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Research on the Remodeling of Regional Meteorological Patterns by Abnormal Ocean Circulation Monitored by Satellites

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Abstract:

This paper aims to explore the remodeling effect of abnormal ocean circulation on regional meteorological patterns under satellite monitoring. Through the analysis of relevant satellite data, it elaborates on the manifestations of abnormal ocean circulation and its relationship with changes in regional meteorological elements, revealing how abnormal ocean circulation affects regional meteorological elements such as atmospheric circulation, temperature, and precipitation through changes in the transportation and distribution of heat, watervapor, etc., and thus remodels the regional meteorological patterns. This provides a scientific basis for a deeper understanding of the interaction between the ocean and the atmosphere and the mechanism of climate change.

Keywords:

Satellite monitoring
Abnormal ocean circulation
Regional meteorological patterns
Remodeling

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1. Introduction

Ocean circulation plays a crucial role in the global climate system. By transporting substances such as heat, watervapor, and salt, it regulates the global climate distribution. Thanks to the advancement of satellite technology, satellite monitoring provides us with abundant and valuable data resources for studying abnormal ocean circulation and its impact on regional meteorological patterns. A deep understanding of how abnormal ocean circulation remodels regional meteorological patterns is of great significance for improving the accuracy of climate prediction and effectively responding to climate change.

2. Methods and data sources for satellite monitoring of abnormal ocean circulation

2.1. Satellite altimeter measurement

Satellite altimeters are one of the important technical tools for monitoring changes in ocean circulation. Their working principle is based on the accurate measurement of the dynamic changes in sea-surface height. This technology reveals the secrets of ocean circulation by capturing the subtle fluctuations of the sea level. Taking the TOPEX/Poseidon and Jason series of satellite altimeters as examples, these altimeters use cutting-edge measurement technologies and can extremely sensitively record every change in sea-surface height. Their role is not limited to observation but also accurately invert the circulation state of the ocean surface through these data, including key parameters such as the velocity vector and flow direction of ocean currents. The accurate determination of these parameters provides direct and reliable data support for scientists to deeply study and understand the dynamic characteristics of ocean circulation. The data of the TOPEX/Poseidon and Jason series of satellite altimeters not only reveal the basic patterns of ocean circulation but also can track their evolution over time, thus enabling a better understanding of how the ocean affects the global climate system.

2.2. Satellite gravity measurement

The satellite gravity measurement technology is based on the accurate determination of the Earth's gravity field and its spatiotemporal changes. With the help of high-precision gravity measurement instruments carried on satellite platforms, fine-grained data of the global gravity field are obtained. On this basis, by integrating multi-source observation data and using complex geophysical modeling algorithms, an ocean circulation model with high precision and high resolution is constructed. Using the data of the GRACE gravity satellite and the Envisat/CryoSat-2 altimetry satellites to monitor and analyze the spatiotemporal changes of the polar ocean circulation, the comparison of gravity and altimetry results shows that the two are in good agreement. However, GRACE has more advantages in monitoring the changes of the polar ocean circulation. Different from the geometric measurement of altimetry satellites, which is severely restricted by the sea ice in the polar regions, GRACE gravity measurement can more accurately construct the spatiotemporal changes of the ocean circulation. Through EOF analysis, GRACE has more accurately identified the spatial characteristics of the polar ocean circulation and its changes over time for the first time. It can be found that the main spatiotemporal changes of the ocean circulation are restricted by the seabed topography [1].

2.3. Ocean satellite remote sensing

The ocean satellite remote-sensing technology, with advanced sensors carried on satellites, realizes the large-scale and high-frequency synchronous monitoring of various physical and biochemical parameters on the ocean surface. This technology not only broadens our understanding of the ocean but also can indirectly reveal the deep-seated characteristics of ocean circulation. Ocean satellite sensors represented by MODIS, with their wide-band and high-sensitivity detection advantages, can capture the surface temperature information of vast sea areas in real-time [2]. The spatiotemporal resolution provided by these sensors meets the requirements of refined analysis and is sufficient to meet the needs of studying the complex coupling relationship between abnormal ocean circulation and the dynamic changes of sea-surface temperature. The data collected by sensors such as MODIS not only cover a vast ocean area but are also continuous in time, providing rich and crucial data resources for scientists to deeply explore the mechanism of the impact of ocean circulation on regional and even global climates.

3. Manifestations of abnormal ocean circulation

3.1. Abnormal ocean current velocity

Many cutting-edge research results have revealed that within specific ocean regions, the velocity of ocean currents shows a significant acceleration or deceleration trend. Taking the equatorial Pacific region as an example, through the analysis of long-time-series observational data, it can be seen that within the past three decades (1993–2022), significant dynamic changes have occurred in the upper-layer ocean circulation of the equatorial Pacific. Among them, the near-surface ocean current flowing westward in the central equatorial Pacific has increased in velocity by about 20%. At the same time, the pole-ward ocean currents in the regions north and south of the equator have experienced significant accelerations of 60% and 20% respectively. These series of changes have had a profound impact on the energy exchange and material transportation processes between the regional ocean and the atmosphere [3].

3.2. Change in circulation path

The path stability of the ocean circulation system may be disrupted under the drive of external environmental factors, leading to the deviation or deformation of the circulation path. Against the backdrop of global climate change, the continuous melting of sea ice in the Arctic region has become one of the key factors affecting the structure of the upper-layer ocean circulation [4]. Specifically, the original dominant structure of the Transpolar Drift has gradually weakened, and is replaced by the strengthening and expansion of the boundary-current structure. This structural transformation has profoundly changed the water-mass distribution, heat-transfer path in the Arctic Ocean, and the interaction mode with the surrounding ocean systems, triggering a non-negligible chain reaction in the feedback mechanism of the global climate system.

3.3. Changes in oceanfronts

Oceanfronts, as the intersection boundaries of seawater with different physical and chemical properties, the fluctuations in their intensity, the migration of their geographical locations, and the changes in their spatial ranges constitute important external signs of abnormal ocean circulation. Especially in the oceanfront area of the mid-latitude North Pacific, this region is the most sensitive area for the interaction between the ocean and the atmosphere. The variation of front-face characteristics, through a series of complex air-sea coupling processes, has a significant regulatory effect on the generation, development, and propagation of atmospheric transient eddies. This regulatory effect not only affects the basic pattern of the atmospheric circulation but also plays a crucial role in the abnormal changes of the atmospheric circulation pattern. These changes, in turn, affect the dry-wet and cold-warm distribution of the regional climate and play a vital role in the breeding and triggering mechanisms of extreme weather events. Even a slight change in the mid-latitude North Pacific oceanfront area may, through a chain reaction, amplify into a widespread climate phenomenon, thus having a profound impact on various aspects of the ecosystem, agricultural production, water-resource management, and even human society.

4. Influence mechanisms of abnormal ocean circulation on regional meteorological patterns

4.1. Heat transport and temperature changes

Ocean circulation, as a crucial heat-transfer link in the Earth's climate system, plays a key role in maintaining the global heat balance. Once the circulation is abnormal, it will break the original steady-state heat distribution and trigger significant changes in the regional temperature field. Taking the Kuroshio Extension region as an example, the abnormal changes in the ocean circulation in this region can directly cause the sea-surface temperature to deviate from the normal state, forming an abnormal sea-temperature distribution pattern [5]. On the one hand, this sea-temperature anomaly can change the thermal structure of the atmosphere in the surrounding area through the heat-exchange process at the air-sea interface, thus having a profound impact on the atmospheric temperature. On the other hand, the fluctuations in the intensity of its front and the migration of its position will have a crucial modulating effect on the activity range and intensity of the storm track, as well as the shape and evolution path of the atmospheric circulation, further amplifying its influence on the regional climate.

4.2. Water-vapor transport and precipitation distribution

The dynamic changes in ocean circulation have a profound regulatory effect on the spatial distribution and transport path of watervapor. Abnormal circulation situations will inevitably disrupt the normal transport trajectory of watervapor, causing the water-vapor-gathering areas to change, and thus remodelling the geographical distribution pattern of precipitation. The Indonesian Throughflow, as an important warm current in the Indo-Pacific ocean circulation system, with its strong material and energy transport capabilities, is deeply involved in the dynamic regulation process of the regional water-vapor balance [6]. When this circulation is abnormal, the water-vapor flux it carries, the transport direction, and the evaporation-precipitation feedback mechanism will all change accordingly, directly interfering with the water-vapor budget balance in the Indo-Pacific region, and ultimately leading to significant abnormal characteristics in the spatiotemporal distribution of regional precipitation and exacerbating the risk of local droughts and floods.

4.3. Adjustment of atmospheric circulation

Abnormal ocean circulation, as one of the key driving forces for the adjustment of atmospheric circulation, can trigger adaptive changes in the intensity, position, and shape of the atmospheric circulation system. In the equatorial central and eastern Pacific region, the abnormal ocean circulation is like a stone thrown into a calm lake, causing ripples and triggering a chain reaction on the atmospheric circulation. Specifically, the abnormal ocean circulation here will significantly interfere with the intensity and geographical location of the Western Pacific Subtropical High, thus breaking the original dynamic balance of the East Asian monsoon system [7]. The breaking of this balance causes the intensity of the East Asian monsoon to fluctuate and its path to deviate, ultimately causing the regional climate to deviate from the normal state, showing a series of climate-abnormal phenomena such as abnormal precipitation and temperature, which have many adverse effects on the local ecosystem, agricultural production, and human social activities.

5. Remodeling of regional meteorological patterns by abnormal ocean circulation in different regions

5.1. Tropical Pacific region

Within the scope of the tropical Pacific, the acceleration of the equatorial Pacific Ocean currents has led to an intensification of the sea-temperature gradient in the equatorial region, manifested as a steeper equatorial temperature line. From the theoretical perspective of climate dynamics, this phenomenon is likely to weaken the amplitude of the El Niño/Southern Oscillation (ENSO) in the eastern Pacific and create favorable conditions for the frequent occurrence of central Pacific El Niño events [8]. Given that ENSO is one of the key driving modes of global inter-annual climate variability, changes in its amplitude and occurrence region will have a far-reaching impact, completely rewriting the regional and even global climate patterns closely related to it, and thus deeply disturbing a series of meteorological elements such as the spatiotemporal distribution of precipitation, the temperature distribution, and the wind-field structure in the tropical Pacific region, and remodeling the regional meteorological pattern.

5.2. Arctic Region

With the acceleration of the global warming process, the continuous melting and retreat of sea ice in the Arctic region have become the key inducement for the transformation of the upper-layer ocean circulation structure. Specifically, the original dominant pattern of the Transpolar Drift is gradually replaced by the boundary-current structure. As a result, the distribution range, movement trajectory, and material-transport path of sea ice in the ocean area have all undergone fundamental changes. At the same time, the upward movement tends to disappear, and the boundary current is strengthened. This process of remodeling the circulation structure, through a complex air-sea interaction chain, has a significant impact on the intensity and polarity characteristics of the Arctic Oscillation (AO), thus affecting the balance of the entire climate system in the Arctic region, making the key climate elements such as temperature, precipitation, and sea-ice dynamics in the Arctic region show new change trends, which has far-reaching significance for the stability and evolution of the Arctic ecosystem [9].

5.3. Mid-latitude North Pacific Region

The mid-latitude North Pacific oceanfront area, as a sensitive front-line position for air-sea interaction, the variation of its own characteristics, especially the dynamic changes in the intensity, spatial scale, and north-south displacement of the front area, can, through its close coupling relationship with the activity of atmospheric transient eddies, induce significant abnormalities in the atmospheric circulation [10]. It is worth noting that under the modulation of the thermal background in different seasons, the feedback response of the changes in the above-mentioned characteristics of the oceanfront area to the atmospheric circulation shows distinct seasonal differences, and thus differentially shapes the types of weather systems, evolution paths, and climate-characteristic distributions in this region in each season, profoundly affecting the climate variability and extremeness in the mid-latitude North Pacific region and bringing many challenges to regional climate prediction and disaster prevention.

6. Conclusion

Satellite-monitoring data shows that the abnormal changes in ocean circulation have a significant remodeling effect on regional meteorological patterns through various complex mechanisms. The acceleration or deceleration of ocean current velocity, the deviation of the circulation path, and the abnormal changes in oceanfronts will all change the transportation and distribution of heat and water vapor, thus affecting the atmospheric circulation and the configuration of regional meteorological elements. The abnormal ocean circulation in different regions has its own characteristics in affecting the local meteorological patterns. For example, the acceleration of ocean currents in the tropical Pacific can trigger the El Niño/Southern Oscillation phenomenon, the transformation of the circulation in the Arctic region can affect the pattern of the Arctic Oscillation, and the changes in the oceanfront area in the mid-latitude North Pacific can affect the performance of atmospheric transient eddies and the overall atmospheric circulation.

Disclosure statement

The author declares no conflict of interest.

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