2023 Volume 4, Issue 2
Satellite Oceanography and Meteorology
ISSN(Online): 2424-9505
ISSN(Print): 2424-8959

Collaborative Construction of Satellite Monitoring for Marine Storm Surges and Coastal Meteorological Support Systems

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Abstract:

This paper explores the importance, current status, strategies, and methods of the collaborative construction of satellite monitoring for marine storm surges and coastal meteorological support systems. By analyzing satellite monitoring data and the key elements of the meteorological support system, it elaborates on the positive significance of their collaborative work in improving the accuracy of marine storm surge early warnings and forecasts and enhancing the coastal disaster prevention and mitigation capabilities. The aim is to provide theoretical support and practical reference for building a more complete and efficient marine disaster prevention and mitigation system.

Keywords:

Marine storm surge
Satellite monitoring
Coastal meteorological support system
Collaborative construction

Online publication: December 22, 2023

1. Introduction

Marine storm surges, as a highly destructive marine disaster, pose a serious threat to the economic development, lives, and property of people in coastal areas. Statistics show that the global economic losses caused by storm surges reach billions of dollars each year, and China is also one of the countries severely affected by storm surges. With the continuous development of satellite technology and meteorological science, using satellite monitoring of marine storm surges and collaborating with coastal meteorological support systems has become an important means of improving the ability to defend against marine disasters.

2. Overview of satellite monitoring of marine storm surges

2.1. Principles and technical means of satellite monitoring

Satellite monitoring of marine storm surges is mainly based on various remote-sensing technologies. For example, satellite altimeters monitor the water level rise caused by storm surges by measuring the minute changes in sea surface height. Synthetic Aperture Radar (SAR) can observe the sea surface roughness and wave patterns with high resolution, thus obtaining relevant information about storm surges. Ocean color satellites can indirectly reflect the changes in the marine environment by monitoring the optical property changes of seawater, providing auxiliary data for storm surge monitoring.

2.2. Advantages and limitations of satellite monitoring

With the rapid development of marine satellite-related technologies, the monitoring and forecasting functions of marine satellites have been widely accepted. Marine satellites and their remote-sensing monitoring technologies have become a relatively mature method for providing important information on the marine environment. The information provided by marine satellites on marine disasters, marine pollution, and marine resource development plays an irreplaceable role in fields such as storm surge forecasting, wave monitoring, and sea ice inversion [1]. However, satellite monitoring also has certain limitations. For example, it is greatly affected by weather conditions, and data acquisition may be restricted when the clouds are thick. The accuracy of some satellite sensors needs to be further improved, and there may be errors in monitoring storm surges in complex marine environments.

3. Analysis of the current situation of the coastal meteorological support system

3.1. Coastal meteorological observation network

The coastal meteorological observation network forms the fundamental framework of the meteorological support system, covering a diverse cluster of observation facilities such as coastal weather stations, marine observation buoys, and automatic weather stations. Coastal weather stations, as traditional observation points, precisely focus on the fixed-point monitoring of meteorological elements in coastal areas. Marine observation buoys, due to their unique location on the sea surface, dynamically capture the real-time changes in surface meteorological and hydrological parameters. Automatic weather stations, with their high-frequency and automated data-collection mode, widely cover key areas such as the coastal urban-rural fringe and key protected port areas [2]. These devices work in coordination to accurately measure the core meteorological elements in coastal areas in real-time, such as the vector changes in wind speed, the slight deflections in wind direction, the transient fluctuations in air pressure, and the rhythmic changes in temperature. This builds a solid foundation of meteorological background data for the early warning and forecasting of marine storm surges, deeply empowering the subsequent disaster assessment process.

3.2. Meteorological forecasting models and technologies

At present, meteorological departments widely rely on numerical weather prediction models in the field of marine storm surge prediction. Relying on the fine numerical simulation core of atmospheric physical processes, these models deeply integrate key marine environmental information such as sea temperature, salinity, and ocean currents contained in ocean observation data, as well as high-altitude dynamic observation results such as cloud images and water vapor distribution feedback by meteorological satellite data. Thus, they can accurately predict the key characteristics of storm surges, such as path trends, intensity evolution, and water-level rise amplitude [3]. At the same time, with the in-depth embedding of cutting-edge data assimilation technology into the model system, the initial field of the model is continuously optimized to more accurately reflect the true state of the atmosphere and ocean. The booming development of machine-learning algorithms further excavates the hidden laws in massive historical data, injecting intelligent power into model prediction.

3.3. Emergency response and service mechanisms

In the face of marine storm surge disasters, coastal areas have established relatively complete emergency response and service mechanisms. Disaster warnings are quickly transmitted through multiple channels such as official text messages, radio, electronic screens, and social media to ensure that information is delivered in a timely and accurate manner. Evacuation procedures are carried out in an orderly manner according to scientific roadmaps, taking into account factors such as population density, buildings, and transportation, guiding residents to evacuate. Ship berthing is reasonably arranged according to port capacity and ship types. However, in actual operations, there are problems such as response lags, insufficient information flow, and coordination between departments, which need to be improved from aspects such as system optimization and information technology upgrading.

4. The necessity of the collaborative construction of satellite monitoring for marine storm surges and coastal meteorological support systems

4.1. Improving the accuracy of early warnings and forecasts

Satellite monitoring, with its macroscopic perspective, can capture the dynamic evolution information of marine storm surges in a large-scale spatial range, such as key indicators like abnormal changes in sea surface height and wave spectrum characteristics. These data outline the overall profile of the storm surge system. The coastal meteorological observation network, relying on various observation stations densely distributed in the near-shore zone, can accurately collect meteorological elements in the local area, such as the vertical profile of near-shore wind speed, the change in air pressure gradient, and the fine distribution of sea surface water temperature and salinity. These fine-grained data provide support for an in-depth understanding of the local generation and intensification mechanisms of storm surges [4]. The combination of satellite monitoring and coastal observation data is like a complementary jigsaw puzzle, with the former filling in the macroscopic information and the latter refining the key details. Through fusion analysis techniques, the accuracy of storm surge early warnings and forecasts is significantly improved, reducing uncertainty, providing more time for coastal disaster prevention and mitigation work, and enhancing the initiative in disaster response.

4.2. Enhancing disaster monitoring capabilities

The wide-area coverage of satellite monitoring, relying on the continuous patrol of multiple networked satellites, can conduct high-frequency and uninterrupted scans of the vast ocean area. With a keen “vision,” it can capture the subtle signs of the emergence of marine storm surges, such as abnormal sea surface roughness in the open sea and sudden changes in sea color, accurately locate potential risk areas, and achieve early warnings. At the same time, the coastal meteorological support system focuses on key protected areas. With the help of advanced equipment such as high-resolution weather radars, marine buoy arrays, and shore-based automatic observation stations, it increases the observation frequency of the near-shore waters and the land-sea interface and finely analyzes the evolution details of storm surges in complex terrains such as near-shore shoals and estuaries, including wave - height breaking patterns and the spatio-temporal differences in the water-level rise process [5]. The two work in coordination to form a crisscrossed, dense and sparse disaster monitoring network, comprehensively covering the open sea, near-sea, and coastal areas, multi-dimensionally capturing the dynamics of storm surges, effectively strengthening the monitoring capabilities of this marine disaster, and building a solid safety line for coastal areas.

4.3. Optimizing emergency response decisions

The in-depth coordinated operation of satellite monitoring and the coastal meteorological support system can track the development trajectory of storm surges in real-time and accurately. From monitoring the intensity and movement path of the tropical cyclone at the source of its generation to the energy accumulation and propagation speed changes in the sea areas it passes through, and then to estimating the tide-level rise amplitude and inundation range when it impacts the coastal zone, the entire process is dynamically grasped. Based on such detailed and accurate information, emergency response decisions can be made according to scientific models and practical experience. Evacuation routes for people can be reasonably planned, taking full account of risk levels, evacuation capacities, and traffic convenience in different regions. Relief supplies can be efficiently allocated to ensure that food, drinking water, medical supplies, etc., are accurately delivered to key disaster-affected nodes as needed. Protective projects can be activated in a timely manner, such as closing seawall sluice gates and strengthening the foundations of coastal buildings [6].

5. Strategies and methods for collaborative construction

5.1. Data sharing and fusion

Build an integrated sharing platform for satellite monitoring data and coastal meteorological observation data. Relying on a high-speed network communication architecture and advanced data-exchange protocols, ensure that data can be shared in real-time, continuously, and stably among different departments. At the same time, focus on the research and development of key technologies for multi-source heterogeneous data fusion. In view of the global coverage and periodic sampling characteristics of satellite remote-sensing data, as well as the high-resolution, high-frequency update characteristics of coastal meteorological observation data in local areas, use cutting-edge means such as data mining and machine learning to design and implement adaptable data-fusion algorithms. Through cleaning, converting, calibrating, and integrating data from different sources and with different formats, a unified, standardized data set with high credibility and strong application value is condensed, providing a solid data foundation for the accurate early warning and forecasting of marine storm surges and scientific decision - making in coastal disaster prevention and mitigation.

5.2. Coordination of Business Processes

Deeply optimize the independent yet closely related business processes of satellite monitoring and the coastal meteorological support system. Guided by systems engineering thinking, carefully sort out and clarify the responsibility boundaries and collaborative linkage mechanisms of departments and positions involved in each business link. Specifically, in the whole-process monitoring and early warning of marine storm surges, the satellite monitoring department, with its spatial-coverage advantage, captures the sea-surface abnormal information related to storm surges in the first place, quickly completes preliminary data analysis and feature extraction, and then pushes the monitoring results to the meteorological department in real-time [7]. The meteorological department, based on this, organically combines the refined meteorological element data collected by coastal meteorological observation stations and its self-developed forecasting model system to carry out comprehensive, multi-level analysis and in-depth prediction.

5.3. Technology research and innovation

Unswervingly strengthen the in-depth research and cutting-edge innovation of satellite monitoring technology and meteorological forecasting technology, focusing on improving the overall data acquisition and processing capabilities from both the data-collection source and the information-processing terminal. On the one hand, vigorously promote the research and development process of the new - generation satellite sensors. Integrate optical, microwave, and other multi-band detection technologies, and combine advanced processes such as micro-nano processing and intelligent chip integration to break through the technical bottlenecks of traditional sensors in terms of sensitivity, resolution, and dynamic range, achieving a leap-forward improvement in satellite monitoring accuracy and spatial resolution. On the other hand, focus on the optimization of meteorological forecasting models. Introduce deep-learning algorithms of artificial intelligence and big-data knowledge-discovery technologies to deeply analyze the laws in meteorological data, enhancing the adaptability, prediction ability, and accuracy of the models [8]. At the same time, the research focuses on improving the collaborative technology between satellite monitoring and the meteorological support system, solving problems such as multi-source data fusion, cross-departmental information interaction, and real-time decision-making. Use interdisciplinary knowledge to develop efficient and robust collaborative methods to support the progress of marine disaster prevention and mitigation technologies.

6. Key technical supports for collaborative construction

6.1. Data assimilation technology

As a key link connecting observation data and meteorological forecasting models, data assimilation technology has the ability to accurately assimilate the massive and dynamic ocean data obtained from satellite monitoring and the high-timeliness and high-accuracy local meteorological data collected by the coastal meteorological observation network into the core architecture of meteorological forecasting models [9]. By continuously and deeply optimizing the structure of the assimilation algorithm and finely adjusting key parameters, seamless docking and efficient integration of satellite data and meteorological forecasting models can be achieved in multiple dimensions such as time-space scale and physical process description, enabling the model output to more realistically restore the actual situation of the evolution of marine storm surges, and thus significantly improving the forecasting accuracy.

6.2. Multi-source data fusion algorithm

In view of the characteristics of satellite monitoring data, such as large area coverage, periodic acquisition, and immunity to environmental factors, and the characteristics of coastal meteorological observation data, such as high spatio-temporal resolution, strong pertinence, and vulnerability to the complex terrain near the shore, it is urgent to develop a multi-source data fusion algorithm suitable for their integration. Based on cutting-edge mathematical methods such as Bayesian estimation and Kalman filtering, a dynamic weighted-fusion mechanism is constructed. According to multi-dimensional indicators such as data source, quality, and timeliness, different weights are assigned to different data, fully exploring the effective information contained in each data source, maximizing their complementary advantages, and effectively improving the overall quality, reliability, and usability of the fused data, laying a solid foundation for subsequent accurate analysis and decision-making [10].

6.3. Satellite communication and data transmission technology

In the process of the collaborative construction of satellite monitoring for marine storm surges and coastal meteorological support systems, ensuring the immediate, stable, and high-speed transmission of satellite monitoring data is of utmost importance. Vigorously develop satellite communication technologies with high bandwidth, low latency, and strong anti-interference capabilities, and combine customized data-transmission protocols to adapt to the complex electromagnetic environment of the ocean and the needs of massive data transmission. From optimizing the satellite communication link design, adopting advanced coding and modulation technologies, to constructing a redundant transmission path protection mechanism, comprehensively improve the data-transmission rate and reliability, ensuring that satellite monitoring data can be accurately delivered to the information-processing terminal of the coastal meteorological support department with a millisecond-level response speed and an almost zero-error rate, providing a rock-solid technical support for their collaborative operation.

7. Conclusion

This paper deeply explores the importance, strategies, and methods of the collaborative construction of satellite monitoring for marine storm surges and coastal meteorological support systems, pointing out that this collaborative construction is the key to improving the accuracy of storm surge early warnings and forecasts, enhancing disaster monitoring capabilities, and optimizing emergency response decisions. By integrating the efficiency of satellite monitoring and the real-time nature of the coastal meteorological support system, more solid support can be provided for coastal disaster prevention and mitigation. With the continuous progress of satellite technology, meteorological science, and information technology, this collaborative construction will face new opportunities as well as many challenges. Looking to the future, it is necessary to strengthen technological innovation, deepen cooperation and exchanges, and continuously improve the technical system and business processes to enhance the ability to prevent and mitigate marine disasters, thus contributing more to the sustainable economic and social development of coastal areas.

Disclosure statement

The author declares no conflict of interest.

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