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The Sea Level Rise under Global Warming

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Abstract: Global warming is the biggest environmental issue facing humanity in the 21st century, and the resulting sea level rise (SLR) is a major disaster that humans need to confront. According to predictions, even in the most optimistic scenario, global temperatures will still rise by 0.3-1.7℃ before 2100, and sea levels will continue to rise by at least 2.3 meters within the next 2000 years. Even though many regions are currently experiencing severe SLR and many countries have implemented corresponding strategies, there is little can be done for small and underdeveloped countries. This study summarizes the current situation and predictions of SLR through a literature review, and compiles various hazards caused by SLR, as well as how different countries in different regions are responding to it, and proposes opinions on how to deal with SLR. It can be used as a reference for readers who want to understand SLR, its hazards, and how to deal with it, so that readers can have a clear understanding of the relevant knowledge about SLR.

Keywords: Sea Level Rise (SLR), global warming, hazard, strategy

1. Introduction

There are many reasons for global sea level rise (SLR), such as changes in atmospheric pressure, changes in ocean circulation, crustal movements, and global climate warming. Among them, global climate warming is a long-term and persistent factor, and the melting of glaciers and the thermal expansion of seawater caused by global warming can lead to serious and persistent SLR. Furthermore, since modern times, the global warming trend has intensified, and the response of sea level to climate warming has become a research hotspot.

Since the last century, global warming has already become a major challenge that the Earth and humanity are facing. The impacts caused by temperature rise involve various aspects such as climate, climate systems, ecosystems, and socio-economic systems0. Due to human activities, especially the extensive burning of fossil fuels such as coal and oil, as well as deforestation, a large amount of greenhouse gases such as carbon dioxide, methane, and nitrogen oxides have been produced. These gases are emitted into the atmosphere, increasing the concentration of greenhouse gases in the atmosphere and intensifying the greenhouse effect, leading to a significant rise in global temperatures[2]. The rise in global temperatures has triggered a series of natural disasters, such as an increase in the frequency and intensity of extreme weather events, melting glaciers and ice caps, SLR, and loss of biodiversity, posing a serious threat to human survival and development[3]. SLR is one of the most serious consequences of climate change, which can lead to dangerous floods and threaten the lives and infrastructure of low-lying coastal areas. Short-term SLR caused by storms and

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hurricanes, combined with ten-year and longer-term SLR, can result in extreme sea level events with devastating socio-economic consequences. So since the beginning of the last century, scientists have been observing and predicting global SLR under the background of temperature increase, and have put forward numerous viewpoints on disaster prevention and control.

Although the disaster of SLR is global, its manifestations vary in different regions, resulting in different levels of harm and loss. This difference has led to significant differences in the measures taken by countries. For example, there is a very large gap between the measures taken by African countries and European countries, and there are cases of lack of cooperation between countries in the same region, such as the Pacific island countries. So it is necessary to summarize the harm of SLR and the measures taken in different regions.

In this thesis, the hazards of SLR are listed, the current situation and future development of global warming, as well as the response measures of different countries in different regions of the world are summarized, providing references and suggestions for more effective prevention of the hazards caused by SLR, and is more conducive to people's understanding of the impact of global warming and helping people cope with SLR.

2. Status quo and predictions of global warming

Global warming has been 0.6°C in the past thirty years and 0.8°C in the previous century. Hansen J summarized in his paper: “In the century before 1975, global warming was slow and fluctuated greatly, and then it rapidly warmed at a rate of approximately 0.2°C per decade”. From the end of the 19th century (the earliest time when global average temperature can be accurately defined) to 2000, global warming was approximately 0.7°C, consistent with the continued warming in the first half of the 21st century at a rate of +0.2°C per decade. According to the latest assessment report by the IPCC, global average temperature has risen by approximately 1.1 degrees Celsius since the end of the 19th century[4]. And from the data, the rate of climate warming in the past fifty years is approximately twice that of the previous fifty years[5]. The concentration of carbon dioxide in the atmosphere also indicates the severity of this problem. In the past 70 years, the concentration of carbon dioxide in the atmosphere has exceeded the sum of the previous 2000 years[6].

In order to systematically predict future temperature change trends, Detlef van Vuuren et al. from the Netherlands Environmental Assessment Agency proposed the concept of Representative Concentration Pathways (RCPs). Simply put, RCPs describe a future in specific circumstances, including specific greenhouse gas concentration trajectories and their potential impacts on climate, environment, and socio-economic factors[7-8]. RCPs include four scenarios: RCP2.6, RCP4.5, RCP6.0, and RCP8.5, where the numbers represent the expected radiative forcing levels (unit: W/m^2) at the end of the 21st century[9]. RCP2.6 (also known as “peak and decline scenario”) assumes that global greenhouse gas emissions will peak around the middle of the 21st century and then gradually decrease; RCP4.5 and RCP6.0 are moderate emission scenarios, assuming some greenhouse gas emission reduction measures are implemented; while RCP8.5 (also known as “high emission scenario”) assumes greenhouse gas emissions continue to increase at current trends. According to the Fifth Assessment Report (AR5) of the Intergovernmental Panel on Climate Change (IPCC), under the RCP2.6 scenario, the global average temperature could increase by 0.3-1.7℃ compared to pre-industrial levels; under the RCP4.5 scenario, it could increase by 1.1-2.6℃; under the RCP6.0 scenario, it could increase by 1.4-3.1℃; and under the RCP8.5 scenario, it could increase by 2.6-4.8℃ [10-11]. RCPs provide an important framework for assessing future climate change possibilities and provide a scientific basis for developing strategies to address climate change. So many scientists have conducted a series of studies and predictions on SLR in the context of RCPs.

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3. Status quo and predictions of SLR

According to records, the sea level has been rising since the last century. By analyzing tidal gauge records from 1870 to 2004, Church & White (2006) found that the rate of SLR has accelerated by 0.013±0.006 millimeters per year. Between 1900 and 1930, the growth rate was not significant. In the following 50 years, the rate increased and reached 1.8 ± 0.3 millimeters per year. According to IPCC AR4 summary: from 1961 to 2003, the contributions of thermal expansion, glaciers, and ice caps are estimated to be 0.4 ± 0.06 millimeters per year, 0.5 ± 0.1 millimeters per year, and 0.2 ± 0.2 millimeters per year, respectively[12]. Peter U. Clark et al. and Anders Levermann et al. studied the extent to which sea levels may rise in the next few thousand years under different RCP scenarios, figuring out that even under the most objective emission reduction scenario, due to the inertia of the climate system, sea levels will continue to rise after the 21st century[13]. And it will continue to rise for thousands of years to come[14]. According to Levermann et al., even if the temperature rises by 1 degree after 2000, the sea level will still rise by 2.3 meters. Moreover, a temperature increase of 4 degrees is a rather terrifying number. In the study by Tebaldi et al. (2021), the Coupled Model Intercomparison Project Phase 5 (CMIP5) model and the Poisson-Generalized Pareto Distribution (GPD) model were combined. Under the conditions of a 2.0°C increase corresponding to RCP2.6 and a 4-5°C increase corresponding to RCP8.5, conclusions were obtained by fitting the pre-sampled 179 global locations and 7,283 locations: by the end of this century, nearly half of the study locations will experience at least one extreme sea level (ESL) event that currently occurs once every hundred years annually, even if global temperature rise is limited to 1.5°C or a maximum of 2°C. Horton et al. made predictions using LSL for three representative RCPs: RCP 2.6, RCP 4.5, and RCP 8.5, which correspond to potential global mean temperature increases of 1.9-2.3°C, 2.0-3.6°C, and 3.2-5.4°C, respectively, for the period 2081-2100 compared to the 1850-1900 level[15].

Against the backdrop of inevitable global temperature rise in the future, the melting of glaciers and thermal expansion of seawater caused by temperature increase are two major factors contributing to global SLR. The rising global temperatures cause glaciers and ice caps to melt, releasing a large amount of water. These waters eventually flow into the ocean, causing SLR. Especially the ice caps of Greenland and Antarctica, their massive ice bodies melting will have a significant impact on global sea levels. In their study on the contribution of ice caps to future SLR, Bamber et al. pointed out that under RCP8.5 scenario in 2100, the contribution of ice caps to SLR is projected to be 6-35 cm[16]. Gregory et al. believe that if the annual average temperature and area average of Greenland Island warm more than the global average, the net surface mass balance of the Greenland ice sheet will become negative. In this case, the Greenland Island ice sheet may eventually disappear, resulting in a global average SLR of 7 meters[17]. As global temperatures rise and seawater temperatures increase, the volume of water expands when heated, leading to SLR. Church et al. predict that by 2050, with a global average temperature increase of 3.0°C, the component of SLR caused by thermal expansion will be approximately 0.2 to 0.3 meters. If the thermal expansion component is included, the total SLR will be approximately 0.35 meters[18].

4. Hazards of SLR due to global warming

From previous research, it is clear that the rise in global temperature significantly affects the rise in sea levels, and there is a strong correlation. And from existing research, the impact of global warming on sea levels is mainly reflected in two aspects: thermal expansion and glacier melting[19]. With the increase in global temperature, the temperature of the sea water also rises. Due to the expansion of substances when heated, this causes the sea level to rise[20]. The melting of glaciers has a more significant impact on SLR, and this impact will continue to increase in the future, even if humans have already controlled carbon emissions[16]. From a human perspective, no matter how much effort

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is put into reducing CO2 emissions, due to the inertia of the climate system, sea levels will continue to rise in the coming centuries. This potential impact, such as catastrophic floods, could be particularly devastating to low-lying coastal areas, causing significant socio-economic damage to humanity and posing a threat to global ecology.

Gornitz et al. showed in their study that under a very high SLR (2.2 m by 2100), all wetlands in the United States would decrease by at least 22%. Additionally, Gornitz et al. mentioned in their thesis that the CORINE project assessed the coastal erosion risk in 11 European Union countries. This project indicates that beach erosion is occurring in all evaluated countries, especially in Portugal, France, Greece, Belgium, and the Netherlands, where 40-50% of beaches are receding[21-22]. Revell et al. predicted that by the year 2100, California coastal dunes will erode by approximately 170 meters. The method for predicting sand dunes includes three factors: extreme SLR, storm events that occur once every 100 years, and historical trends in coastline changes. The overall average contribution rate of extreme SLR to the erosion hazard zone of sand dunes is 48%, the storm event with a return period of 100 years is 45%, and the historical trend is 7%. The highest sand dune danger zone (>500 meters) is located near Humboldt Bay on the northern California coast and nearby marsh systems, with dunes expected to erode up to 600 meters by the year 2100[23]. In addition, SLR will cause the intrusion of saltwater into freshwater resources, posing a threat to agricultural and drinking water; SLR will also cause changes in the coastline and coastal landforms, affecting changes in coastal ecosystems such as wetlands, reed beds, and beaches, and having adverse effects on wildlife and plants. The most threatened areas are the Delta, low-lying coastal plains, coral islands, beaches, barrier islands, coastal wetlands, and river mouths[24]. SLR will change the position of the estuary, causing significant changes in fish habitats and breeding grounds. For example, shrimp reproduce and develop in brackish water, which is a mixture of saltwater and freshwater. SLR will cause this interface to retreat, thereby changing the habitat of shrimp.

The rising sea level will also submerge coastal cities' houses, transportation systems, bridges, etc., causing huge economic losses. On a global scale, the proportion of land lost is relatively small. According to the study by Bosello F et al., Energy Exporting Countries (EEx) suffered the greatest losses, losing 0.18% of arable land, followed by Japan and the Rest of the World (RoW), which lost 0.15% of land. The loss caused purely in terms of numbers is relatively large, but compared to GDP, it appears to be very small. In terms of GDP, all regions globally have experienced a decline, especially China (0.030%), EEx (0.021%), and RoW (0.017%). Generally speaking, the direct losses in developing regions are higher than in developed countries, because their economies have a larger proportion of agriculture, with relatively higher land value. The GDP losses of EEx and RoW are lower than the direct costs of land loss, while the opposite is true for the United States, the European Union, Japan, and China. In the case of Japan, GDP losses are even 10 times higher than the direct costs of land.[25]

SLR has also caused various social problems. In Bangladesh, approximately 800 kilometers of roads, 28 kilometers of railways, 85 towns, and one port will be submerged due to topography and terrain reasons. The coastal embankments stretching over 4,200 kilometers and an area of 7,500 square kilometers of polders are also under threat[26]. SLR can cause large-scale population migration, which in turn can lead to group conflicts. There has been a long-standing conflict over the distribution of Ganges water between Bangladesh and India, and SLR will exacerbate the conflicts among these environmental refugees[27]. The island of Male in the Maldives is one of the most densely populated cities in the world. Due to population pressure and SLR, the Maldives has built a new island, Hulhumalé, on the adjacent reef near Male, and raised the island to more than 2 meters above the average sea level[28]. However, these policies have faced opposition from the residents of smaller and more remote islands, who believe that the policy "has destroyed the country's 3,000-year-old cultural identity and social structure"[28].

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IPCC CZMS conducted vulnerability assessment studies for 19 countries in 1992[29]. The results show that there are significant differences in the degree of impact among countries, but small islands, delta regions, and coastal ecosystems appear to be particularly vulnerable[29]. Due to limited surface area and scarce resources, small islands are usually vulnerable to the impact of SLR. Especially for South Asia, Southeast Asia, and East Asia, these densely populated delta regions. The small islands in the middle of the Pacific, Atlantic, and other regions such as the Mediterranean will also face serious ecological and social issues.

5. Targeted strategies for SLR

Hence humans not only need to control greenhouse gas emissions, but also need to take various measures such as developing clean energy, improving energy efficiency, protecting and restoring forests as carbon sinks, as well as researching and implementing carbon capture and storage technologies. Scientific evidence emphasizes the importance of global collaborative action, not only in reducing greenhouse gas emissions, but also in developing adaptive strategies for communities at risk. Different regions around the world have adopted different measures and policies to address SLR. In some European countries, coastal infrastructure has been planned for decades for SLR[31]. The Netherlands is under serious threat from SLR, with about 60% of the country's area and 10 million people in the affected area[32]. The new Dutch national law requires the maintenance of the current coastline position[33]. On the west coast of Africa, unlike Europe, the local area is relatively underdeveloped. Apart from the ports, there are limited coastal engineering projects, but the local population is still growing rapidly[34[35]. In Senegal, local coastal protection measures have been taken to eliminate most direct human impact. In Nigeria, most people are not affected, but 600,000 people living in the Niger Delta may need to relocate because without significant investment and the application of new technology, the local government cannot establish seawalls for protection. In Benin, it is feasible due to the low cost of coastal protection. For South Asia, Southeast Asia, and East Asia, these regions have conducted in-depth research on coastal protection and have established raised embankments. In order to prevent land from being flooded and unable to grow food crops, China has developed rice that can grow in seawater environments. For islands in the Pacific Ocean, due to their small size and few highlands, many coastal residents live by the sea and reclaim land from the sea, and they also cut down coral reefs and mangroves. The local response to SLR typically focuses on planned coastal evacuation and the construction of coastal protection facilities[36]. However, for some islands in atoll environments, the options are very limited, and the possibility of abandoning the islands in the face of SLR is high. For Pacific islands, regional cooperation is crucial in developing vulnerability assessments and response strategies because these issues are highly common and many countries are too small to address them individually[24].

There are significant differences in future SLR in different regions under the background of climate warming. When analyzing the effect of human-enhanced greenhouse effect on sea level, this factor also needs to be taken into consideration. Due to the existence of some commonalities within each region, it is worthwhile for regions to cooperate and coordinate vulnerability assessments, and jointly develop comprehensive response measures[24]. If the boundaries at the national level are blurred on this issue, the formulated solutions will be more effective. For small island countries, regional cooperation is crucial[24].

6. Conclusion

The current trend of climate warming is severe. In a predicted scenario, the best case scenario is that the temperature may rise by 0.3 degrees within 100 years, while the worst case scenario is that the temperature may rise by 4.8 degrees. However, even in the most optimistic scenario, the current

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situation of SLR will continue until 2100, causing severe disasters to coastal deltas and islands, but inland countries cannot be immune. Many countries are facing problems such as coastal ecological damage, threatened biodiversity, land submergence, severe GDP losses, large-scale population relocation, and social conflicts. In different regions, multiple countries have adopted different strategies. Developed countries often use methods that require large economic investment, such as building sea dikes and land reclamation, while developing countries and some small countries can only afford to take on higher risks and carry out large-scale relocations. When facing the disaster of SLR, economically backward countries appear extremely vulnerable. For them, facing it alone is the most difficult choice. Coming together, cooperating with each other, and seeking technical assistance from major countries is the correct way out. So in the face of rising sea levels, what is needed is the establishment of regional joint organizations, with multiple countries participating in the formulation of policies and the construction of protective facilities. Small countries and developing countries should learn from developed countries' technology and seek assistance. Only by uniting can we minimize the disaster.

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