT) and Weathernews, with the following scale: StormGeo AS (AWT) has installed its route optimization software on over 5,800 ships in the field of weather routing, generating over 68,000 optimized routes each year, and over 3,000 ships subscribe to their charts and publications; Weathernews has been providing meteorological services for the shipping sector for 55 years, serving over 10,000 ships annually.

3.3.3.2 Domestic weather routing service companies

The most representative domestic weather routing service provider is the NMC. According to the market performance data released by this organization, the service volume has shown a clear growth trend since the company's self-developed weather routing system was introduced in 2019. From November 2019 to June 2022, the daily average number of ships served by the company is as follows:

Figure 3

Daily Average Vessel Service Quantity of NMC

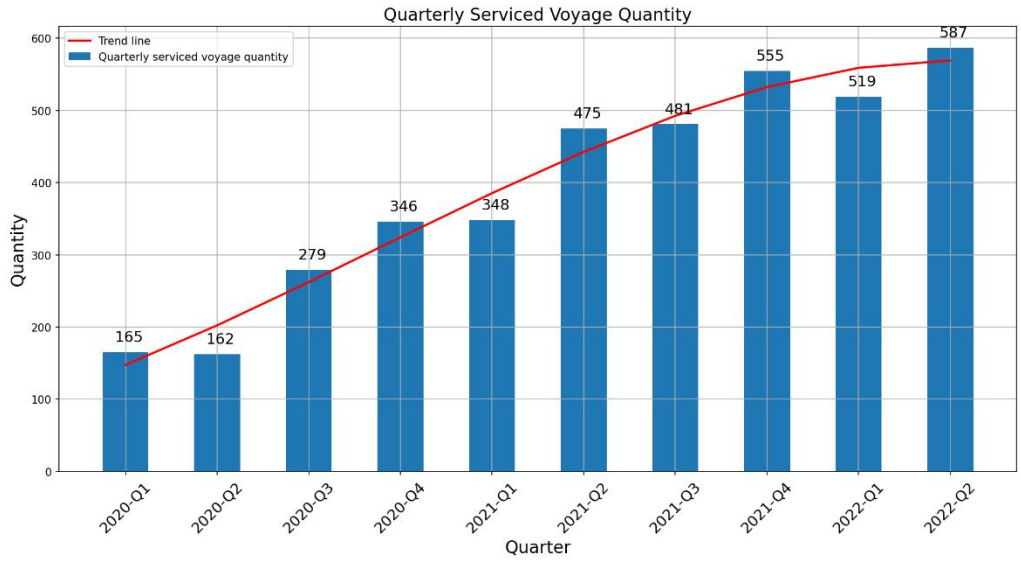


Note. Date collected from personnels of NMC

It is understood that as of February 1, 2023, the company's daily service for ships has reached more than 180 vessels, an increase of nearly 450% compared to the figure two years ago, with an average monthly growth rate of 12% in service volume from 2020 to 2022. During the period from the first quarter of 2020 to the second quarter of 2022, the quarterly number of service voyages of the company also showed a clear upward trend.

Figure 4

Quarterly Voyage Service Quantity of NMC



Note. Date collected from personnels of NMC

Compared to 162 voyages in the second quarter of 2020, there was a 262% increase in the number of voyages to 587 in the second quarter of 2022.

Despite the strong momentum shown in growth rate, there is still a huge gap in service volume between NMC and internationally renowned weather routing service providers.

Table 5

Comparison of Market Performance of Major Domestic and International Weather Routing Service Providers

Comparison of Market Performance of Major Domestic and International Weather Routing Service Providers		
Provider	**Nationality**	**Market Performance**

StormGeo AS（AWT）	Norway	2022: Serviced more than 5,800 ships throughout the year (StormGeo AS, 2023).
Weathernews	Japan	2022: Serviced more than 10,000 ships throughout the year (Weathernews, n.d.).
OneOcean	UK	2022: Serviced over 15,000 vessels (OneOcean, 2023)
NMC	China	2022: Served 2600 voyages, with an average daily active user base of 184 vessels (NMC, 2020).

3.4 Summary of this chapter

Based on the research of information about weather routing providers, Chinese weather routing policies, and the overview of domestic and international weather routing markets mentioned above, several characteristics can be summarized.

In terms of weather routing providers. Foreign weather routing services started earlier and, after a long period of full market competition and selection, cultivated a large number of privately-owned commercial weather routing enterprises with strong technical strength and excellent service quality. In contrast, most of China's weather routing providers have government backgrounds or belong to state-owned enterprises under the supervision of CMA. Due to the late start and backward technology, coupled with insufficient market incentives and competition in the domestic market, China's weather routing service providers have not yet formed their relative advantages in the international field. To quickly break through the technology bottleneck, using the domestic market to exchange for foreign technology has become one of the development strategies of China's weather routing service providers. Therefore, joint ventures between domestic and foreign meteorological service companies can still be seen in the Chinese market, while the weakest players in this market are Chinese private meteorological service enterprises.

In terms of China's weather routing policy direction, China's meteorological authorities have recognized the phenomenon of foreign capital's long-term monopoly on the weather routing market and are accelerating efforts to solve this problem. In the future, the research and development of weather routing services and products will be further strengthened, and the technology gap with international peers is expected to be reduced, and even in some fields, China's weather routing service providers are expected to catch up and surpass their international competitors which will increase their share in the global market and realize the vision of ***National Weather Routing service for National Ships***. However, for future domestic private commercial weather routing service providers in China, their development still faces severe challenges, and the market share may not be so sufficient. On the contrary, China's meteorological authorities will further strengthen cooperation with other functional government departments in China. For the Chinese maritime authorities and navigation service department that seek to transform from traditional businesses to high-quality development, strengthening cooperation with the meteorological department through this opportunity will become one of their breakthroughs in business upgrading, and realizing “Meteorology + Maritime” initiatives.

Regarding the Chinese weather routing market, it is necessary to recognize that the offshore shipping weather routing market will still maintain its characteristics of internationalization, marketization, and liberalization. During the research process, the author did not find any signs indicating that the relevant Chinese regulatory authorities intend to intervene in this market (Chinese ships) through administrative regulations. In the future, Chinese weather routing products and services are expected to gain greater profits and still need to face challenges from international peers, relying on their own strength to win more users through free market.

CHAPTER 4 RESEARCH ON THE USER END OF WEATHER ROUTING

4.1 Survey and questionnaire design on the user end of weather routing

4.1.1 Survey purpose

The previous chapter conducted research and analysis on the supply and market environment of weather routing through online materials collection and reached corresponding conclusions. However, in order to gain a more intuitive understanding of the demand side of weather routing, it is necessary to start from the perspective of frontline users. By understanding their experiences and feelings, recommendations can be provided for the development and improvement of weather routing services and products.

4.1.2 Research subjects

The research subjects of this survey are mainly the direct users of weather routing services and products, including crew members, shipowners, ship management companies, charterers, ship agents, and other related personnel.

4.1.3 Survey method

This survey will be mainly conducted through the Internet, and a well-designed questionnaire will be accurately distributed to the relevant survey objects. The planned sample size for the survey is 50. The ideal ratio of survey objects is 70% for crew members, 10% for ship owners or ship management companies, 10% for charterers, and 10% for other objects.

4.1.4 Data to be collected and questionnaire design

The main purpose of this survey questionnaire is to understand 10 aspects of information related to navigation users, and each aspect corresponds to several questions. Therefore, the questionnaire design is as shown in the following table.

Table 6

Design Approach for the Survey Questionnaire

No.	Information expected to be obtained	Description	Specific questions
1	User's basic information and background	The potential users of weather routing are not singular, and in order to understand the usage of different types of users, it is necessary to clarify the user information in the questionnaire, which is conducive to the subsequent classification of data.	1. Name of your company (or Organization) 2. Nationality of your company (or Organization) 3. Your Occupation 4. The type of the ship you are on
2	User's basic needs	Trying to understand what motivates users to use	5. Whether your ship is using (or has used) weather routing service (i.e.

		weather routing services and what objective factors are driving their usage.	recommending or optimizing ship routes based on weather information) 6. Do you need weather routing service? 7. If so, your strongest requirements for you to use weather routing service are?
3	Basic situation of the market share of weather routing services and products	Trying to understand the basic situation of the market share of different weather routing service providers and products, and at the same time introducing questions about the popularity of Chinese weather routing service providers.	8. Which weather routing company is the most used by you or your company? Roughly the proportion? 9. Which weather routing company is the second most used by you or your company? Roughly the proportion? 10. How many weather routing providers' services does your vessel use? 11. Have you ever heard the weather routing service provider from China?
4	Basic situation of weather routing service delivery method	Considering that different weather routing service providers have different service delivery methods, this part specifically includes a question to investigate which delivery method is the most popular in the current market.	12. How is the weather routing service provided by the provider you choose right now
5	Factors that attract users to weather routing products or services	The main objective is to understand the factors that are most likely to attract users to weather routing services or products, in order to provide data support for the development of Chinese weather routing service products and services.	13. Which of these service delivery methods do you prefer? 14. What is your top priority when choosing weather routing provider?

6	The usage experience and expectations of users towards future developments of weather routing	The survey aims to investigate users' subjective experience in using existing weather routing services and products, and to introduce questions related to judging the development of the future weather routing service market based on this experience, in order to understand users' expectations for future products.	15. What do you think of the weather routing service you are using 16. What is the adoption rate of the routes recommended by weather routing providers? 17. What do you think of the development of weather routing in the next 5 years
7	Pain points of using weather routing for users	Investigate and understand the main shortcomings of current weather routing services and products on the market.	18. Do you think it's easy to operate the product, system or software of the weather routing providers? 19. Are you having difficulties or problems using the weather routing service? 20. What is the most annoying problems do you think when using weather routing services? 21. Do you have any suggestions for the improvement of weather routing services?
8	Price sensitivity of weather routing products and services for users	The main focus is to investigate the different perceptions of price among different user groups for the weather routing services and products they use.	22. Do you think weather routing services are expensive? 23. What do you think is a reasonable price range for ship weather routing services?
9	User stickiness of weather routing products and services	This part aims to investigate the user stickiness of weather routing products and services, in order to understand whether there are barriers to entry for	24. Do you think it will be inconvenient to change a new weather routing company?

		new brands entering the market.	
10	Respondents' willingness to participate in future interviews	This section will reserve a registration window for users who are willing to participate in further surveys	25. Would you like to be interviewed later?

4.2 Survey report

4.2.1 Data collection of the survey

A total of 57 responses were collected for the survey questionnaire. Among them, responses with a response time of less than 200 seconds or with contradictory options were screened. Four responses were considered invalid due to having 2 or more obvious contradictions in the screened responses. Therefore, a total of 53 valid responses were obtained, resulting in an effective rate of 93.0%.

4.2.2 Survey questionnaire data analysis

4.2.2.1 Users' basic information and background

All respondents in this survey have a background in the shipping industry, with 73.58% being crew members, 7.55% being shipowners or ship management companies, 9.43% being charterers, and another 9.43% being other personnel (including maritime authority personnel, marine scientific research personnel, ship agents, etc.). The ships served by all respondents are distributed as: 75.47% for ocean-going merchant ships, 11.32% for coastal and inland merchant ships, 13.21% for non-convention ships such as fishing boats, yachts, and other ships (including

government vessels, ocean engineering ships, research ships, cruise etc.). 84.9% of the companies (or organizations) served by the surveyed respondents are from China, and another 10% are from Hong Kong and Singapore. It should be noted that most of the companies (or organizations) from China may have some foreign-flagged vessels served by the surveyed respondents who may work for labor service dispatch companies. The specific data charts are as follows:

Figure 5

Distribution of the Respondent Categories

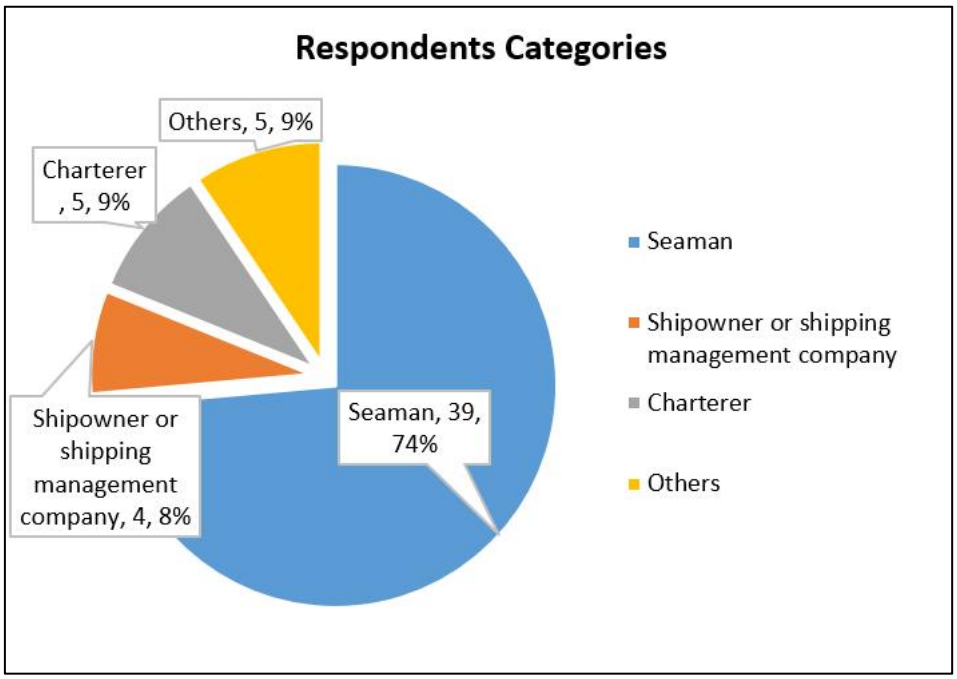
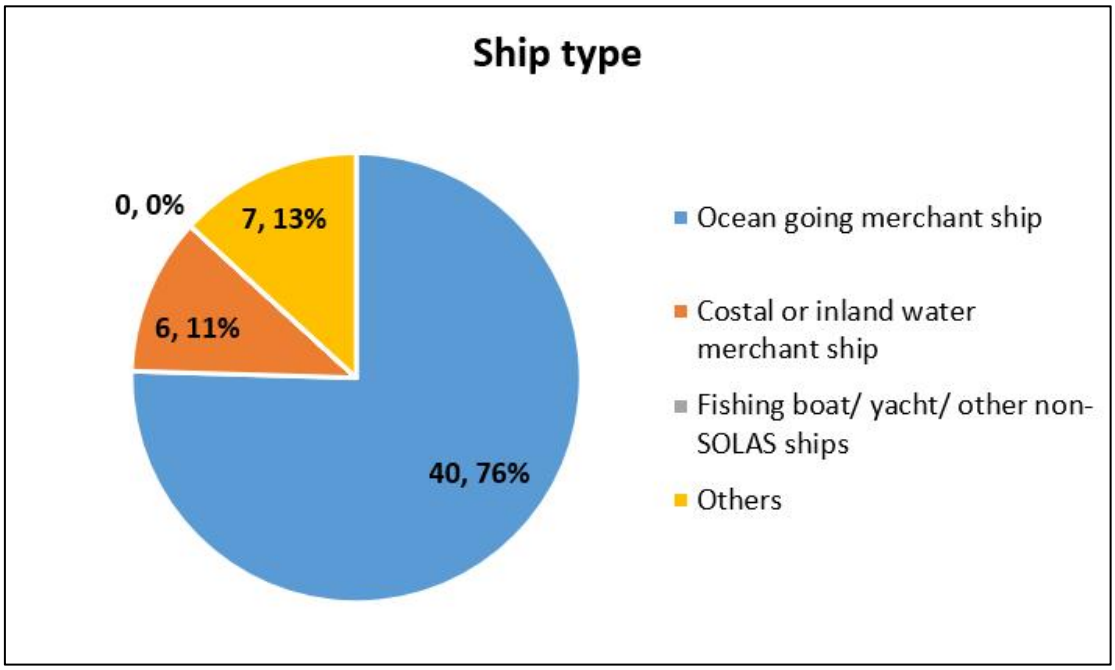


Figure 6

Distribution of Ship Type



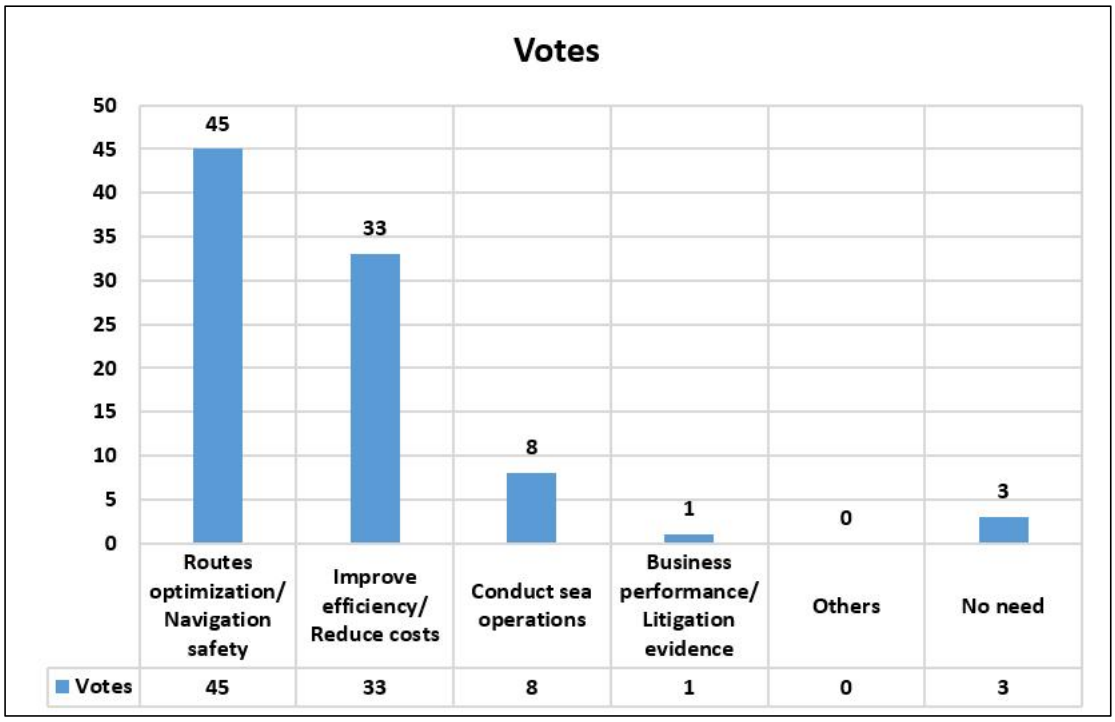
The sample size and type distribution of the surveyed objects in this study basically met the expected goals, which can to some extent reflect the recognition and opinions of first-line users of weather routing services and products.

4.2.2.2 Basic needs of users

Among the respondents, 60% of the personnel stated that the vessels they serve are currently or have used weather routing services, while more than 73% of the respondents expressed their need to obtain weather routing services. In terms of the types of weather routing needs, the votes obtained in different application scenarios are shown in the following figure:

Figure 7

Votes for Different Requirements



The survey results show that 60% of respondents' vessels are currently using or have used weather routing services or products, while over 75% of respondents indicate a need for such services. These two data points reflect that there is still great potential for user development in China, and awareness of weather routing needs to be improved. The greatest demand is to strengthen navigation safety and improve navigation efficiency, largely due to the large proportion of crew members in the sample.

4.2.2.3 Basic situation of market share for weather routing services and products

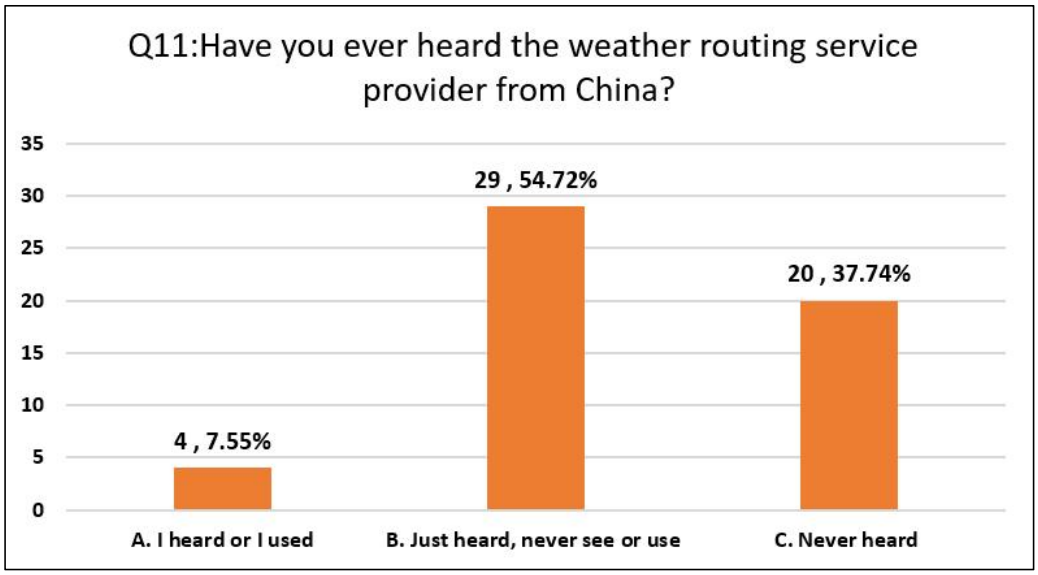
In this part, the author used ship owners, ship management companies, and charterers as the shore-side group, and crew members as the ship-side group for inter-group comparison. The statistical results showed that 55.5% of the shore-side group knew

about the weather routing products used by themselves or their companies, while only 41.1% of the ship-side group knew about the weather routing products used by their ships or their companies. Among all valid samples, nearly 70% of the objects' served ships had one weather routing service product, and 18.7% of the objects' served ships had 2-3 weather routing service products. The weather routing service providers mainly used by the surveyed objects include Windy, WNI, Spos (DTN), CMRC (NMC), Bridge, SMHI (Swedish Meteorological and Hydrological Institute), BVS (StormGeo), Turbowin (National Oceanic and Atmospheric Administration, NOAA), OneOcean, Searoute, and WRI.

In terms of the popularity of domestic weather routing services and products, only 7.55% of the objects have used Chinese weather routing products, nearly 55% have only heard of them, and nearly 38% of users have no knowledge of Chinese weather routing products.

Figure 8

Distribution of the Answers to Question 11



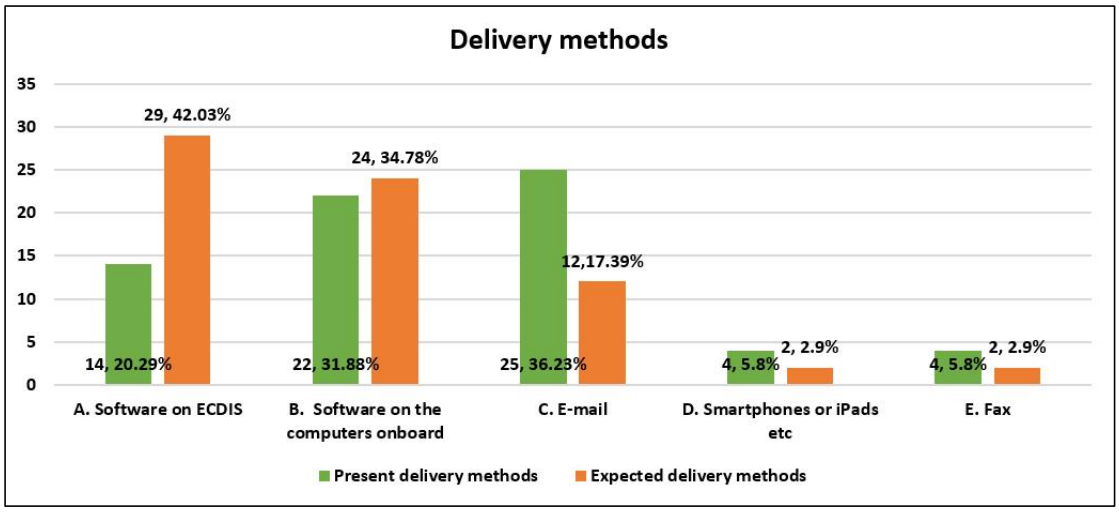
Crew members showed little interest in knowing the specific names of weather routing products and service providers, and less than 10% of them have used domestic weather routing services in China, indicating that the market is still dominated by foreign providers.

4.2.2.4 Basic information on weather routing service delivery methods and user preferences

Questions 12 and 13 in the questionnaire collected information on this aspect. Since they were multiple choice questions, the author selected the responses that indicated specific services based on the vote count, and both questions had 69 valid votes. The number and proportion of current service methods are represented by green bars, while preferred service methods are represented by orange bars in the figure below:

Figure 9

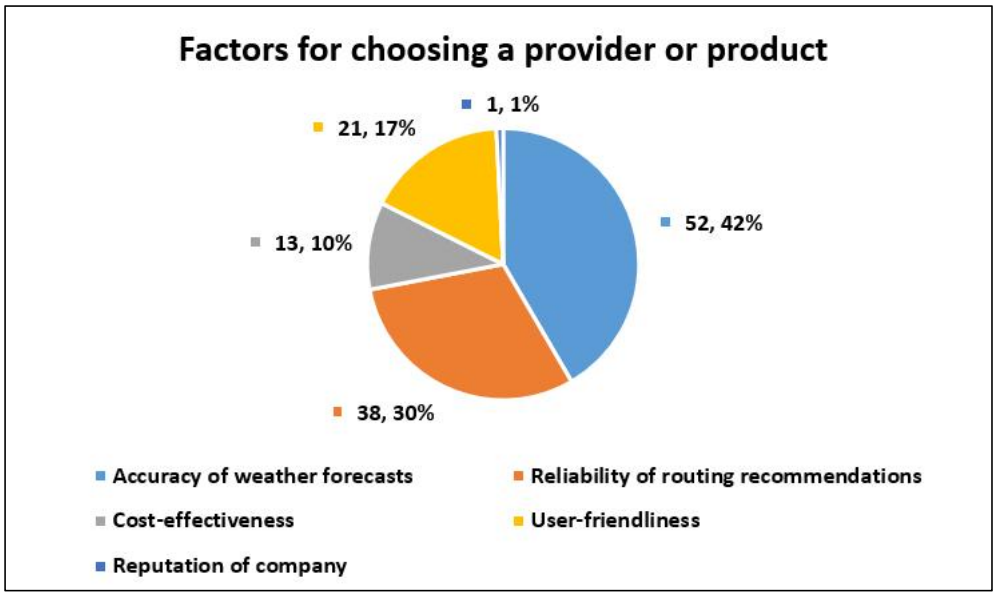
Distribution of Different Delivery Methods



The primary factors that users consider when choosing a weather routing service provider were collected through 125 valid votes, and their distribution is as follows:

Figure 10

Distribution of the Factors for User to Choose a Provider or Product



Among the 69 valid votes in Figure 10, more than half of them chose the weather routing software in shipboard computer and **Electronic Chart Display and Information System** (ECDIS), and email remains the most popular way to provide weather routing services. However, mobile apps such as those on smartphones or tablets are not mainstream in the maritime industry, and the traditional method of fax is also not popular. However, there is still a gap between the current service delivery methods and user expectations, mainly in the areas of ECDIS and email. Almost all email users have switched to using ECDIS, indicating that a significant proportion of users expect weather routing services to be integrated directly into ECDIS.

The most important factors for 80% of users when selecting weather routing services and products are accurate weather forecast information and reliable route recommendation services, while cost-effectiveness accounts for only 13.1%. Even if we only look at the statistics of ship owners and charterers, cost-effectiveness only accounts for 19%.

4.2.2.5 User experience and expectations for the future of weather routing

In terms of user experience, over 37% of respondents indicated that it was very helpful, while more than 43% of users found it somewhat helpful; in terms of the adoption rate of recommended routes, nearly 36% of respondents had an adoption rate of 80%-100%, and 24.53% had an adoption rate of 60%-80%.

As for expectations for the future development of weather routing, a staggering 88.68% of respondents expressed that weather routing services will become more important and widely used in the future.

Basically, around 80% of users affirmed the role of weather routing, and nearly 90% of users held a positive attitude towards the future development of weather routing in the next five years, indicating that the domestic weather routing market has good prospects for expansion.

4.2.2.6 Pain points of users using weather routing

According to the survey, among users currently using weather routing, 60.5% are satisfied with the ease of operation of current weather routing products, and no users

gave a ***very inconvenient*** evaluation; However, almost half of the users encountered varying degrees of malfunctions or problems during use, and the most hated problems among users are: inaccurate forecast information, poor weather recommendation for routes (14 votes), unstable network (5 votes), insufficient real-time performance (5 votes), inconvenient operation (3 votes), software and hardware malfunctions (3 votes), disagreements with shipping companies (2 votes), too many feedback requests for ship side (1 vote), biased towards charters (1 vote), and a lack of a clear definition of constant-speed sailing (1 vote).

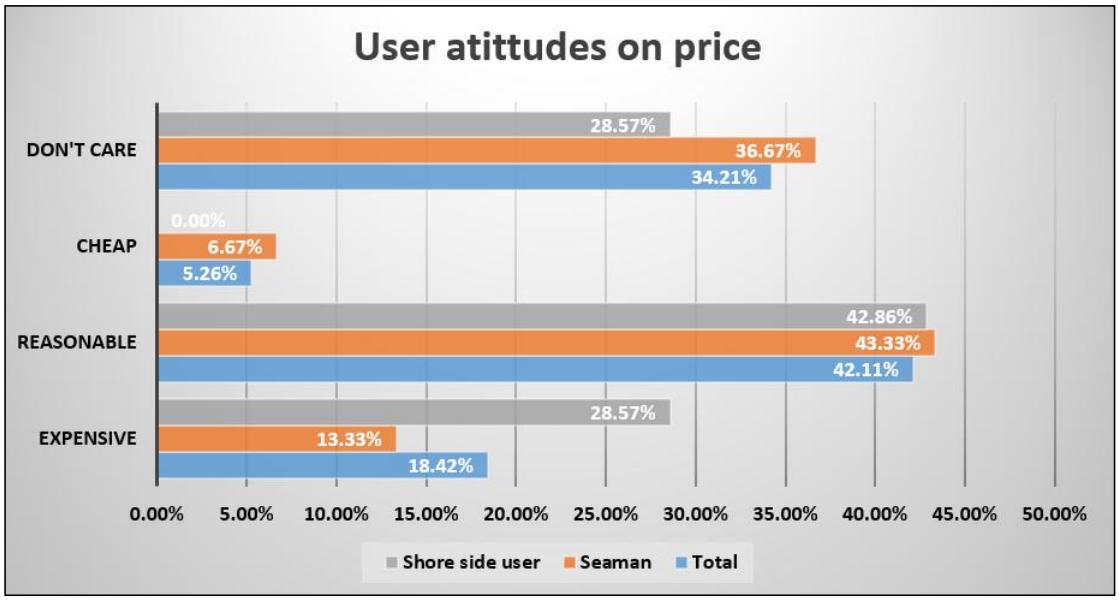
Users' suggestions for improving weather routing services and products mainly include: improving forecast accuracy (13 votes), improving real-time forecast (8 votes), improving cost-effectiveness (3 votes), making the operation more convenient with fewer ship-side reports (3 votes), increasing automation and intelligence (3 votes), diversifying route recommendations (2 votes), improving the stability of communication channels (1 vote), more comprehensive functions (1 vote), and improving the integration with nautical charts (1 vote).

4.2.2.7 User price sensitivity

The author grouped and compared the surveyed subjects who provided clear answers on the prices of weather routing services and products, dividing the eligible subjects into ship-side users (seafarers) and shore-side users (ship owners, charterers, etc.). The attitudes of different groups towards the prices of weather routing services and products are shown in the following figure.

Figure 11

Distribution of the User Attitudes on Price



A considerable portion (approximately 43%) of users consider the current weather routing services and products to be reasonable, while the second largest group of users do not care about their price. From the diagram, it can be seen that shore-based users are significantly more price-sensitive than ship-based users, with 28.57% of shore-based users considering the current service prices to be expensive, and none considering them to be cheap. However, there are still 28.57% of shore-based users who do not care about the price, a proportion that is significantly lower than that of seafarers.

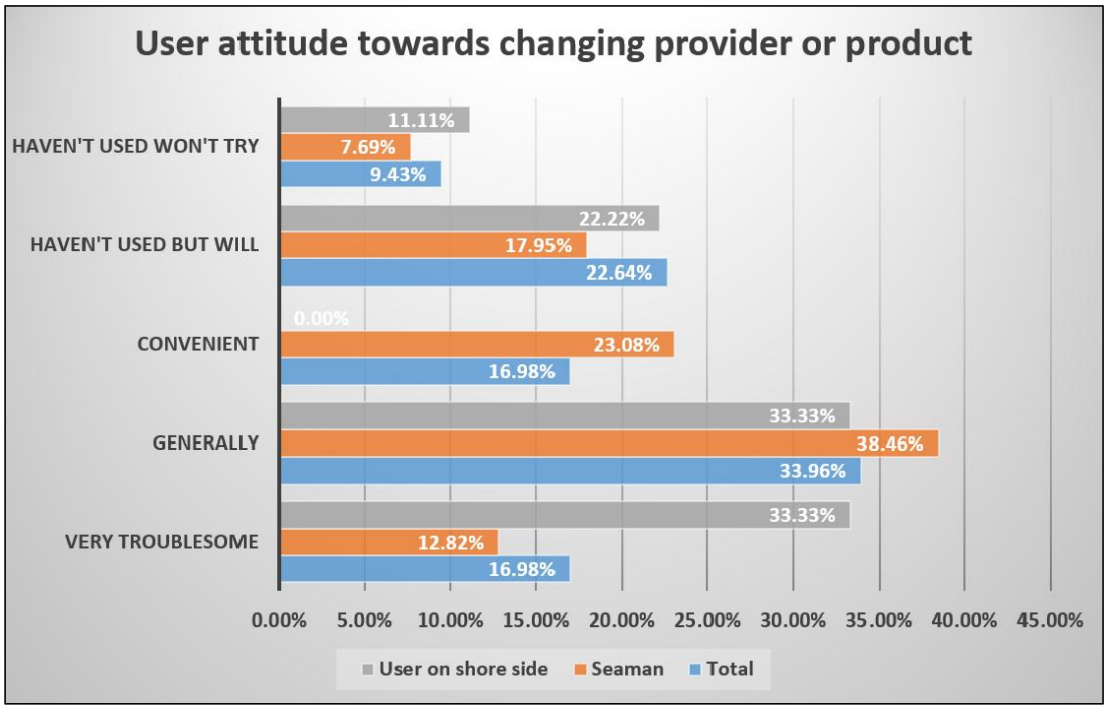
4.2.2.8 User stickiness of weather routing products and services

Finally, regarding user stickiness of weather routing services and products, the number of respondents who consider it very inconvenient or convenient to change their weather routing service provider or product is the same, accounting for 16.98%

of the total respondents, while those who consider it not too inconvenient account for 33.96%. Additionally, 22.64% of respondents who have not used weather routing services before are willing to try, and less than 10% of respondents expressed no interest in weather routing services. Similar to price sensitivity, there are also significant differences in user stickiness among different user groups, as shown in the figure below.

Figure 12

Distribution of the user attitude towards changing provider or product



In general, the user stickiness of weather routing services and products is significantly higher for shore-side users than that for ship-side users, and no shore-side users believe that switching service providers or products is convenient, which is in sharp contrast to ship-side users.

4.3 Summary of this chapter

The sample size and distribution of the research subjects in this survey basically meet expectations, and the required operations for the survey were carried out according to the predetermined procedures. The research data can reflect to some extent the real feelings of frontline users of current weather routing services and products. Through analyzing the data collected from this survey questionnaire, the main conclusions on the user side related to the research objectives are as follows:

Popularization and promotion of weather routing knowledge should be put on agenda. Currently, the majority of frontline users in China have a demand for weather routing, but their understanding and awareness of weather routing are still in the early stage and knowledge in this needs to be popularized and strengthened, which also means that the Chinese weather routing market still has a great development potential.

The market share of domestically produced weather routing services or products is less than 10%, and nearly 40% of frontline users in China have never heard of Chinese weather routing products.

There are obvious mismatches and gaps in the current weather routing service delivery methods. Compared to a large number of email notifications for weather routing services, users expect to directly integrate weather routing services provided by ECDIS.

Nearly 90% of users are optimistic about the development of weather routing in the next five years, and users in the Chinese weather routing market have high expectations.

Improving forecast accuracy and real-time updating, as well as enhancing convenience, automation, intelligence, and cost-effectiveness are the most anticipated improvements by users.

Weather routing services have a strong user stickiness for shore-based users, but nearly 30% of them think the current service is too expensive.

At the same time, it should be noted that there are still many limitations in this survey, mainly reflected in the insufficient sample size, limited geographic distribution of the surveyed subjects mainly in China, and the insufficient survey duration. Due to the above factors, there may be a lack of accuracy in the analysis and conclusions drawn from the data.

CHAPTER 5 METEOROLOGICAL SERVICE RESEARCH OF CHINA

5.1 The background of IMO e-Navigation Strategy

On December 19, 2005, seven countries including Japan, the Marshall Islands, the Netherlands, Norway, Singapore, the UK, and the US jointly submitted a proposal (MSC 81/23/10) to the IMO Maritime Safety Committee (MSC) for the development of e-Navigation strategy, marking the beginning of the e-Navigation strategy. The main goal of e-Navigation is to integrate and optimize the navigation and operation of ships through modern communication, navigation, and information technology, and to establish a globally universal and standardized maritime service system, providing timely, comprehensive, and integrated maritime safety and navigation information services for relevant users such as ships and ports, enhancing shipping efficiency, ensuring ship navigation safety, and strengthening marine environmental protection (IMO, 2005). The e-Navigation strategy has been proposed for more than a decade, and several countries have conducted dozens of testbeds related to e-Navigation, gradually putting them into practical use (International Association of Marine Aids to Navigation and Lighthouse Authorities [IALA], 2023). The services provided by the e-Navigation project are reflected in the form of Maritime Services (MS). In 2019, the IMO Maritime Safety Committee (MSC) passed Resolution MSC.467(101), defining MS as the provision and exchange of maritime-related

information and data in a harmonized, unified format (IMO, 2019), and the main services include:

Table 7

Maritime Services Defined by IMO

MS No.	Name of MS	Coordinating organization	Responsible Authorities
MS 1	VTS Information Service（IS）	IALA	National VTS authority; Coastal or port authority
MS 2	Navigational Assistance Service（NAS）	IALA	National VTS authority; Coastal or port authority
MS 3	Traffic Organization Service（TOS）	IALA	National VTS authority; Coastal or port authority
MS 4	Port Support Service（PSS）	IHMA	Local port authority
MS 5	Maritime Safety Information (MSI) Service	IHO	National regulatory agency
MS 6	Pilotage service	IMPA	Pilotage organization or institution
MS 7	Tug Service	To Be Determined (TBD)	National regulatory agency; Local port authority
MS 8	Vessel Shore Reporting	TBD	National regulatory agency; Related service agencies
MS 9	Telemedical Assistance Service（TMAS）	TBD	National health and medical institution; Specialized health and medical institution
MS 10	Maritime Assistance Service（MAS）	TBD	Coastal State/Port State authorities
MS 11	Nautical Chart Service	IHO	National Hydrographic Office
MS 12	Nautical Publications service	IHO	National Hydrographic Office
MS 13	Ice navigation Service	WMO	National regulatory agency
MS 14	Meteorological information service	WMO	National meteorological authorities; Relevant public agencies

MS 15	Real time hydrographic and environmental information service	IHO	National hydrographic and meteorological authorities
MS 16	Search and Rescue Service (SAR)	TBD	Search and Rescue (SAR) organization

Note. From *Digital Maritime Services Under the Framework of e-Navigation Strategy* (pp. 73-74), by Y. Yang, year, China Communications Press Co., Ltd.

5.2 The current development status of China's e-Navigation project

The CHINA MSA has been closely monitoring the development trends of international e-Navigation, and since 2014 has organized the construction of the e-Navigation project in the north, east, and south part of China coast by the three Navigation Service Centers of CHINA MSA. The construction status of the e-Navigation project in each NSC is as follows.

5.2.1 e-Navigation projects of Northern Navigation Service Center

Northern Navigation Service Center has implemented the pilot project of ***Tianjin Port e-Navigation*** and the ***Northern Sea Area VDES e-Navigation*** in the northern part of China coast.

Two multi-functional Aids to Navigations (AtoNs) were developed and deployed for ***Tianjin Port e-Navigation Project*** in Tianjin Port to collect real-time hydrological and meteorological environmental data in the compound channel and transmit it back to the system center, providing ships with real-time hydrological environmental information and other relevant navigation information services. The Northern Sea

Area VDES e-Navigation Project in the northern sea area developed the VDES system shore station, shipborne terminal prototype, and corresponding demonstration verification system software, realizing data transmission of AIS, ASM, and VDE between ships, between ship and shore, and between shore and ship.

5.2.2 e-Navigation projects of Eastern Navigation Service Center

The Eastern Navigation Service Center has implemented the ***e-Yangshan Port*** project and the ***Yangtze River Estuary e-Navigation*** project.

The ***e-Yangshan Port*** project mainly uses technologies such as BeiDou Navigation Satellite System (BDS) high-precision positioning and AIS differential information to provide high-precision positioning and navigation services for ships entering and leaving the port in poor visibility conditions. The ***Yangtze River Estuary e-Navigation*** project has developed an e-Navigation intelligent navigation terminal, which can use BDS positioning to display relevant navigation information such as electronic nautical charts, virtual navigation aids, hydrological and meteorological information to assist ship navigation.

5.2.3 e-Navigation projects of Southern Navigation Service Center

The Southern Navigation Service Center has implemented projects such as the ***Pearl River Delta e-Navigation*** project and the ***e-Navigation Integrated Maritime Safety Information Service System*** project.

The ***Pearl River Delta e-Navigation*** has established a universal shore-based system architecture for e-Navigation that complies with the IMO framework, formulated a

series of e-Navigation technical service standards, and provided a batch of e-Navigation services for experimentation and verification to the public. The ***e-Navigation Integrated Maritime Safety Information Service System*** project upgraded the shore-based system of the previous project and further released 91 standardized e-Navigation technical services out of 7 MS to the public.

5.3 Instance of meteorological service experiment based on Chinese e-Navigation project

The above-mentioned typical Chinese e-Navigation projects mainly focus on the navigation or communication areas of ships, and this section will investigate and evaluate a Chinese e-Navigation project that focuses on meteorological information services.

5.3.1 Basic information of the project

Testbed Name: Meteorological Monitoring and Early Warning System for Key Shipping Channels in the New Western Land-Sea Corridor.

Test Objectives: Based on the requirements of domestic meteorological service policies, establish a shared and co-construction mechanism between maritime authorities and meteorological authorities, share meteorological data and decision-making information of the meteorological authorities; realize the functions of meteorological monitoring and early warning, meteorological forecasting, visibility identification and other functions in specific areas; on the basis of the above, connect the related functions to the superior e-Navigation project (e-Navigation project of Southern Navigation Service Center) according to international technical

standards and provide professional meteorological information services to the public users.

Test Area: The test site is mainly located in the coastal key shipping channels of the Beibu Gulf in Guangxi, including the Qinzhou Port 300,000-tonnage shipping channel and its branches, the Qinzhou Port East Channel, the Qinzhou Port West Channel, the Tieshan Port inbound channel, the Beihai Port inbound channel, the Beihai to Weizhou passenger route, the Fangcheng Port Sanya Channel, the Fangcheng Port West Bay Channel, the Fangcheng Port East Bay Channel, etc.

Figure 13

Test Area for the Testbed

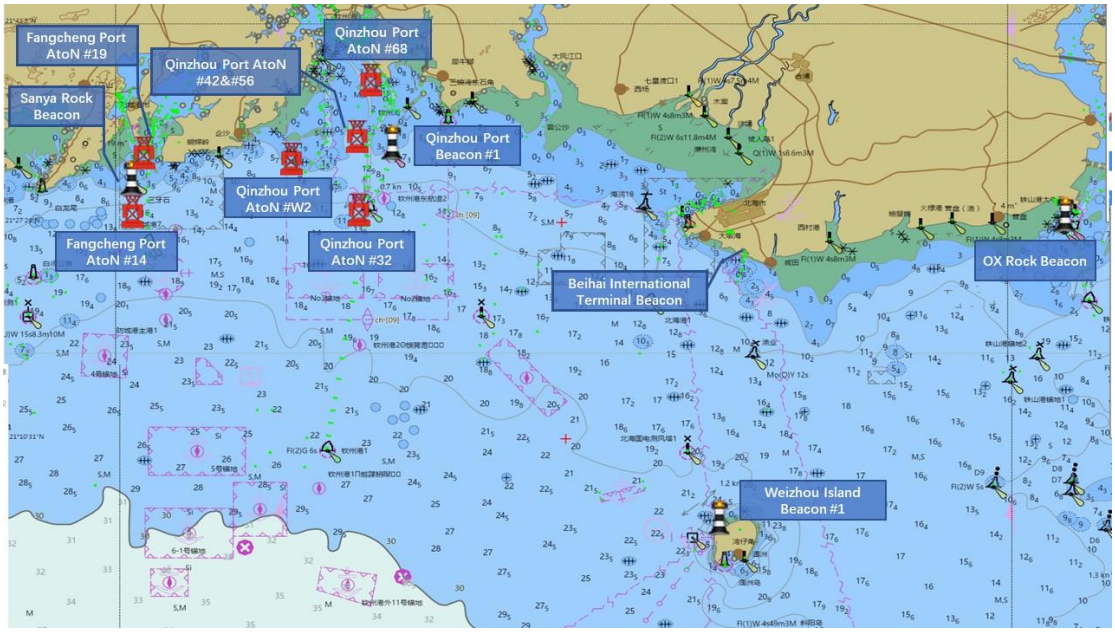
Note. Adapted from *Meteorological Monitoring and Early Warning System for Key Shipping Channels in the New Western Land-Sea Corridor*, Southern Navigation Service Center. Copyright 2023 by Southern Navigation Service Center.

5.3.2 Experimental conditions

12 multi-functional AtoNs are deployed in the coastal waters of the Beibu Gulf (Guangxi) as meteorological data collection stations, which are equipped with sensors capable of measuring meteorological elements such as visibility, wind speed, wind direction, temperature, humidity, air pressure, and rainfall. 6 meteorological observation stations provide more accurate local weather warning services for maritime areas. Two S-band (10 mm) new generation Doppler weather radars are deployed in city of Beihai and Fangchenggang, and one digital radar in Qinzhou is retrofitted into a dual-polarization X-band (3 mm) Doppler radar, which can monitor the occurrence and movement of severe convective weather such as thunderstorms and gales within 230 km offshore in real time. Together with multi-functional AtoNs meteorological stations, timely warnings for strong convective weather at sea such as convective gales can be issued.

Figure 14

Distribution of Multi-functional AtoNs



Note. Adapted from *Meteorological Monitoring and Early Warning System for Key Shipping Channels in the New Western Land-Sea Corridor*, Southern Navigation Service Center. Copyright 2023 by Southern Navigation Service Center.

Figure 15

Distribution of Meteorological Stations

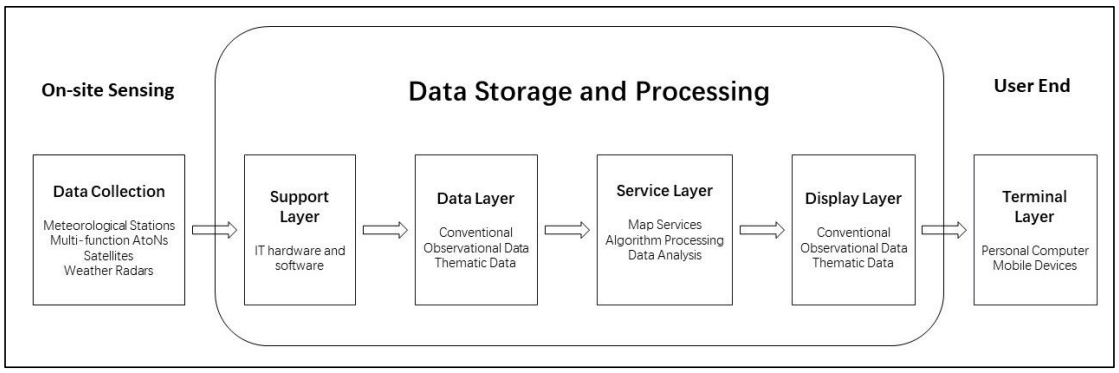
Note. Adapted from *Meteorological Monitoring and Early Warning System for Key Shipping Channels in the New Western Land-Sea Corridor*, Southern Navigation Service Center. Copyright 2023 by Southern Navigation Service Center.

5.3.3 Project system design

The construction and implementation of the system include several parts such as the support layer, data layer, service layer, display layer, and terminal layer, using a layered approach that is independent yet supportive of each other. The specific environment based on the physical support layer is integrated to build a complete system that provides services through front-end requests and back-end responses. The overall architecture and work flow of the system is shown in the following figure:

Figure 16

Overall Architecture and Work flow of Meteorological Monitoring and Early Warning System



5.3.4 Function test

The main meteorological service function of the testbed is in the monitoring and warning section. This section displays real-time weather information and weather forecast data based on land and sea traffic locations, including data in the form of key point time series, statistical tables, and distribution maps. The real-time data includes temperature, pressure, wind, rain, humidity, and visibility data from automatic stations and fusion products, while the forecast data includes 0-6 hours, 0-24 hours, and 5-day forecast data. The functional test results are as follows:

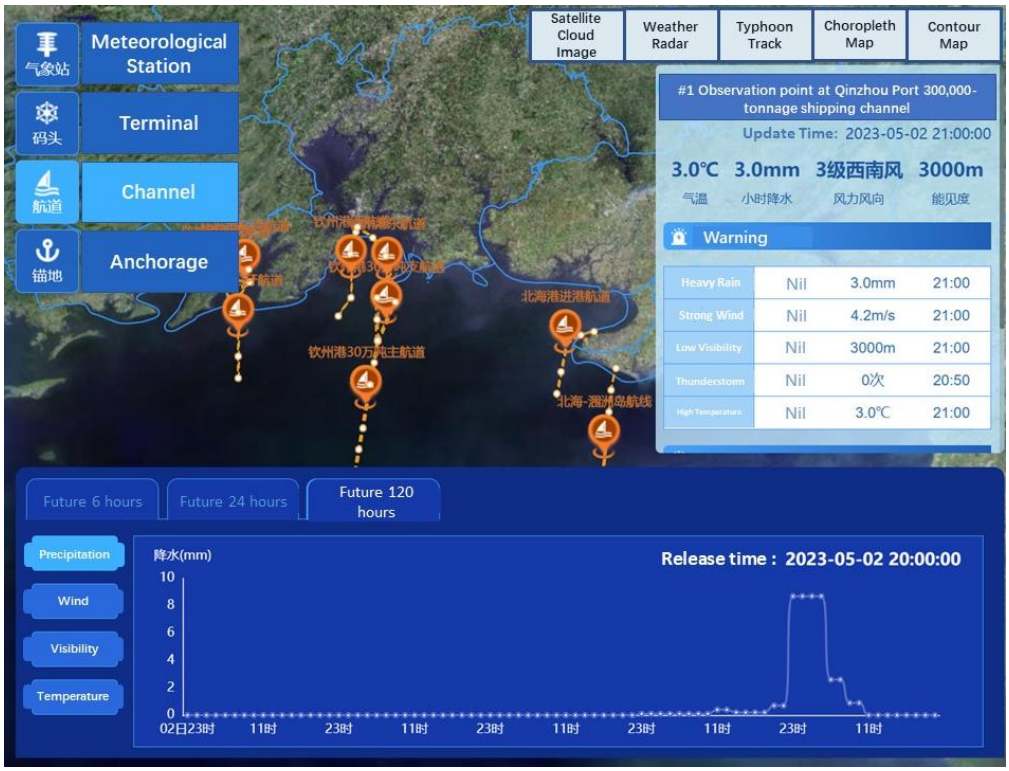
5.3.4.1 Test of forecast information for fixed meteorological points

Taking the #1 observation point at Qinzhou Port 300,000-tonnage shipping channel as an example, the test results for its 120-hour and 6-hour precipitation forecast data are as follows:

Test Results: The 120-hour precipitation forecast was released at 20:00 on May 2, and the request for forecast service was made at 21:00 on May 2. The system successfully provided precipitation forecast information for the period from 23:00 on May 2 to 23:00 on May 7, and since the data is updated every three hours, the forecast function worked normally starting from three hours after the release time.

Figure 17

120-hour Precipitation Forecast Map Requested at 2100 on May 2nd

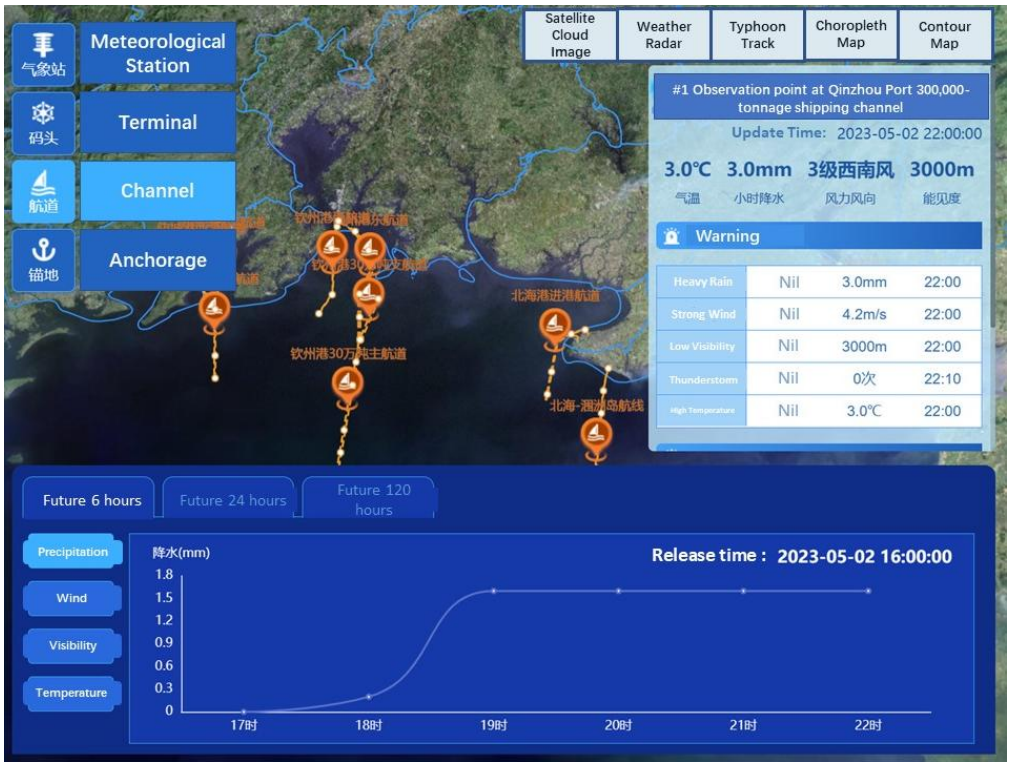


Note. Adapted from *Meteorological Monitoring and Early Warning System for Key Shipping Channels in the New Western Land-Sea Corridor*, Southern Navigation Service Center. Copyright 2023 by Southern Navigation Service Center.

The 6-hour precipitation forecast was released at 16:00 on May 2nd, and the forecast was requested at 22:00 on the same day. The system successfully provided the precipitation forecast information from 16:00 to 22:00 on May 2nd, but it did not provide real-time forecast information for the next 6 hours from the request time, which is a shortcoming. The specific display interface is shown in Figure 19 below:

Figure 18

6-hour Precipitation Forecast Map Requested at 2200 on May 2nd



Note. Adapted from *Meteorological Monitoring and Early Warning System for Key Shipping Channels in the New Western Land-Sea Corridor*, Southern Navigation Service Center. Copyright 2023 by Southern Navigation Service Center.

In addition, the display interface and operation of wind, visibility and temperature are the same, and will not be introduced in detail here.

5.3.4.2 Macro forecast information display for test area

Test Result: The Testbed can also present the dynamics of meteorological elements such as rainfall, wind speed and direction, visibility, temperature, etc. in the test area in the present and past 24 hours through methods such as contour maps and isopleths based on the real-time data of various meteorological stations. The author tested this function and found it to be well-implemented, but the test area and time range were relatively small, and the unit of measurement for the isopleth graph was not clear, which caused some difficulties for users to read. The following figure shows the display interface of the real-time visibility contour map and isopleth graph in the test area.

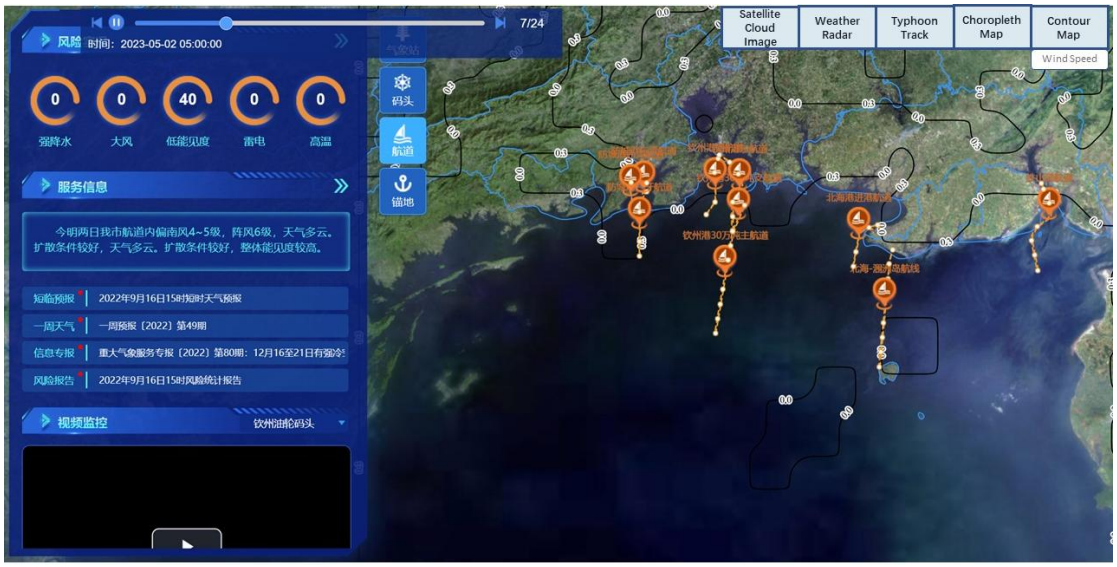
Figure 19

Wind Speed Choropleth Map

Note. Adapted from *Meteorological Monitoring and Early Warning System for Key Shipping Channels in the New Western Land-Sea Corridor*, Southern Navigation Service Center. Copyright 2023 by Southern Navigation Service Center.

Figure 20

Wind Speed Contour Map



Note. Adapted from *Meteorological Monitoring and Early Warning System for Key Shipping Channels in the New Western Land-Sea Corridor*, Southern Navigation Service Center. Copyright 2023 by Southern Navigation Service Center.

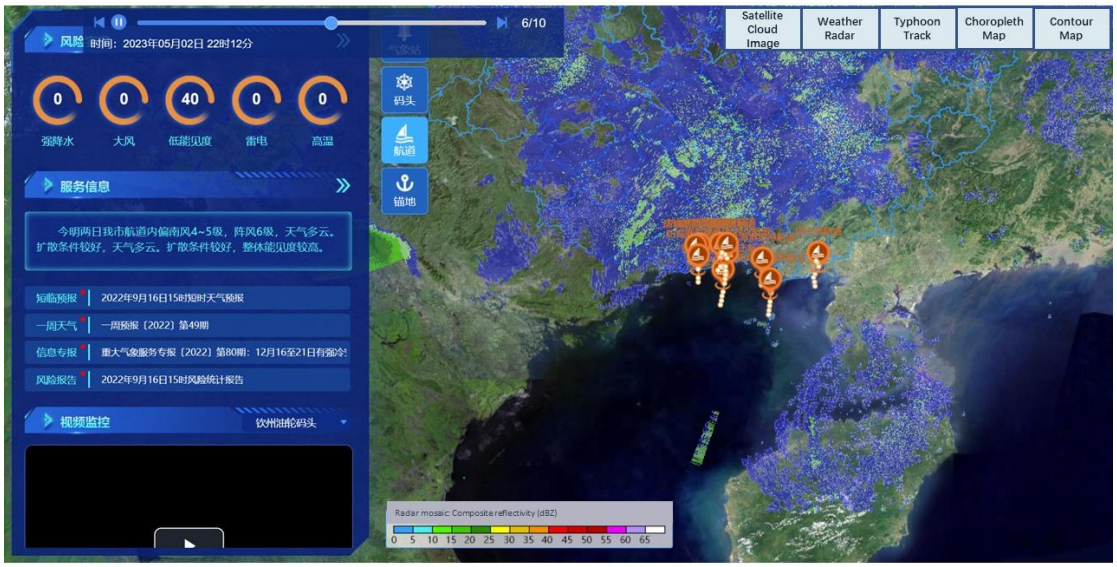
5.3.4.3 Display of meteorological radar information

Test Results: The testbed can superimpose radar meteorological data on a Geographic Information System (GIS) map and supports the display and playback of 10 radar images from the past hour. This information service provides a wider range

of radar images, but it is unable to forecast and can only view past radar data within the last hour. Additionally, there is no guidance on interpreting radar reflection data, which makes it difficult for users to understand. The interface for meteorological radar information is shown below.

Figure 21

Display of Meteorological Radar Information



Note. Adapted from *Meteorological Monitoring and Early Warning System for Key Shipping Channels in the New Western Land-Sea Corridor*, Southern Navigation Service Center. Copyright 2023 by Southern Navigation Service Center.

5.4 Summary of the research on the testbed

5.4.1 Advantages of the testbed

As a testbed exploring meteorological services for the e-Navigation project of the Southern Navigation Service Center of CHINA MSA, *the Meteorological Monitoring and Early Warning System for Key Shipping Channels in the New Western Land-Sea Corridor* has achieved its expected goals in terms of functionality, and its corresponding functions have been realized, making it a representative testbed in the field of meteorological services among many e-Navigation projects in China. Although the e-Navigation projects already built in China have attempted to provide meteorological information services to ships based on hydrological and meteorological information collected by multi-function AtoNs, they are mostly presented in simple modes of lists and texts, which are not intuitive enough. This testbed has solved the corresponding problems.

In addition, because the testbed collaborates with meteorological authorities, its service functions are more professional in the meteorological industry, and more intuitive presentation methods such as contour lines and choropleth maps have appeared. At the same time, compared with the past e-Navigation projects which only implemented hydrological and meteorological information, this experimental platform has realized meteorological forecast services for up to five days in the future. Moreover, under the current meteorological policy framework in China, the testbed has established a cooperation mechanism with meteorological authorities. In the name of meteorological authorities, its related meteorological data and public service has a policy and legal basis.

5.4.2 Deficiencies of the Testbed

Meanwhile, the experimental platform has the following deficiencies. First of all,

according to the definition of weather routing, predicting the weather and sea conditions on the initial planned route of the ship in the future period of time, and providing the ship with route optimization recommendations for avoiding adverse weather and sea conditions based on the predicted information, the testbed still remains at the level of meteorological information services and has not been integrated with the route planning function of the e-Navigation project that has already been developed, so the weather routing service function has not been achieved. Moreover, it does not meet the minimum requirements of the IMO for weather routing services (IMO, 2002).

Secondly, the service content and scope are insufficient. According to the requirements for Meteorological Information Service in e-Navigation Maritime Services (MS 14), the meteorological service data is incomplete, especially the lack of information on waves, which is important to navigators (IMO, 2019). Although isopleth maps, choropleth maps, and meteorological radar maps can provide users with macroscopic and intuitive information within a certain area, the limited test area and playback time of this testbed, as well as its lack of forecasting capabilities for the future, have led to the underutilization of this function's advantages. In addition, the forecast function has not been well-implemented to provide forecasting from any requested time to a corresponding time range.

Furthermore, the meteorological information on this testbed is still limited to data display at fixed meteorological stations and multi-function AtoNs, and to achieve its initial plan of querying the real-time and forecasted meteorological information at any point within the test area through interpolation algorithms, it will be unfavorable for the subsequent development of weather routing functions.

Lastly, the user interface for human-machine interaction is not convenient and aesthetically pleasing, which is not conducive to the promotion of the service to users.

5.4.3 Suggestions for the follow-up development of the testbed

In response to the above drawbacks, the following suggestions are provided for the follow-up improvement of the testbed:

First, in the subsequent development and testing activities, experiments should be conducted to integrate with the e-Navigation project's route planning function, in order to achieve true weather routing services, and the future weather routing services should meet at least the minimum requirements set by the IMO, which are shown in Table 8 below.

Table 8

Minimum Standards of Weather Routing Set by the IMO

No.	Minimum standards (IMO, 2002)
1	Provide the captain with weather information on the recommended route, and the first weather information should be provided before sailing
2	Provide the captain with the accuracy level and probability of weather pattern changes for the recommended information
3	Provide information on waves and swells
4	The recommendation of weather routes should fully consider the characteristics and capabilities of the ship

5	Provide guidance before sailing, and clarify the communication channel of meteorological services
6	Provide weather routing services at regular intervals based on the meteorological conditions of the ship's location
7	Captains should be allowed to make meteorological suggestions during mid-voyage
8	The meteorological service system should be interactive and strengthen communication with the captain
9	Other considerations: operational limitations of the ship, maritime navigation space, adverse weather conditions, etc.

In addition, according to the Maritime Service 14 (MS14), it is particularly necessary to increase information on sea waves, and further enrich the data of meteorological services, striving to achieve through information technology terminal displays all meteorological information required by International **Convention on the Safety of Life at Sea** （SOLAS） at the level of meteorological services, to some extent, realizing modern display means of meteorological information services other than **Global Maritime Distress and Safety System** (GMDSS) equipment, increasing redundancy and intuitiveness of meteorological information service to ensure navigation safety.

Third, improve the application of interpolation algorithm in this testbed to achieve the query of meteorological conditions and forecast information at any point in the experimental area. Improve the forecast function to enable obtaining corresponding time range forecast information at any requested time.

Fourth, improve the user interface, enhance the human-machine interaction experience, further expand the service area, lengthen the playback time, add more

forecast functions, and provide users with more comprehensive meteorological forecasts and information displays.

CHAPTERE 6 SUGGESTIONS AND SUMMARY

6.1 Research output and recommendations

6.1.1 Reasons for the monopoly of China's weather routing market and countermeasures

In terms of weather routing providers. Chinese weather routing service providers generally have a government background and focus more on public welfare while downplaying commercial interests, while international providers are private enterprises and focus more on commercial interests.

Chinese meteorological service providers, which are protected by domestic policies, have monopolized the domestic market, resulting in a decrease in market vitality and the inability to cultivate competitive weather routing companies. In addition, due to the outward-looking nature of the weather routing market, Chinese weather routing providers do not have an advantage when competing with foreign famous companies, ultimately leading to the current situation of being monopolized by foreign peers.

Against this situation, three ways can be tried for Chinese related authorities to strengthen the cultivation of weather routing enterprises: first, by opening up the market to some extent, it can strengthen cooperation with foreign advanced

companies and learn advanced technologies and service models internationally; second, it can strengthen the cultivation of composite talents who understand both information technology, meteorological knowledge, and navigation knowledge, which can be achieved by strengthening cooperation among government departments, research institutions, and enterprises through commercial or government project cooperation; third, under the existing policy background, China's meteorological authorities attempt to balance public welfare and commercial interests, so in order to develop better service products in the field of weather routing, in addition to the current cooperation with some state-owned enterprises, it still needs to further strengthen cooperation with the maritime authorities, and China's maritime authorities should also actively seek opportunities to cooperate with the meteorological authorities, but attention should be paid to avoid homogeneous product competition, and more coordination is needed in different authorities' cooperation and division of labor.

6.1.2 Recommendations for the development and promotion of weather routing services and products

First, establishing a stable and reliable maritime communication channel is the foundation for providing all meteorological services. An increasing number of users are no longer satisfied with traditional fax and email-based weather routing services, and are looking for higher levels of visualization, automation, and intelligent weather routing services integrated with ship-borne ECDIS. Secondly, the accuracy of forecast information is still the most important factor for all types of users and the core competitiveness of weather routing products. On this basis, users also have a high demand for improving the real-time service information. Thirdly, weather routing services and products have a certain degree of stickiness for onshore users. In

such a context, new companies need to invest more in operational convenience and cost-effectiveness to increase their market share. Finally, whether they are established or new providers of weather routing services, they still need to pay attention to the cultivation of frontline Chinese users, popularize knowledge of weather routing, strengthen understanding of weather routing services, and provide product training.

6.1.3 Recommendations for China's e-Navigation weather routing services

Firstly, any meteorological services in the e-Navigation project should be based on cooperation with the meteorological authorities. Secondly, it is necessary to strengthen communication and coordination, explore the establishment of cooperative mechanisms and models that meet the needs and interests of all parties, develop differentiated services and product, and avoid homogenized competition with the products developed by meteorological authorities. Thirdly, there is currently no weather routing product in the domestic e-Navigation project at the technical level. However, if needed, the existing meteorological information services in the e-Navigation project can be combined with route planning functions to upgrade to weather routing functions, but attention should be paid to meeting the minimum requirements of the IMO.

6.2 Summary

This study focuses on the development and application of weather routing in China, summarizes the current background and historical development process of weather routing at home and abroad.

Research has been conducted on the weather routing supply side, Chinese weather routing policies and market overview, which has grasped the profile of mainstream meteorological navigation service providers at home and abroad, analyzed and summarized the policy direction of Chinese weather routing, and provided predictions of future development trends.

A questionnaire survey was conducted on the weather routing user side, and based on the analysis of user feedback, the experience and feelings of first-line users of Chinese weather routing services and products were grasped, which formed user-based suggestions for the development of weather routing services and products.

An evaluation of the application of weather routing in the Chinese e-Navigation project was conducted, and the relevant functions of the Chinese representative meteorological service e-Navigation service testbed were tested and evaluated, and detailed development suggestions were provided for the development of such projects in accordance with international requirements.

Overall, this study has found corresponding answers and explanations to key issues in weather routing services market, Chinese meteorological service policy, user requirements, and Chinese e-Navigation project development. This research achieved the expected goals, and provided valuable references for the construction of Chinese weather routing services in the future.

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Appendix

User Survey Questionnaire for Marine Weather Routing Services

1. Name of your company (or Organization)	
2. Nationality of your company (or Organization)	
3. Your Occupation	A. Seaman (Captain/1 O/2 O/3 O/others (please specify)) B. Shipowner or shipping management company C. Charterer D. Others (please specify)
4. The type of the ship you are on	A. Ocean going merchant ship B. Costal or inland water merchant ship C. Fishing boat/ yacht/ other non-SOLAS ships D. Others (please specify)
5. Whether your ship is using (or has used) weather routing service (i.e. recommending or optimizing ship routes based on weather information)	A. Yes B. No
6. Do you need weather routing service?	A. Yes B. No
7. If so, your strongest requirements for you to use weather routing service are（Multiple choices， No more than 2 choices）	A. optimize the routes, ensure the navigation safety B. Improve operational efficiency and reduce ship energy consumption and costs C. Help to conduct sea operations

	D. Business performance or litigation evidence needs E. Others (please specify) F. No need (please specify the reason)
8. Which weather routing company is the most used by you or your company? Roughly the proportion? (Fill “none” if never used before)	
9. Which weather routing company is the second most used by you or your company? Roughly the proportion? (Fill “none” if never used before)	
10. How many weather routing providers’ services does your vessel use?	A. 1 B. 2 C. 3 D. Others (please specify)
11. Have you ever heard the weather routing service provider from China?	A. Yes, I heard or I used their product (please name the provider) B. I heard a little, never see and use their product before C. No. never heard before
12. How is the weather routing service provided by the provider you choose right now（Multiple choices，No more than 3 choices）	A. By the company's software installed on ECDIS B. By the company's software installed on the computers onboard C. By email D. Mobile devices (smartphone or iPad etc.) developed by the company, with APP in it. E. Fax onboard F. Others (please specify)

	G. Never used before
13. Which of these service delivery methods do you prefer? (Multiple choices, No more than 2 choices)	A. By the company's software installed on ECDIS B. By the company's software installed on the computers onboard C. By email D. Mobile devices (smartphone or IPAD etc.) developed by the company, with APP in it. E. Fax onboard F. Others (please specify) G. Never used before
14. What is your top priority when choosing weather routing provider? （Multiple choices， No more than 3 choices）	A. Accuracy of weather forecasts B. Reliability of routing recommendations C. Cost-effectiveness D. User-friendliness E. Reputation of company F. Others (please specify)
15. What do you think of the weather routing service you are using	A. It's very helpful to my work. It's very important B. It has been some help, I can refer to it C. Little help, no concern D. Others (please specify) E. Never used before
16. What is the adoption rate of the routes recommended by weather routing providers?	A. 80-100%, B. 60-80%, C. 40-60%, D. 20-40%, E. 0-20% F. Never used before
17. What do you think of the	A. More important and more widely used

development of weather routing in the next 5 years	B. Less important and less widely used C. Stays the same
18. Do you think it's easy to operate the product, system or software of the weather routing providers?	A. Yes, it is B. Mediocre C. No, it's difficult to operate D. Other (please specify) E. Never used before
19. Are you having difficulties or problems using the weather routing service?	A. Yes B. No C. Never used before
20. What is the most annoying problems do you think when using weather routing services?	
21. Do you have any suggestions for the improvement of weather routing services?	
22. Do you think weather routing services are expensive?	A. It's expensive and not worth the price B. Reasonable price C. It is cheap and worth using D. Don't care about price E. Never used before
23. What do you think is a reasonable price range for ship weather routing services?	A. I've used it. I think the reasonable price range is (please specify) B. I haven't used it yet, but I think the reasonable price range is (please specify)
24. Do you think it will be inconvenient to change a new weather routing company?	A. Yes, it's very troublesome B. Generally, there is not much inconvenience C. No, the replacement is convenient. D. Others (please specify) E. Haven't used it yet but willing to try

	this new service F. Haven't used it yet and not interested in this service
25. Would you like to be interviewed later?	A. Yes, it’s ok (please leave an email) B. No, thanks