

Mechanisms and Modeling of Sea Level Rise in the Context of Global Warming

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Abstract: Sea level rise due to global warming is an important topic in current climate change research. In this study, we explore how complex natural processes triggered by global warming drive sea level change by analyzing climate models. We focus on the main drivers of sea level rise, including ice sheet melting and ocean thermal expansion. In addition, the article discusses in detail how positive feedback mechanisms and negative feedback mechanisms work together to influence the climate change process. In order to predict the future trend of sea level rise, this article models and simulates the global temperature, glacier changes and ocean dynamics based on the General Circulation Model (GCM). Although the model has some uncertainties, especially in cloud feedback and data completeness, it still provides a valuable predictive tool for understanding future sea level changes. The conclusions of this study point to the possibility of accelerated sea level rise as global temperatures continue to rise, with wide-ranging and far-reaching impacts on coastal ecosystems and human societies around the globe.

Keywords: Sea Level Rise, Climate Feedback Mechanisms, General Circulation Models (GCMs).

1. Introduction

Sea level rise refers to the continued rise in global ocean water levels caused by climate change. It includes both global mean sea level changes and regional sea level changes. As one of the major consequences of climate change, it threatens the lives and livelihoods of millions of coastal residents around the world [1]. In addition, human society developed under a situation with a stable sea level, which is increasing rapidly now [2]. According to some researchers lead by Church using climate model estimation based on physical principles, the increase rate of sea level will almost certainly become higher in the future [2]. There is a possibility that the land ice in the Arctic region is likely to continually melt if ocean temperature and air temperature become warmer due to constant global warming in the future [1]. The result of such a ice melting is that global sea levels will increase up to 3 meters per year, and then many coastal areas will be inundated, even submerged, which will hamper economic development of many developing countries [3]. Under these circumstances, more greenhouse gases will be released from melting ice, probably exacerbating global warming [3]. Understanding the causes, mechanisms and future trends of sea level rise is crucial to developing effective response policies. Previous researches and articles lack a comprehensive description of the mechanisms behind sea level changes caused by global warming. This paper states both positive and

negative feedback mechanisms that exacerbate perturbation of global warming or dampen it, and the factors causing sea level rise are referred, like the finding that major volcano eruption cause temporary global mean sea level small reduction, related to global warming behind increased sea level [4]. Also, there are some predictions of future sea level changes based on climate models which consider greenhouse gas emission, ocean thermal expansion and ice melting in it. It is also valuable to notice the limitations of climate models and understand the rationale behind the climate model. For example, the older data collected from tide gauges in about 200 countries is incomplete, which cannot be used for long-term sea-level studies [4]. This article aims to comprehensively explore how global warming leads to sea level rise through a series of complex natural processes, and by analyzing existing prediction climate models, discuss the possible scope of future sea level rise and its impact on global ecosystems and human society.

2. Overview of the feedback mechanisms that influence global warming

Feedback mechanisms: It is admitted that human should be responsible for a large part of global warming. Since the Industrial Revolution, atmospheric carbon dioxide concentrations have risen from about 280 ppm to over 400 ppm [5]. This phenomenon caused the greenhouse effect: greenhouse gases in the atmosphere cause the Earth's surface temperature to rise by absorbing and reradiating heat from the surface. Increased concentrations of greenhouse gases such as carbon dioxide, methane and nitrous oxide directly contribute to rising global temperatures. At the same time, other human drivers (mostly aerosol) cause climate cooling, but the main tendency is still global warming [6]. The intensification of global warming has driven many changes in the climate system: 1) frequent extreme weather 2) change in precipitation 3) decrease in snow and ice extent 4) sea level rise [7]. Some phenomena in the global warming process will further exacerbate the temperature rise, which are called positive feedback mechanisms. First, after the glaciers melt, the oceans and land are exposed, absorbing more solar energy. Second, evaporation happens more frequently along with an increase in global temperature. Consequently, the water vapor feedback come into being as atmospheric temperature increases. The water vapor belongs to greenhouse gas, absorbing more radiation emitted by the ground [7]. Third, the ice-albedo feedback occurs as more ice and snow melt due to global warming. More bare ground will make the earth darker, then easier to absorb solar radiation [7]. The land ice in Arctic region is likely to continually melt according to estimation [1]. Under this circumstance, global temperature will continually increase, letting more ice and snow melt. Forth, the precipitation-runoff feedback occurs along with increased global temperature. The intensified precipitation induced by global warming will in turn decrease soil moisture [7]. Fifth, the heat storage feedback is related to current heat distribution and the rate at which ocean release and absorb the heat. Oppositely, some negative feedback mechanisms, like increased cloud cover or changes in vegetation growth may slow global warming, can mitigate negative effects of positive feedback mechanisms. The increased cloud cover can reflect solar radiation, and it will influence ice-albedo feedback, a kind of positive feedback [7]. Thus, the cloud feedback is hard to be totally understand while researchers define it as a kind of negative feedback. Actually, the cloud feedback also has something to do with the water vapor feedback [8]. The water vapor lays the foundation for the formation of clouds. Besides, it is hard to solely consider cloud feedback; rather, it is interdependent to other several feedback [8]. It seems that the cloud feedback control the response of hydrological cycle to climate changes [8]. Some intercomparison studies find that cloud feedbacks give rise to uncertainty of climate sensitivity (the extent to which rise in greenhouse gas concentration will affect earth's temperature) to a large extent [9]. However, the overall feedback is still mainly positive, which can be seen in the estimation of future climate: the atmosphere temperature at least increase by roughly 0.5 centigrade [7]. These feedback mechanisms work together to complicate predictions of the impacts of global warming, especially for the efficiency of clouds feedback.

Climate Model: For the climate model, General Circulation Models (or GCMs) are a kind of advanced numerical model simulating climate changes in response to change of greenhouse gas concentration [9]. It models physical process, simulating the interaction between the atmosphere, ocean, glacier and land [7]. The output set in the modeling is mostly assumed to be global mean surface temperature [8]. Sometimes used in conjunction with nested regional models, GCMs can provide essential estimation for impact analysis [9]. Nevertheless, the GCMs have some drawbacks. First, its overall layout is set on the globe, which means that it can't precisely model some physical process related to clouds, which causes uncertainty of results. [9] Second, the difference in process in which the feedbacks and certain physical processes are model can possibly lead to distinction in results from GCMs [9]. Third, the GCMs are models used in feedback diagnostic analysis, and it is inconsequential if the models are not tied to observational data [8]. As for the models, the coincidence of modeled climate system to the reality are difficult to be testified, which cause uncertainty [8]. There is a noticeable thing about feedback mechanisms in the climate model. The additivity and independence of climate model has been proved by Mauristen and his co-author, whose research also shows unconventional synergies of cloud feedback and water vapor feedback to the climate sensitivity [10]. The cloud feedback has no influence on the global mean surface temperature alone, but it in conjunction with water vapor increases climate sensitivity while other synergies has barely influence on the global climate [10].

3. Global warming contributes to sea level rise through several mechanisms

The global warming triggers changes in several factors leading to sea level rise. First, the ocean has a large heat capacity, causing a delay for the ocean to get into its equilibrium state after the stabilization of greenhouse gas concentration [1]. According to the lag, it is a widely held view that global mean sea level will rise for several centuries after global greenhouse gas concentrations has stabilized [1]. Then it can be concluded that the increase rate of sea level could be even higher in the future as a reaction to the contemporary global warming, even if the greenhouse gas emission will decrease significantly in the future [11]. Second, the ocean thermal expansion will arise sea level increase due to a physical trait of water: the water density will decrease as water temperature become higher, and its volume will increase with the same mass. As a result, the thermal expansion can contribute up to 30 percent of sea level rise [4]. It is noticeable that the disproportionate thermal expansion also cause striking regional sea-level changes [4]. Nevertheless, regional sea level changes caused by thermal expansion have no influence on global mean sea level [1]. Third, the ice-melting induced by global warming also contributes to the global mean sea level increase. It is reported that Ocean thermal expansion, glaciers, ice sheets in Greenland and Antarctica respectively contribute 42 %, 21 %, 15 % and 8 % to the global mean sea level over the 1993-2018 period [12]. Besides, there are other factors influencing sea level increase. For example, the terrestrial water balance is influenced by anthropogenic activities, which affects water exchange between land, atmosphere and ocean [12]. The water exchange fluctuation, including run-off, influences global mean sea level. Thus, anthropogenic activities are also conducive to sea level increase.

3.1. Estimation based on modeling

As for modeling future sea level increase, there are two kinds of model. The first kind of model simulate physical process of different contributors to forecasts sea level increase. The GCM (General Circulation Model) is a good example. Another example is the GHM (Global Hydrological Model). The GHM is used to estimate global land water storage, which is a key part for land-ocean-atmosphere water exchange [12]. The second kind of model compensate for weakness in the first kind of model that it underestimates sea level increase in some cases. Accordingly, the second kind of model use

collected past data to get semiempirical relationship describing extent to which global mean sea level will react to climate change, and then use the relationship to approximate the future sea level increase. Both kind of model use computer to simulate. However, there are several limitations for the climate model, including data incompleteness, uncertainties of the model and model deficiencies. There are huge data gaps for data collecting from tide gauges in several countries [4]. Under this circumstance, there are only a few data available for long-term sea level simulation [4]. The second limitation, difference in estimation, is caused by different treatment toward same physical processes and different datasets gotten by researchers [12]. The third limitation is common, which can be seen in the total opposite estimation error due to deficiencies of global hydrological model, and the imprecise general circulation model for cloud analysis due to the way in which it is constructed (it has been explained in part 2) [12].

3.2. IPCC

Created for a summary report about climate change given to governments of 195 Member countries about estimation and observation of sea level conducted by scientists, Intergovernmental Panel on Climate Change aim to be neutral and authoritative. It doesn't conduct research, but IPCC selects scientists to ensure authenticity and objectivity of the data and estimation [13]. The United Nations Intergovernmental Panel on Climate Change (IPCC) regularly releases reports forecasting sea level rise several years or decades later, providing a variety of possible sea level change paths based on different emission scenarios [13].

3.3. Forecasts under different scenarios

Greenhouse concentration scenarios: Based on greenhouse gas emission pathways (representative concentration pathways, RCP and share socioeconomic pathways, SSP), the IPCC predicts sea level rise under different greenhouse gas emission scenarios. The SSP include more greenhouse gas and air pollutant futures than RCP, considering future socioeconomic trends and covering more effective radiative forcing [6]. There are some recent projections, according to IPCC report in 2021, under SSP 5-8.5 (high emissions scenario), global mean sea level possibly rise by 0.63-1.01 by 2100, while under SSP 1-1.9 (low emissions scenario), the rise could be only 0.28-0.55 m [14]. Besides, IPCC report in 2013 adapts RCP scenarios, estimating sea level increased by 0.44[0.28-0.61] m under RCP 2.6 and 0.74[0.53-0.98] m under RCP 8.5 [2].

3.4. Time scale

Forecasts are divided into short-term (to 2050) and long-term (to 2100 and beyond). Estimation are more accurate over the short term, while uncertainty is higher over the long term. Future greenhouse emissions policies, mitigation policies and global warming trends will greatly influence the magnitude of long-term sea level rise, all of which are related to greenhouse gas emission in the future. Also, the time which it costs to get to different kinds of global mean sea level estimated under different scenarios is uncertain, and this is likely a crucial factor needed to be considered for future adaptation policy [14].

4. Conclusion

SecRising sea levels due to global warming is an important consequence of climate change. It is driven by a variety of complex mechanisms, such as thermal expansion of the ocean, melting ice caps, groundwater extraction and cloud-vapor interaction. As global greenhouse gas emissions continue, sea level rise is likely to increase in the future. This article summarize several feedback mechanisms

of global warming and contributors to sea level change, explaining climate model and pointing several drawbacks. At the same time, this article do not claim some intricate relationship between each feedback and more complicated modeling treatment. Further research is needed on the long-term effects of ocean heat absorption, the rate at which ice sheets melt and a more thorough description of several model. In addition, a clearer understanding of climate processes and physical processes of contributors to the sea level increase is essential for more accurate estimation of sea level increase and climate change. More accurate climate models need to be developed to provide more reliable predictions based on the more comprehensive recognition of the contributors to sea level changes, subsections and subsubsections.

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