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# Correlation between Global Ocean Heat Content and Meteorological Trends Recorded by Satellites in the Past Three Decades

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**Abstract:**

This paper focuses on the past three-decade period. By using multi-source satellite data, field monitoring data, and data from authoritative databases, it deeply explores the correlation between global ocean heat content and meteorological trends. The study finds that from 1955 to 2023, the global ocean heat content from 0–2000 meters has significantly increased, especially from 2014 to 2023, reaching a peak in 2023. In terms of stratification, the warming rate from 0–2000 meters is $0.9 \pm 0.1$ W/m², and there is an increase below 2000 meters but with uncertainties. Meteorologically, the concentration of greenhouse gases has increased, the sea surface temperature has risen, and the frequency of floods and extreme temperature disasters has increased in the past 30 years. The number of deaths from flood disasters has decreased, and the economic losses from storm disasters have increased. The ocean heat content is positively correlated with the sea surface temperature and the concentration of greenhouse gases, and it also exacerbates disasters such as tropical storms, hurricanes, and marine heatwaves, threatening the coastal ecology and economy. This research provides a key basis for understanding the mechanism of climate change.

**Keywords:**

Past three decades
Global ocean heat content
Meteorological trends
Correlation
Satellite records

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## 1. Introduction

The ocean, as a core component of the global climate system, the fluctuations in its heat content play a decisive role in climate change. In the past three decades, with the continuous advancement of satellite observation technology, we have obtained a large amount of high-quality data on global ocean heat content and meteorological elements, which provides a solid foundation for in-depth exploration of the interaction between the two. The accumulation and analysis of these data enable us to more accurately understand the complex relationship between global ocean heat content and meteorological trends. This is of immeasurable value for revealing the internal mechanisms of climate change, predicting future climate trends, and formulating effective climate change response strategies. Therefore, continuous research and monitoring of changes in ocean heat content not only help us better understand the operation of the Earth's climate system but also provide a scientific basis for protecting our living environment and mitigating the negative impacts of climate change.

## 2. Characteristics of global ocean heat content changes in the past three decades

### 2.1. Overall change trend

Looking back on the evolution of the past three decades, through in-depth exploration using multi-source satellite observation data and a large number of field monitoring data, it has been found that the global ocean heat content shows a very prominent and statistically significant upward trend. Through a comprehensive analysis of a series of reports released by international authoritative ocean research institutions, the results of joint ocean scientific research projects of various countries, and other authoritative research materials, it can be seen that from 1955 to 2023, a period of nearly seven decades, focusing on the key ocean depth range of 0–2000 meters, the global ocean heat content has consistently maintained a steady upward trend [1]. This trend is not a random fluctuation but is supported by solid data. Many long-term fixed-point observation stations and satellite remote-sensing inversion data mutually confirm each other, jointly outlining this clear warming trajectory. Particularly notable is that from 2014 to 2023, in this nearly ten-year period, with the more advanced high-precision satellite thermal imaging technology and the data fed back by the widely distributed deep-sea temperature sensor arrays, it has undoubtedly become the warmest ten years in the history of modern ocean observations. Among them, 2023, with its excellent performance of breaking past historical extreme values in multi-point monitoring data in each quarter and each sea area, reached a new peak [2]. The emergence of this peak not only reflects short-term climate fluctuations but is also closely related to the long-term global climate change pattern, sounding the alarm for the subsequent in-depth exploration of the interaction mechanism between the ocean and the climate.

### 2.2. Characteristics of stratified changes

From the key dimension of ocean vertical stratification, relying on advanced scientific research means and precise monitoring equipment, with the high-precision data collected by Argo floats, the research team used cutting-edge data analysis models for in-depth calculations and accurately revealed that within the ocean water body range of 0–2000 meters, the warming rate of the global ocean heat content reaches $0.9 \pm 0.1$ W/m². This key value, compared with the average warming rate obtained through long-term, continuous, and systematic observations in the past, shows a very significant upward trend through rigorous statistical tests [3]. Behind this lies complex ocean thermal-dynamic processes. Many factors, such as changes in the penetration depth of solar radiation and the alteration of the heat exchange mode between surface and deep-sea water, jointly drive this jump in the warming rate. At the same time, at the comprehensive research level, researchers strive to comprehensively understand the overall picture of ocean heat content through the collaborative analysis of satellite altimetry, satellite gravity, and Argo float multi-source data. It has been found that in the deep-sea area below 2000 meters, although the existing data initially indicate that the ocean heat content also shows a growth trend, with a rate of about $0.18 \pm 0.36$ W/m², it must be clearly recognized that due to the extreme high-pressure, low-temperature, dark environment, and complex ocean currents and geological structures in the deep sea, as well as the inherent limitations of current observation techniques in deep-sea exploration, such as the challenges of the pressure resistance and stability of deep - sea sensors and the problem of signal transmission attenuation, this data has a relatively large uncertainty range [4]. This not only points out the direction for future research but also highlights the urgency of further overcoming the difficulties in deep-sea observation to more accurately grasp the essence of changes in ocean heat content.

## 3. Analysis of global meteorological trends in the past three decades

### 3.1. Change trends of meteorological elements

In the past three decades, against the backdrop of global climate change, many key meteorological elements have shown significant dynamic changes, among which the upward trend of global greenhouse gas concentration is particularly prominent. Based on the high-precision data accumulated from the long-term and continuous monitoring of the Waliguan Atmospheric Background Station, it clearly reveals that since the start of the 1990s, carbon dioxide, as a key component of greenhouse gases, has shown a steadily increasing trend year by year. Behind this lies deep - seated factors such as the intensification of human activities and the imbalance of the energy consumption structure. Large-scale industrialization processes, deforestation, and the over-burning of fossil fuels continuously emit huge amounts of carbon dioxide into the atmosphere, causing its concentration to accumulate and rise. At the same time, the global average sea surface temperature has also experienced a significant change trajectory in the past three decades, generally showing an upward trend. Through in-depth mining and rigorous analysis of authoritative ocean observation databases, it can be seen that from 1870 to 2023, the global average sea surface temperature was 0.85 ℃ higher than the relatively stable average value from 1870 to 1900 [5]. This increase in temperature is not an isolated phenomenon. It is closely related to the soaring global greenhouse gas concentration. Greenhouse gases are like a “thermal blanket” wrapped around the Earth, enhancing the atmospheric greenhouse effect, causing more solar radiation energy to be absorbed by the surface water of the ocean, and thus driving the continuous increase of the sea surface temperature, profoundly affecting the global ocean thermal - dynamic cycle and the stability of the marine ecosystem.

### 3.2. Evolution characteristics of meteorological disasters

According to the detailed data provided by the global authoritative Emergency Events Database (EM-DAT), in the past 30 years, the frequency of flood disasters and extreme temperature disasters has shown a significant upward trend globally. In terms of the frequency of disasters, the frequency of flood disasters has increased, and the number of occurrences has significantly increased in the past 30 years. The occurrence of extreme temperature disasters has also become more frequent, bringing many adverse effects around the world. At the same time, the annual number of deaths from global flood disasters has shown a significant downward trend. The emergence of this phenomenon is due to many factors, such as the gradual improvement of the awareness of disaster prevention and mitigation globally, the continuous improvement of flood-control infrastructure, and the increasingly sound disaster early-warning and emergency rescue systems [6]. The comprehensive effect of these positive factors has effectively controlled casualties in the face of flood disasters, resulting in a downward trend in the number of deaths. However, it is necessary to pay close attention to the fact that the annual economic losses from storm disasters have shown a significant upward trend in the past 30 years. With the rapid development of the global economy, the total economic volume in coastal areas and storm-prone areas has been continuously increasing. Once a storm disaster occurs, the economic losses it causes also increase significantly [7]. In addition, factors such as the increase in storm intensity and the expansion of its impact area have further exacerbated the economic damage caused by storm disasters, making the annual economic losses caused by storm disasters show a severe upward trend.

## 4. Correlation analysis between global ocean heat content and meteorological trends

### 4.1. Correlation with meteorological elements

Ocean Heat Content (OHC) is an important indicator for understanding the Earth’s climate, a crucial form of expression and a direct reflection of ocean heat storage. The vertical distribution of the Earth’s Energy Imbalance (EEI) caused by greenhouse gases in the ocean is of great significance for understanding the ocean-climate system. Only by fully understanding the distribution and redistribution process of ocean heat can we better understand and predict future climate changes [8]. In the complex interaction network of the global climate system, the global ocean heat content and the sea surface temperature show a high degree of positive correlation. From the perspective of the physical mechanism, when the ocean continuously absorbs external heat, its internal heat content gradually accumulates and increases. At the same time, the sea surface, as the interface of heat exchange between the ocean and the atmosphere, also shows a synchronous upward trend in temperature. Taking the El Niño phenomenon as an example, during this climate-abnormal event, the seawater in the eastern and central equatorial Pacific Ocean, under the combined action of abnormal atmospheric circulation and disordered ocean current systems, shows a significant abnormal increase in temperature. Accompanying this is a sharp increase in the ocean heat content in this region. The synchronous changes of the two clearly demonstrate the close internal relationship between them. Further exploration reveals that there are also intricate connections between ocean heat content and greenhouse gas concentration. As human activities lead to a continuous increase in greenhouse gas emissions, the greenhouse effect of the Earth's atmosphere is continuously enhanced. More solar heat that should originally be radiated back into space is retained within the Earth system. Among them, the ocean, with its huge heat capacity, becomes the main absorber of heat, thus promoting a steady increase in ocean heat content and profoundly reshaping the energy-balance pattern between the global ocean and the atmosphere. In the long run, the chain reaction caused by this imbalance is intensifying. The atmospheric circulation is disrupted, and extreme climate events are becoming more frequent. Torrential rain, floods, high-temperature droughts are raging in many places, and the sea level is rising rapidly due to the thermal expansion of seawater. Low-lying islands and coastal cities are facing a severe risk of inundation, and the living space of humanity is facing an unprecedented challenge.

### 4.2. Correlation with meteorological disasters

Against the background of global climate change, there are close and complex relationships between the dynamic changes in ocean heat content and extreme weather systems such as tropical storms and hurricanes [9]. The continuous increase in ocean heat content essentially injects a more abundant energy source into extreme weather systems such as tropical storms and hurricanes. From the physical process of energy conversion, the warming seawater contains more thermal energy. When certain atmospheric dynamic conditions are met, this additional heat can be efficiently converted into the kinetic energy that drives the generation and development of storms and hurricanes, thus directly increasing their frequency of occurrence and significantly enhancing their destructive power. Many cutting-edge studies, through long-time-series observation data and high-resolution climate model simulations, have strongly shown that as the ocean gradually warms, the thermal difference between the ocean surface and the deep sea becomes more significant. This thermal imbalance causes abnormal adjustments in the atmospheric circulation, creating a more favorable environment for the frequent breeding of tropical storms and hurricanes, making them occur more frequently and with greater intensity. Moreover, when the ocean heat content shows an abnormal increase, it often induces the phenomenon of marine heatwaves [10]. As an extreme high-temperature event in the ocean, marine heatwaves have a profound impact on the fragile coastal ecosystems and human production and living activities. Taking the coral reef ecosystem as an example, continuous high-temperature stress can lead to frequent coral reef bleaching. The symbiotic relationship between corals and symbiotic algae is damaged, resulting in a sharp decline in the biodiversity of the coral reef ecosystem, the decline of fishery resources, the weakening of the coastal protection function, and a series of chain reactions. Eventually, secondary disasters such as ocean acidification and the loss of marine habitats are triggered, seriously threatening the sustainable development of coastal areas.

## 5. Conclusion

In general, the satellite records of the past three decades have unveiled the mysterious relationship between global ocean heat content and meteorological trends. It clearly presents the change characteristics of ocean heat content at different depth levels, the evolution trajectories of meteorological elements and disasters in the same period, and deeply explains their intertwined and mutually influencing relationships. The increase in ocean heat content is not an isolated phenomenon. It goes hand in hand with the increase in global greenhouse gas concentration and the rise in sea surface temperature. At the same time, it has also become a key factor contributing to the frequent occurrence and intensification of extreme meteorological disasters, bringing many challenges to the Earth's ecosystem and human society. Looking to the future, given the current limitations of research, follow-up research should focus on breakthroughs in many aspects. On the one hand, it is necessary to vigorously promote the innovation of observation technologies, overcome the difficulties in deep-sea observation, and improve the accuracy of ocean heat content monitoring, especially to reduce the uncertainty of deep-sea data below 2000 meters, in order to obtain more complete and accurate information on the ocean thermal state. On the other hand, theoretical research on the ocean-atmosphere coupling mechanism should be deepened, and more refined and reliable climate models should be constructed to accurately quantify the feedback loops between changes in ocean heat content and various meteorological trends. In addition, cross-disciplinary and cross-border cooperative research urgently needs to be strengthened. Integrate resources and wisdom from all parties to jointly address the global issues brought about by climate change, lay a solid foundation for the sustainable development of human society, and help the Earth's homeland move forward steadily in the tide of future climate change.

## Disclosure statement

The author declares no conflict of interest.

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