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Applications of Remote Sensing in China's Coastal Zones and Islands: Recent Progress and Suggestions

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Abstract: To summarize the recent achievements and problems of remote sensing application in China's coastal zones and islands, this study reviews a number of typical studies selected from the last decade in a space order of "offshore land area, intertidal zone, and offshore waters island". Classical remote sensing in land cover change and coastline dynamics remains a research focus. With the rapid economic development and urbanization in China, coastal environmental problems have become serious. Remote sensing is increasingly applied to research on land subsidence, seawater intrusion, intertidal ecosystem monitoring, mariculture, red tide, and island reef sovereign evidence, which strongly supports Chinese government ocean strategies. However, the acquisition of remote sensing data still depends largely on foreign satellites. The update frequency of the remote sensing data is low; and different disciplines in this field are often isolated. In this study, we propose promoting the fusion of multisource data and different disciplines, to ultimately realize high precision, automatic, and regular monitoring supported by cloud computing at both national and regional levels.
Keywords: remote sensing; coastal zone management; ocean strategy; coastline; mariculture

1 Introduction

As a transition area between land and ocean, coastal zones are a gathering place for materials and energy and are also strong coupling areas for various physical, chemical, biological, and geological structures. Therefore, coastal zones have also become a region of substantial human activity. For example, the coastal area of China, which only accounts for 14% of the land area of the country, contains three major metropolitan areas, more than 50% of large cities, 40% of small and medium cities, approximately 50% of the population, and produces 60% of GDP [1]. Under the pressure of climate change and enhanced human activity, the coastal ecological environment has been deteriorating [2] and has become a key area of ecological fragility and frequent disasters. In addition, as small pieces of land surrounded by the sea, island reefs can be used as fulcrums for oceanic development. In the context of global oceanic economic advancement, the development/utilization intensity of island reefs are increasing rapidly and playing an imperative economic and military role. Therefore, monitoring coastal zones and island reefs is of great significance in guiding countries to formulate marine development strategies.

Remote sensing has many advantages as an untouched long-distance observation technology, such as wide space coverage, time consistency, and short re-observation cycle [3]. It has become an important monitoring method for fast-changing, wide-space coastal zones and islands and reefs with poor accessibility [3].

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Understanding coastal zones, in a timely and accurate fashion for island reef remote sensing research/existing issues can provide a rapid informational support for China's coastal zone/island reef ecosystem research and management, socioeconomic development and planning, and sustainable development. For this purpose, this study reviews the developing status and current problems of remote sensing in China's coastal zones and islands reefs over the past 10 years, and presents several suggestions to serve the maritime power development strategy.

2 Current research status

To systematically review the status of current research, coastal areas were divide into four regions: near-shore lands, tidal zone, near-shore ocean, and island according to the direction from the inland areas to the ocean (Fig. 1), and were reviewed separately.

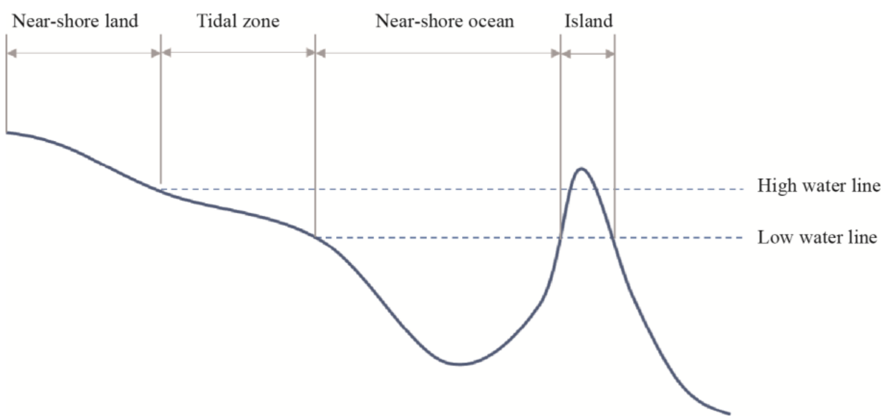

Fig. 1. Region dividing of the coastal area as near-shore land, tidal zone, near-shore ocean, and island.

2.1 Remote sensing in near-shore land zones

2.1.1 Land use/cover change remote sensing progress

Land use/cover change (LUCC) is not only a major theme in global environment change research, but also an equally important theme of the coast remote sensing monitoring. China was the first to produce and share GlobeLand30, a global LUCC data with 30-m resolution [4] worldwide. It covers the LUCC of Chinese and other global coastal areas. Without the particularity of coastal areas, Hou et al. [5] mapped a time series LUCC of Chinese coastal areas from 2000 to 2015 at five-year intervals and a more detailed classification system than used in this study. Wang et al. [6] developed an automatic LUCC updating method by utilizing the relationship between the historical LUCC and corresponding historical remote sensing data. Additionally, mapping the interior structure of a city is possible, as higher spatial resolution of remote sensing images has become available, such as the Gaofen-2 images with 1-m resolution that can recognize a car in the images. This can provide a powerful tool for purposes of research in urban areas and the corresponding ecological environments through their interior spatial structure [7].

2.1.2 Specific targets remote sensing progress

A few studies concerning specific targets using remote sensing have been completed. A long-term change in mangrove forests throughout the coastal areas of China has been mapped, based on Landsat data, which can be applied in promoting land siltation, protecting the sea/biodiversity, and promoting global carbon balance [8]. Mangrove species mapping in local areas, which can significantly help the refined management of mangroves, has also attempted with high spatial resolution data [9]. Ren et al. [10] mapped aquaculture ponds and the expansion of salterns from 1984–2016 using remote sensing data. Ge et al. [11] evaluated the amount of cargo in ports that connect transportation between ocean and land [11].

2.1.3. Progress of remote sensing in land subsidence

Underground water resources are used excessively due to rapid urbanization expanding into coastal areas, which causes marine saltwater intrusion and land subsidence. Higgins et al. [12] studied land subsidence in the Yellow and Pearl river deltas with a millimeter accuracy using interferometry synthetic aperture radar (InSAR)

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techniques, and confirmed that the subsidence originated mainly due to rapid urbanization and groundwater extraction for aquaculture.

2.2 Remote sensing in tidal zones

2.2.1. Remote sensing of coastlines

As a boundary between the sea and land, coastlines can quantitatively measure the results of human activities and the natural interaction between sea and land, and reflect the rising trend of sea levels due to global climate change. Gao et al. [13] mapped the coastline changes in the mainland of China for the past 30 years after establishing the coastline remote sensing interpretation mark.

2.2.2. Remote sensing of biological invasions

Biological invasion has often occurred in coastal ecosystem protection practices. For example, *Spartina alterniflora* has replaced a large amount of the native sea trilobum, earning its status as a serious biological invasion species after it made it difficult for waterfowl to obtain food. Liu et al. [14,15] identified the spatial pattern of *Spartina alterniflora* invasions and their temporal changes based on remote sensing data with a resolution of 15/30 m in the coastal areas of Zhejiang, thereby providing useful references for its management and control.

2.2.3 Remote sensing of seawater intrusion and soil salinization

Rapid urbanization, especially groundwater extraction, has caused seawater intrusion and soil salinization that has seriously affected coastal ecological environments. Remote sensing can be used to evaluate the development and impact of seawater intrusion and soil salinization via differences in spectral characteristics of salinized soil surfaces and changes in surface vegetation cover, providing scientific guidance for related governance [16].

2.3 Remote sensing of near-shore ocean zones

2.3.1 Remote sensing of sea-surface aquaculture

Marine aquaculture is not only one of the major industries of the coastal zone economy, but also an important victim of disasters. As the resolution of remote sensing data has greatly improved in both spatial and grayscale aspects, some types of marine aquaculture, such as sea-surface aquaculture, can be mapped easily. Wang et al. [17] developed a raft aquaculture extraction algorithm based on the relationship between object-oriented primitives and linear segment primitives and tested it on the Chinese ZY-3 satellite image. For raft aquaculture with complex backgrounds, Wang et al. [18] introduced a visual attention mechanism into the object-based extraction method and realized the extraction.

2.3.2 Remote sensing of marine disasters

Marine disasters such as storm surges, oil spills, and red tides occur rapidly and cover a wide range. Remote sensing can quickly obtain the spatial distribution and dynamic status of disaster elements in a large area, thereby playing an important role for assessment/disaster relief operations [19]. Hu et al. [20] combined the surface wind, sea surface temperature, and other parameters retrieved from remote sensing data using model algorithms and completed the path prediction of the prolifera outbreak in the Shandong Peninsula. It was found that the prolifera outbreak originated from the coastline of Jiangsu Province.

2.4 Remote sensing in island zones

2.4.1 Remote sensing of islands and reefs

Both islands and coasts face the sea; therefore, remote sensing technologies in the coastal zone can be used as a reference in many aspects, for example, to monitor island/reef mapping with shoreline extraction, measure land subsidence based on InSAR [21], classify coral reefs with high precision, and map/monitor the change in coral reefs [22].

2.4.2 Remote sensing of island and reef evidences

In many cases, islands and reefs involve territorial sovereignty of the seas; therefore, they often become an important focus in disputes involving the national maritime sovereignty of various nations. The existing arbitration mechanisms mostly use the first country that landed and established effective control as the principle of island and reef sovereign authentication, while the historical archive function of remote sensing data just meets this demand.

Xia [23] systemically summarized the current relevant cases and analyzed the value of the burden of proof of remote sensing evidence, submission methods, and factors affecting its weight in combination with remote sensing technology/industry development trends. Jiang et al. [24] used the Nansha Islands and Reefs in China as an example, using remote sensing imagery and historical literature surveys concluding that the method of identifying islands and reefs in the *United Nations Convention on the Law of the Sea* was not rigorous.

3 Problems

The coastal zone is a complex area with strong interactions between the sea and land. The research content of remote sensing covers a broad spectrum and therefore, they cannot all be listed here. This study is only a representative summary. In general, China's coastal remote sensing development is relatively comprehensive and advanced, which can effectively support the national economic construction and marine strategy. However, based on the above analyses, the following major problems are found.

3.1 Remote sensing data acquired by domestic satellites is not frequently used

With the successful implementation of some of the satellite projects, such as resource satellites, ocean satellites, and meteorological satellites, specifically based on the Gaofen Project, China's satellite image acquisition capabilities have been improved significantly. However, due to user habits or inadequate data sharing mechanisms, most researchers still consider foreign data first when choosing options for selecting remote sensing data. For example, the LUCC introduced above are mostly based on images acquired by the US LandSat series satellites. This custom of heavily relying on foreign remote sensing data, especially in coastal areas with high frequency of change and intensive human activities, can be easily controlled by the developed countries, and is not a good practice in the context of attempting to foster quality improvement of domestic remote sensing satellite images through using feedback.

3.2 Remote sensing information products are updated in low frequency

Although remote sensing mapping has greatly improved the mapping cycle, many thematic information products are still updated slowly. For example, LUCC nationwide is updated every five years. This frequency is difficult to meet the demand for active and frequent coastal zones. In addition, when facing marine disasters such as typhoons and storm surges, many emergency data are mostly the basic data of pre-disaster reserves, and the live information still mainly depends on manual interpretation after image acquisition and step-by-step summary implementation, which is very poor in timeliness. Although many algorithms for automatic extraction of remote sensing information have been developed, they are mostly concentrated in special conditions in small areas, and it is difficult to directly extend them to large areas and complex backgrounds.

3.3 Disciplinary research develops in isolation, making it difficult to meet practice needs

The coastal zone is an extremely complex and comprehensive system. In actual management, remote sensing is just one of most important technologies for observing the system – but, it also has significant limitations. For example, although high spatial resolution remote sensing images can provide a key background when dividing and classifying land use scenes in coastal areas that have a significant impact on the offshore environment, there remain many difficulties based on remote sensing images. It is required to provide additional block boundaries, and other non-remote sensing data such as point of interest information. When studying the correlation between aquaculture and outbreaks of prolifera, the projects not only need remote sensing experts to provide dynamic information such as aquaculture distribution and water quality status, but also multi-domain knowledge provided by experts like marine hydrodynamic, marine microorganisms, and mariculture experts. It is only possible to fully understand their complex relationships by conducting coupled experimental simulations.

4 Suggestions

Based on above-mentioned summary and analysis of several issues, the following suggestions are presented.

4.1 Continuously improving domestic data sharing

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Based on a series of remote sensing satellites launched in China, including high resolution, resource, and ocean satellites, specifically the “Earth Big Data Science Project”, a Priority A strategy project led by the Chinese Academy of Sciences, there is a need to continue to improve domestic data sharing and publicity. This not only requires continuous financial and institutional support at a national level, but also requires the continued investment of service providers in technical improvements and maintenance. End user support and its use are also important, to optimize sharing and collaborative use of data and to increase the proportion of domestic data use. Finally, it is only beneficial to enhance the use of multi-data fusion to solve complex coastal ecosystem problems in coordination.

4.2 Strengthening the research of coastal zone remote sensing algorithms to realize large scale and local high precision monitoring automation using cloud platforms and big data systems

Based on cloud platform and big data systems, the research and integration of remote sensing information automatic extraction and updating algorithms for coastal zone targets can be strengthened. In addition to the need for algorithms to extract information from the original image, there is also a need for algorithms to reuse existing data. Deep learning technology can automatically fit intermediate features and processes, which is very helpful for data-driven law discovery. However, it should also be noted that this algorithm is with unknown median mechanism, it is inconvenient to modify it manually when problems are encountered. It is recommended to combine deep learning with conventional methods to maximize strengths and avoid weaknesses [25]. In addition, there is a need to focus on the accumulation of algorithm libraries. Many years of research and practice have shown that there is no single algorithm that can solve all information extraction problems. Therefore, the advantages and disadvantages of various algorithms, as well as the applicable conditions and scope should be clarified, so that data can be accurately and in a timely manner, after data acquisition to generate information on products. It is then possible to realize automation and normalization of large areas and local monitoring with high precision.

4.3 Consolidating and supporting major scientific issues and promoting cross-disciplinary integration

The data obtained by remote sensing is comprehensive, and it is quite advantageous in the study of complex coastal zones. The level of complexity of the data is such that single experiments can benefit multiple users. Remote sensing is a high-level technology. As Peng noted, “the scientific team without technical support is backward, and technology without scientific theoretical guidance is blindness”, the participants in research should condense and support a number of major scientific issues, such as the evolution of coastal zones, the mechanism of disasters caused by marine disasters, and the mechanism of red tide formation. This can help remote sensing technology find its own position and developmental direction, and contribute to a better scientific and technological strength in coastal zone management.

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