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El Niño Phenomenon: Meteorological Chain Reaction Tracked by Satellite Oceanography

Piotr Sankowski*
Department of Botany and Plant Pathology, Oregon State University, Corvallis, OR 97331, USA

Corresponding author: Piotr Sankowski, sank@mimuw.edu.pl

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Abstract:

This paper mainly explores the El Niño phenomenon and the meteorological chain reactions it triggers under the tracking of satellite oceanography. Through the analysis of relevant observational data and research results, it elaborates on the formation mechanism, development process of the El Niño phenomenon, and its multi-faceted impacts on the global climate system, emphasizing the significant role of satellite oceanography in monitoring and studying the El Niño phenomenon.

Keywords:

El Niño
Satellite
Ocean
Meteorological chain reaction

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1. Introduction

El Niño, as an important climatic phenomenon, has a profound impact on global climate and ecological environment. With the continuous development of satellite oceanography technology, we can more accurately monitor and track the occurrence and development process of El Niño, thereby gaining a deeper understanding of the meteorological chain reactions it triggers. This is of great significance for improving climate prediction capabilities and formulating response strategies to mitigate its adverse effects.

2. Overview of El Niño

El Niño refers to the abnormal warming of sea surface temperatures in the central and eastern equatorial Pacific. This phenomenon typically occurs every few years, with a cycle generally lasting between 3 to 7 years. According to the definition of the National Oceanic and Atmospheric Administration (NOAA) of the United States, an El Niño event is identified when the sea surface temperature anomaly index in the central and eastern equatorial Pacific exceeds 0.5 °C and persists for at least six months. Satellite observation data show that during El Niño events, the sea surface temperature in the central and eastern equatorial Pacific shows a significant increase. El Niño affects the East Asian monsoon system through atmospheric circulation in a "teleconnection" form. Due to the different sea surface temperature anomaly patterns of central and eastern El Niño events, their atmospheric responses are different, and their impacts on climate also vary greatly. Domestic and foreign scholars have conducted extensive research on the impact of the two types of El Niño on precipitation, and different types of El Niño have opposite effects on precipitation in some regions of China [1].

3. Application of satellite oceanography in El Niño research

3.1. Satellite observation of sea surface temperature

Satellite oceanography, with a series of advanced observation methods, has laid a solid data foundation for in-depth analysis of El Niño. In terms of satellite monitoring of sea surface temperature, it plays a crucial role and has become one of the key ways to monitor the dynamics of El Niño. By using high-precision sensors carried by satellites, this technology demonstrates an extraordinary ability to collect real-time and wide-area sea surface temperature data with extremely high accuracy and continuity, closely tracking the subtle changes in sea surface temperatures in the central and eastern equatorial Pacific [2].

The data captured by these sensors not only reveal the slight fluctuations in sea surface temperature but also provide important clues for researchers to identify the early signs of El Niño and track its subsequent development. Through these continuous sea surface temperature records, researchers can more accurately predict and explain the occurrence, intensity, and impact range of El Niño, providing an important basis for climate prediction and the formulation of response strategies. In addition, these detailed data have deepened the understanding of the interaction between the ocean and the atmosphere, the dynamic balance of the global climate system, and the response of ecosystems, promoting the deepening of the application of satellite oceanography in climate research.

3.2. Application of satellite altimetry

Satellite altimetry, as a core monitoring technology in satellite oceanography, plays a crucial role. Its main responsibility is to precisely measure changes in sea level height, a function that is crucial for understanding ocean dynamics and climate change. In fact, sea level fluctuations are closely related to changes in ocean heat content, and their interaction reveals the distribution and transfer of heat energy within the ocean.

During the El Niño cycle, especially when it occurs, the sea level height in the central and eastern equatorial Pacific region will significantly rise. Behind this phenomenon is the rapid increase in ocean heat content, which causes seawater to expand and subsequently leads to a rise in sea level. Through its high-precision sensors, satellite altimetry can continuously and meticulously monitor these subtle changes in sea level, providing researchers with a detailed map of ocean heat content distribution [3]. Through these data, researchers can indirectly infer the spatial distribution characteristics of ocean heat content and their temporal variation paths. This in-depth insight enables scientists to track the development process of El Niño more precisely and reveal its complex internal mechanisms.

3.3. Satellite gravity measurement technology facilitates

Satellite gravity measurement technology, like a fresh breeze injected into the research field, brings a powerful impetus to the exploration of El Niño with its unique perspective. This technology focuses on the precise monitoring of the dynamic changes in the distribution of ocean mass. During the entire life cycle of El Niño, from its formation to its evolution and eventual dissipation, the distribution of ocean mass is not static but follows certain patterns of continuous adjustment [4]. With its high-resolution measurement capability of ocean mass changes, satellite gravity measurement technology opens up multi-dimensional information channels for in-depth analysis of El Niño, allowing researchers to comprehensively and stereoscopically interpret the complex characteristics of El Niño and push related research to new heights.

4. Meteorological chain reactions triggered by El Niño

4.1. Abnormal atmospheric circulation

When El Niño occurs, the abnormal warming of sea surface temperatures in the central and eastern equatorial Pacific drives significant changes in atmospheric circulation. Under normal climate conditions, there is a stable Walker circulation system from east to west in the equatorial region. However, the emergence of El Niño events weakens the Walker circulation and may even cause it to reverse. This change directly disrupts the original balanced distribution pattern of atmospheric circulation and has a profound impact on the global climate system. For example, during El Niño years, the high-pressure system in the western Pacific weakens, while the low-pressure system in the eastern Pacific strengthens. As a result, the atmospheric circulation presents an abnormal state, and its subsequent effects widely affect various regions around the world, causing deviations in wind direction and precipitation distribution from the norm.

According to relevant statistical data, during the 1982–1983 El Niño event, due to severe abnormalities in atmospheric circulation, some regions worldwide suffered extremely rare severe droughts, with drought severity reaching levels not seen in decades or even centuries; at the same time, other regions were plunged into years of unprecedented heavy rain and flood disasters, causing heavy blows to local ecological environments, social economies, and many other aspects [5].

4.2. Global climate anomalies

The impact of El Niño on the global climate system is extensive and complex. Regionally, in the west coast of South America, El Niño often leads to a high probability of heavy rain and floods; in contrast, regions such as Australia and Indonesia tend to experience drought. For instance, during the 2015–2016 El Niño event, countries like Peru and Ecuador in South America suffered extremely severe rain and flood disasters, causing massive infrastructure damage and agricultural production losses; at the same time, Australia was mired in severe drought, with a series of problems such as a sharp decline in crop yields and a shortage of water resources, posing a serious challenge to local production and living order [6].

Further investigation reveals that El Niño also deeply influences the global temperature distribution pattern. During El Niño years, the global average temperature generally shows an upward trend, and the frequency of abnormal temperature phenomena such as warm winters and cold summers increases significantly. For example, during the 1997–1998 El Niño cycle, the global average temperature rose by about 0.2 ℃ compared to normal years. In that winter, the southern part of the Yangtze River in China showed a significant warm winter characteristic, with temperatures deviating from the average of the same period in normal years, bringing many chain reactions to local energy consumption, agricultural production arrangements, and other aspects [7].

4.3. Changes in marine ecosystems

El Niño also has a significant impact on marine ecosystems that cannot be underestimated. The abnormal rise in sea temperature has severely disrupted the biodiversity and ecological balance within the ocean. Specifically, during the occurrence of El Niño, some cold-water fish species along the coast of Peru, unable to adapt to the rapidly rising water temperature, either died in large numbers or were forced to migrate to more suitable habitats, resulting in an immediate and significant reduction in local fishery resources and a severe blow to the fishery economy [8]. At the same time, the population of warm-water fish species, stimulated by the more favorable water temperature, is highly likely to increase, gradually altering the original species structure and functional layout of the marine ecosystem.

Satellite observation data precisely reveal that under the influence of the 2014–2015 El Niño event, the temperature of the waters off the west coast of the United States significantly increased. This change directly led to a sharp decline in the starfish population, almost to the point of extinction. As natural predators of sea urchins, the sharp reduction in starfish numbers triggered an explosive reproduction of sea urchins, which voraciously consumed kelp forests, severely damaging the local marine ecological landscape. Additionally, the rise in sea temperature further exacerbated the bleaching of coral reefs, causing numerous marine organisms that depend on coral reefs for survival to lose their habitats. The development of related industries such as marine ecotourism was also hindered, facing severe challenges.

5. Prediction and response to El Niño phenomenon

5.1. Prediction level

With the continuous advancement of satellite oceanography technology and the deepening of research on the El Niño phenomenon, humans have achieved remarkable success in predicting this complex climate event. Currently, by constructing high-precision numerical models and organically integrating a large amount of ocean data obtained from satellite observations with multi-source meteorological observation data, researchers can make relatively accurate predictions of the triggering time, evolution path, and intensity level of the El Niño phenomenon.

These numerical models integrate knowledge from multiple disciplines such as ocean dynamics, atmospheric physics, and climate system science, making the prediction work more detailed and comprehensive. By continuously monitoring key indicators such as sea surface temperature, ocean current patterns, and wind direction changes, researchers can capture the early signs of the El Niño phenomenon and predict its possible evolution trends. This improvement in predictive capabilities not only provides valuable decision support for government departments, enabling them to take effective preventive measures before disasters strike, but also offers important reference information for fields such as agricultural production and water resource management, thereby enhancing the global ability to respond to climate change.

5.2. Response strategies

Given the complexity, suddenness, and wide-ranging nature of the meteorological disasters caused by the El Niño phenomenon, it is urgent for countries around the world to collaborate in building a comprehensive and multi-level monitoring and early warning system. This system will rely on diversified means such as satellite remote sensing monitoring, ground meteorological monitoring networks, and ocean buoy monitoring to monitor abnormal meteorological signals in real time. Once potential disaster risks are detected, advanced information dissemination technologies will be used to promptly and accurately issue warning information to the public, enterprises, and government departments, ensuring they have sufficient time to take response measures and make preparations for disaster prevention and mitigation in advance.

In the field of agricultural production, in response to the drought and floods caused by the El Niño phenomenon, measures should be taken from two aspects: optimizing the planting structure and strengthening irrigation facilities. Based on long-term climate change patterns and the abnormal precipitation and temperature patterns that may be brought about by El Niño, the planting structure of crops should be adjusted in a timely manner, prioritizing the promotion of drought-resistant and flood-resistant crop varieties. At the same time, investment in irrigation infrastructure should be increased, with repairs and expansions carried out, and efficient water-saving irrigation technologies promoted to ensure that crops receive the necessary water supply during droughts and can effectively drain water during floods, thereby ensuring the stability and sustainability of agricultural production. In the management of water resources, in the face of the increasingly uneven distribution of water resources and the contradiction between supply and demand caused by the intensification of El Niño, all countries must strengthen the comprehensive management of water resources. By establishing a cross-basin and cross-regional water resource allocation network, breaking the restrictions of administrative divisions, and achieving a scientific and reasonable distribution of water resources, we can address these issues. Additionally, strict water usage quota standards should be established, water-saving equipment should be popularized, and water conservation education and publicity should be strengthened to enhance the awareness of all social strata regarding water conservation and maximize the efficiency of water resource utilization, in order to cope with the water shortage challenges that may be caused by El Niño.

6. Conclusion

As a key climatic phenomenon, El Niño can be precisely tracked through satellite oceanography, allowing us to gain a deeper understanding of the meteorological chain reactions it triggers. This phenomenon not only causes abnormal atmospheric circulation and global climate change but also profoundly affects the balance of marine ecosystems. With the continuous advancement of technology, our ability to predict and respond to El Niño is gradually improving. However, to more effectively deal with this complex climatic phenomenon and mitigate its negative impacts on human society and the ecological environment, we still need to increase research efforts and deepen our understanding of it.

Disclosure statement

The author declares no conflict of interest.

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