2024 Volume 5, Issue 1
Satellite Oceanography and Meteorology
ISSN(Online): 2424-9505
ISSN(Print): 2424-8959

Long-term Satellite Observations of Coral Reef Ecosystems under Combined Marine and Meteorological Stresses

R. Jude Acker*
NASA Goddard Earth Sciences Data and Information Services, ADNET Systems Inc., Greenbelt, MD 20771, USA

***Corresponding author:** R. Jude Acker, judeacker@adnet-sys.com

Abstract:

This paper mainly explores the issues related to coral reef ecosystems under combined marine and meteorological stresses. Through the analysis of long-term satellite observation data, it elaborates on the impacts of marine and meteorological factors on coral reef ecosystems, including aspects such as sea water temperature, sea-level change, and ocean acidification. It reveals the current situation and threats faced by coral reef ecosystems under combined marine and meteorological stresses and puts forward suggestions for future research directions and protection strategies.

Keywords:

Coral reef ecosystem
Marine meteorology
Satellite observation
Combined stress

Online publication: June 28, 2024

1. Introduction

The coral reef ecosystem is one of the most biodiverse ecosystems on Earth, providing habitats, breeding, and foraging grounds for numerous marine organisms. However, in recent years, under the combined stresses of various marine and meteorological factors, the coral reef ecosystem is facing a serious degradation crisis. The development of satellite observation technology provides a powerful means for long-term and large-scale monitoring of coral reef ecosystems and the marine and meteorological stresses they are subjected to. This paper aims to comprehensively use long-term satellite observation data to deeply analyze the situation of coral reef ecosystems under combined marine and meteorological stresses, providing a scientific basis for the protection and management of coral reef ecosystems.

2. Overview of the coral reef ecosystem

Coral reefs are formed by the continuous accumulation of the gray-matter skeletons of reef-building organisms such as corals, calcareous algae, and foraminifera. They provide habitats for rocky-reef-type marine organisms, have extremely high primary productivity and biodiversity, and are thus known as the "oases of the ocean." The coral reef ecosystem provides humans with abundant fishery and tourism resources, protects the coastline, and has high scientific research and cultural value [1]. In terms of distribution, coral reefs are mainly distributed in tropical and subtropical waters where environmental conditions such as water temperature, light, and salinity are suitable. For example, there are extensive coral reef distributions in the Western Atlantic Ocean, the Great Barrier Reef, and the South China Sea.

3. Application of satellite observation technology in the study of coral reef ecosystems

Satellite observation technology has the unique advantages of large-scale, long-term, and continuous observation. It breaks through the spatiotemporal limitations of traditional field observations and can accurately collect wide-area and long-term data that are difficult to reach by traditional means. In the study of coral reefs, optical satellite remote sensing, by accurately measuring the spectral reflectance of seawater, uses inversion algorithms to precisely infer the distribution, coverage area, and bleaching conditions of coral reefs. Satellite data such as Landsat and MODIS help researchers analyze their spatial distribution and dynamic laws. Radar satellite remote sensing focuses on monitoring marine and meteorological elements such as sea-level and wave height, and can also keenly capture subtle changes in the topography and geomorphology of coral reefs. Altimeter satellites quantify the changes in sea-level height with high precision, laying a data foundation for studying the impact of sea-level rise on coral reefs [2]. In addition, satellite sea-surface temperature (SST) data is crucial for monitoring the thermal stress of coral reefs. The SST products of NOAA satellites have a resolution of about 50 km, and the GHRSST merged data products have a resolution of about 1 km, which can accurately reflect the temperature changes in sea areas and support related research.

4. Combined stresses of marine and meteorological factors on coral reef ecosystems

4.1. Stress from seawater temperature changes

The rise in seawater temperature caused by global warming is one of the main threats faced by coral reefs. When the seawater temperature exceeds the suitable survival temperature range of coral reefs for a long time, the symbiotic relationship between corals and zooxanthellae is disrupted. Zooxanthellae leave or die, resulting in coral bleaching. Long-term satellite observation data shows that since the 1980s, the seawater temperature in global tropical and subtropical waters has been on the rise. In years such as 1998 and 2016, large-scale global coral reef bleaching events occurred. For example, in the 1998 bleaching event, about 16% of the world's coral reefs were severely affected. If the global average temperature rises by 1.5 degrees Celsius compared to the pre-industrial level, it is estimated that 70–90% of coral reefs will disappear by 2050 [3].

4.2. Stress from sea-level changes

The rise in sea - level is reshaping the hydrodynamic environment and light conditions of coral reefs. On the one hand, as the sea - level rises, coral reefs may be covered by deeper seawater, which can lead to insufficient light, affecting the photosynthesis of zooxanthellae and thus having an adverse impact on the growth and reproduction of corals. On the other hand, the rise in sea level may also increase the erosion of coral reefs by waves, damaging their structural integrity. According to satellite observation data, the global sea level has risen by about 15 - 20 cm in the past century. In coral reef areas near low-altitude island countries such as the Maldives, the effects of sea-level rise are particularly prominent, and there have been phenomena such as slow growth and even reef-body damage.

4.3. Stress from ocean acidification

The increase in carbon dioxide concentration in the atmosphere has led to the ocean absorbing more carbon dioxide, triggering ocean acidification. Ocean acidification reduces the concentration of carbonate ions in seawater, affecting the calcification process of coral reefs, slowing down the growth rate of coral reefs, and making the reef-body structure fragile. According to satellite observations combined with field monitoring data, since the Industrial Revolution, the pH value of the global ocean surface seawater has decreased by about 0.1 unit [4]. It is estimated that by 2100, the ocean pH value may further decrease by 0.3–0.4 units, which will pose a serious threat to the survival and development of coral reefs.

4.4. Stress from extreme meteorological events

Extreme meteorological events such as hurricanes and typhoons can cause direct physical damage to coral reefs. Strong winds and huge waves can destroy the reef-body structure of coral reefs, breaking and killing a large number of corals. At the same time, extreme precipitation events such as heavy rain may lead to a large amount of terrestrial substances entering the ocean, increasing the turbidity of seawater, affecting the light conditions of coral reefs, and may also bring pollutants, causing pollution stress to the coral reef ecosystem. Satellite observations have recorded the impacts of many extreme meteorological events on coral reefs. For example, after Hurricane Irma hit the Caribbean region in 2017, satellite images showed that the coral reef coverage in this area decreased significantly, and the damaged area of coral reefs in some areas exceeded 50% [5].

5. Spatiotemporal characteristics of coral reef ecosystems under combined marine and meteorological stresses

5.1. Spatial characteristics

On a global scale, the degree of combined marine and meteorological stresses on coral reefs in tropical and subtropical waters shows obvious regional differences. Especially in the Western Atlantic Ocean, the Caribbean Sea region, and the vast area across the Indian-Pacific Ocean, coral reefs are facing particularly severe challenges. Well-known coral reef regions such as the Great Barrier Reef, the Maldives, and the Philippines are experiencing particularly significant coral bleaching and reef-body degradation due to the increase in seawater temperature and the intensification of ocean acidification. On a more refined regional scale, different parts of the coral reefs also bear different degrees of stress. Generally, coral reefs located at the reef edge and in shallow water areas are more vulnerable to the direct impact of seawater temperature fluctuations, sea-level rise, and wave erosion. These areas are often the most fragile parts of the coral reef ecosystem and the most intuitive places to show the impacts of environmental changes [6]. In contrast, coral reefs inside the reef flat and in deep-water areas are relatively less affected by these short-term factors, but they may suffer from the chronic effects of long-term stresses such as ocean acidification. Although these chronic effects are less noticeable, they can cause serious damage to the structure and function of coral reefs over the long term. Therefore, protection and management strategies for coral reefs need to consider these regional and local differences and adopt more detailed and targeted measures to protect and restore these ecologically fragile and crucial marine ecosystems.

5.2. Time characteristics

Long-term observations show that against the background of the intensifying global climate change, the frequency and intensity of combined marine and meteorological stresses faced by coral reef ecosystems are gradually increasing. Since 2009, about 14% of the global coral reef area has disappeared, which reveals the severe challenges faced by coral reef ecosystems. On an inter-annual time scale, the degradation of coral reefs shows periodic and non-periodic change patterns. Especially during El Niño-Southern Oscillation (ENSO) events, the abnormal increase in seawater temperature often triggers widespread coral reef bleaching, which has a huge impact on the health of coral reef ecosystems [7]. Further observing on a decadal time scale, we find that the degradation rate of coral reef ecosystems is accelerating, which is closely related to the acceleration of global warming and the intensification of human activities. With the increase in greenhouse gas emissions and the continuous deterioration of the marine environment, coral reef ecosystems are facing unprecedented pressure. This accelerated degradation not only threatens the survival of coral reefs themselves but may also have a serious impact on coastal communities that depend on coral reef ecosystems for their livelihoods. Therefore, there is an urgent need for global action to mitigate the impacts of climate change and implement effective coral reef protection measures to ensure the future of these precious ecosystems.

6. Response mechanisms of coral reef ecosystems to combined marine and meteorological stresses

6.1. Physiological response

In the face of the combined stresses of marine and meteorological factors, corals exhibit complex physiological adaptation strategies. For example, when the seawater temperature rises, corals can up-regulate the expression of heat-shock proteins. These proteins, like guardians within cells, protect other proteins and organelles from the damage of high temperatures. In addition, in the face of the challenge of ocean acidification, corals try to adjust the ion-transport mechanism in their calcification process to maintain their normal calcification rate and thus the stability of their skeletal structure [8]. However, this physiological regulation ability is not unlimited. The adaptation strategies of corals may reach their physiological limits in the face of continuous or excessive environmental pressure, threatening their survival and reproduction. Therefore, the protection and restoration of coral reefs urgently need to be strengthened to help these ecosystems maintain their ecological functions and biodiversity under increasingly severe environmental conditions.

6.2. Community structure response

Under the long-term combined stresses of marine and meteorology, the biological community structure of coral reefs has undergone significant changes. Coral species that are more sensitive to environmental changes gradually decline and may even disappear completely in some areas, while coral species with stronger environmental tolerance may gain an advantage in competition, and their relative numbers increase. This change in species composition not only affects the ecological diversity of coral reefs but also indirectly affects other symbiotic marine organisms. For example, the species and numbers of fish, shellfish, and other organisms that rely on coral reefs for shelter and food sources also change accordingly. These changes further cascade and affect the food chain and food web structure of the coral reef ecosystem, possibly leading to the reorganization of ecological functions and the decline of ecological services. Therefore, the health and stability of the coral reef ecosystem are seriously threatened, and effective protection and restoration measures need to be taken to maintain the long-term well-being of these complex and fragile ecosystems [9].

6.3. Ecosystem function response

Coral reef ecosystems play crucial roles, including biological production, nutrient cycling, and providing diverse ecological services. However, under the influence of combined marine and meteorological stresses, these functions are being severely challenged. In terms of biological productivity, the output of coral reefs has significantly decreased, especially the calcification rate of reef-building corals has slowed down, which not only leads to slow reef-body growth but also weakens the contribution of coral reefs to the marine ecosystem. In terms of nutrient cycling, the disturbance of coral reefs has led to abnormal cycling patterns. For example, the death caused by coral bleaching events releases a large amount of nutrients into the seawater, which may break the original nutrient balance, change its concentration and distribution, affecting the growth and reproduction of plankton and further disrupting the nutrient flow and energy transfer of the entire ecosystem [10]. In addition, coral reefs have also been affected in providing ecological services. As a natural coastal defense line, the protective function of coral reefs has been greatly weakened due to reef-body degradation and structural damage, making coastal areas more vulnerable to the erosion of wind, waves, and tides. At the same time, as a natural resource that attracts tourists, the aesthetic and economic value of coral reefs has also decreased due to ecological degradation. These changes not only threaten the health of coral reefs themselves but may also have a profound impact on the communities and economies that depend on them. Therefore, protecting and restoring coral reef ecosystems and maintaining their functions and services are crucial for the sustainable development of the marine environment and human well-being.

7. Conclusion

Through the analysis of long-term satellite observation data, we find that coral reef ecosystems are suffering from combined stresses of various marine and meteorological factors such as sea water temperature changes, sea-level rise, ocean acidification, and extreme meteorological events. These problems have led to phenomena such as coral reef bleaching, reef-body degradation, and a decrease in biodiversity. Although coral reef ecosystems have certain self-regulation and adaptation capabilities, under the background of global climate change, the ecological pressure in some areas has exceeded the threshold, and the ecosystem is at a serious risk of degradation. Therefore, future research should strengthen interdisciplinary and multi-method comprehensive research to deeply understand the response mechanisms and adaptation strategies of coral reefs to stresses. At the same time, combined with satellite and field observation technologies, a more complete monitoring network should be established to improve monitoring accuracy and early-warning capabilities. In terms of international cooperation, it is necessary to jointly formulate and implement protection policies, reduce greenhouse gas emissions, and mitigate marine and meteorological stresses to promote the sustainable development of coral reef ecosystems.

Disclosure statement

The author declares no conflict of interest.

References

[1] Li Y, Gao Y, Zheng X, et al., 2022, Generation Mechanisms and Evaluation Methods of Coral Reef Ecosystem Functions. Journal of Applied Oceanography, 41(3): 475–482.

[2] Chen Z, Yu K, Su F, et al., 2021, Development of a Dataset of Thermal Stress and Prediction of Coral Reefs in the South China Sea Islands (1982–2100). Journal of Global Change Data & Discovery (Chinese and English), 5(1): 79–88 + 192–201.

[3] Zuo X, Su F, Zhang Y, et al., 2020, Identification and Analysis of Protection Priority Areas in the South China Sea Islands Under Global Climate Change. Acta Geographica Sinica, 75(3): 647–661.

[4] Ma Z, Song Y, Zou Y, et al., 2022, Remote-Sensing Information Extraction of Coral Reefs in the Yongle Islands of the Xisha Islands Based on Deep Learning. Journal of Applied Oceanography, 41(4): 644–654.

[5] Wang W, Zou X, Li H, 2022, Multispectral Remote-Sensing Bathymetric Inversion in the Optical Shallow-Water Area of Coral Reefs in the South China Sea. Geological Journal of China Universities, 28(5): 758–767.

[6] Li W, Huang Z, Li T, 2022, Research on the Application of High-Resolution Satellite Remote-Sensing Technology in the Field of Marine Rights Protection. China Plant Engineering, 2022(17): 61–63.

[7] Li M, 2022, Population Genetics of the Widely-Distributed *Porites lutea* and the Dominant Low-Latitude *Pocillopora verrucosa* in the South China Sea, thesis, Guangxi University.

[8] Wu W, 2022, Construction of Time-Series Images of Ocean Night-Light Remote Sensing and Research on Human Activities in Coral Reef Areas Indicated by Them, thesis, Guangxi University.

[9] Duan Z, 2022, Evaluation of the Ecological Resistance of Coral Reefs in the Xisha Islands Based on Remote-Sensing Technology, thesis, Guangxi University.

[10] Xiong Y, 2022, Estimation of the Area of Coral Reefs in the Xisha Islands Based on Multi-Temporal Remote-Sensing Images, thesis, Guangxi University.

Publisher's note

Whioce Publishing remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.