Predicting and responding to sea level rise in the coming decades

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Abstract

This paper explores the impact of rising global temperature on the melting of ice floes and ice sheets in the Arctic Ocean, Greenland and Antarctic. This paper notes that the current understanding of the impact of climate change on Arctic, Greenland and Antarctic ice floes and ice sheets may be significantly underestimated. This article presents evidence from three aspects. The first is the rate of global temperature rise after the end of the last glacial maximum, which is now 10 times faster than after the end of the last glacial maximum. This also means that the current rate of sea level rise will also be likely to be 10 times faster than the rate of sea level rise at that time. The second piece of evidence is the analysis and fitting of curves from the available observation data, and many of the polynomial formulas that fit the curves show that the magnitude of sea level rise due to global climate change is accelerating. Some results suggest that global sea levels are likely to rise to around 10 meters by about 2050. The third piece of evidence is the very simple model of the impact of rising global temperature on Arctic Greenland and Antarctic ice floes and ice sheets. The model's estimates also suggest that global sea level will rise by about 7 meters by about 2050 due to the dissolution of the Antarctic and Greenland ice sheets. In any case, this evidence suggests that the magnitude of sea level rise in the coming decades will be enormous, and this will certainly affect the development of human society. Therefore, this article calls on countries around the world to take proactive measures to respond to this rapid sea level rise as soon as possible. These responses may include, but are not limited to, large-scale population migrations, the construction of coastal dams, and more. Given the drawn-up to rapid global sea level rise, especially in countries like China and the United States, coastal dam construction should begin planning and pre-construction work now.

Content

1 Introduction

Climate warming is a global problem. In fact, global warming will eventually affect everyone's life. Is the global climate really warming? There has been a lot of discussion in the past few decades, but in recent years, the general public has begun to pay attention to this issue as temperature records continue to be broken in some regions.

Although the evidence for global warming is abundant, the current focus is on what level of global warming will affect human life. This is worth exploring. Some people feel that the global temperature rise will have little impact on human society, and even some well-known people, such as former US President Donald Trump, believe that it will take 497 years to rise one-eighth of an inch [1]. These extreme weather events even include the issue of rising sea levels, which do not seem to be very serious at the moment. For example, since the Industrial Revolution, although the current temperature has risen by 1.5°C compared to 1910, the sea level has risen by less than 30 cm [2], which has had a very slight impact on many countries. Therefore, many people, many governments, do not pay enough attention to this, thinking that at least in their lifetime and the expected term of government, global warming will not affect the stability and development of most countries and regions. Even if an international organization such as the IMF is willing to take the lead in organizing the participation of countries around the world to jointly solve the problem of global warming, the specific implementation of policies is indeed very unsatisfactory, and the enthusiasm of countries to participate is not very high [3,4].

Other views are held by scholars working on climate change. Current projections through scientific instrumentation and the construction of new theoretical models have shown that the current rate of climate warming is unprecedented [5]. Many authors also discuss the impact of such rapid change on the global climate as a whole, as well as the impact of sea level rise. For example, some authors have discussed the dissolution of glaciers in the Himalayas in Asia when global temperatures rise to 1.5 degrees Celsius [6]. Other authors discuss the need to limit the rise of global warming to 1.5°C [7]. It can be seen from this that there is basically a consensus in the academic community on controlling the rise of global temperatures. Other studies suggest that global sea levels will rise by 1.4m after 2150 [8]. Of course, such a temperature increase also seems to have a relatively small impact on the survival and development of human beings. At present, there seems to be no urgency to respond positively. After all, a sea level rise of about 1 meter will affect coastal cities at most. In fact, the construction of a small number of dikes and so on is sufficient. But now it seems that these are still a serious underestimation of the impact of climate change on human society.

At present, with the development of satellite measurement technology, there are relatively accurate data on the rise of global sea level. From the results of these data, it is very certain that sea level rise is accelerating. According to some studies, sea levels have risen by nearly 30 centimeters in more than 100 years. There are many factors contributing to sea level rise. Current evidence suggests that sea level rise is largely linked to global temperature rise.

Of course, this rate of increase does not seem to be very large at the moment, and it does not seem to have much impact on some cities. Sea levels have risen by nearly 30 centimeters, which seems to be within the normal range of fluctuations compared to the past few thousand years. However, these two facts should be given our due attention, including:

1. The rate of global sea level rise is accelerating. And it is already evident from the available data. This suggests that the rate of global climate change has reached a level that can be directly felt by human sensory organs, rather than a planetary motion that lasts for a long time.

2. The rise in global temperatures is unprecedented. It has been shown that for every degree of increase in global average temperature over the past 20,000 years, the corresponding rise in sea level is about 10 meters [9]. It means that global temperatures have risen by nearly 1.5°C over the past 100 years, and if maintained, it is believed that such temperatures could lead to a 15-meter rise in sea levels. This is a very large increase and will directly affect most coastal cities.

Our research shows that the effects of climate change seem to be even more severe. Our research shows that the global sea level will rise by about 1 m in the next 20 years or so. Of course, such a rise is only a warning to human society, that is, we can start to do more to prepare for the future of even greater sea level rise. In addition, the credibility of our study is relatively high. We look at from three different aspects of the impact of climate change on global sea level rise. First, we estimate the potential sea level rise of about 100 m over the 7,000 years after the end of the last glacial period [5, 9] to estimate the potential sea level rise of the current rapid rise in global temperatures. In the second aspect, we analyze the existing observation data and then construct a polynomial function in order to fit the existing data to the greatest extent possible, and make predictions about the future trend of these data. Finally, we theoretically analyze the impact of global warming on the dissolution of the Greenland and Antarctic ice sheet. After all, the current dissolution of the Greenland and Antarctic ice sheets will cause the global sea level to rise by about 70m. This would be a very large sea level rise. In addition, the model we construct during theoretical calculations is as simple as possible. It is precisely because of such a simple model that we can get closer to the essence of the problem, and at the same time, it also helps us to expand the whole model and find and solve the problems in the model in time. The analysis of these three aspects basically leads to a relatively consistent conclusion, that is, the sea level will rise by about 10m in the next few decades. In the next 20 years, the rise in sea level will accelerate after reaching 1 m.

2 The current sea level rise can be inferred from the rise in sea level after the end of the Last Glacial Maximum

The Last Glacial Maximum occurred about 19,000 years ago, when the sea level was about 80-120m lower than it is today. The end of the last glacial period was about 11,700 years ago, that is, it lasted for more than 7,000 years. In those 7,000 years, global temperatures have risen by about eight degrees Celsius. This allows us to estimate that sea levels will rise by more than $1m$ over a period of 100 years. However, the situation is very different now, and since the Industrial Revolution, the global temperature rise has reached nearly 1.5°C.

According to the findings of Osman, Denton et al. [5,9], the global temperature and sea level changes have been relatively flat for more than 20,000 years, but in the past 100 years, that is, since the Industrial Revolution, the global temperature has suddenly risen sharply by nearly 1.5°C, and such a large temperature increase actually corresponds to the temperature increase more than 1000 years after the end of the Last Glacial Maximum. In other words, temperatures are rising at least 10 times faster than they have since the end of the Last Glacial Maximum. If we take into account the rise in sea level caused by the rise in atmospheric temperature over the past 100 years, which can be approximated linearly for the entire physical law, it means that the current sea level rise rate will be 10 times higher than the sea level rise after the end of the Last Glacial Maximum. This means that if the sea level rises by more than 1 meter every 100 years in the last glacial period, then at the rate of global temperature rise since the Industrial Revolution, sea levels should now rise by more than 1 meter every 10 years and by more than 10 meters every 100 years. Of course, the very complex interaction between the Greenland and Antarctic ice sheets and global temperatures means that the rate of increase will be slower in some years over the course of the century. The slower rate of rise does not mean that these ice sheets, which have less melt, will not be compensated for in the future. Conversely, uneven rates of sea-level rise can lead to more dramatic changes in climate and geology.

3 Trend analysis with historical data

Based on the observed data that we have already obtained, we can fit the curve and derive the function of the curve. This allows us to predict the rate of sea level rise over a number of years in the future.

However, this fitting is not based on any physical laws, so the fitted curve is greatly affected by small changes or errors in the data. In order to make the curve fit data more in line with the realistic trend, we should pay attention to the following: first, use as many polynomial terms as possible, so as to describe the law of the data more accurately. The second is that the direction of growth should be monotonous, and there should be no sudden and large inflection points. After all, we don't have any physical laws that can explain the existence of such an inflection point.

Figure 1 is a sea level rising trend curve based on data from Frederikse et al. after 1968 [10]. Here, Excel was used for the fitting of the curves. Since we didn't model the data, we used polynomials to fit the curves. The advantage of this fitting method is that it can not rely on any theoretical model, but its disadvantage is also obvious, that is, it is easily affected by some small changes in the data. The polynomial is

$$y = 6 \times 10^{-6} x^5 - 0.0618 x^4 + 246.11 x^3 - 490008 x^2 + 5 \times 10^8 x - 2 \times 10^{11}$$

The fitted curve is shown in Figure 1. And we use Excel to predict the future trend.

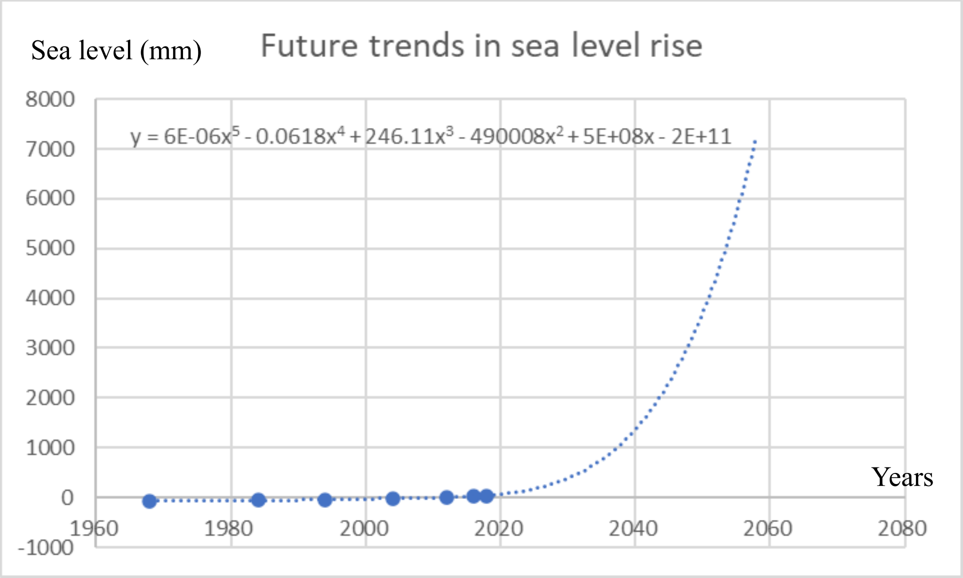

Fig. 1

As can be seen from Fig. 1, sea level rise will reach more than 1 meter by about 2040. By 2060, sea levels will rise by more than eight meters. And show an accelerated upward trend.

Of course, in addition to the above polynomials, we can use Excel to combine many other polynomial curves. If the number of terms in the polynomial is small, the curve is closer to a straight line. Therefore, when fitting curves, polynomial functions with a large number of terms should be used as much as possible. However, if the polynomial is not suitable, a large turn in the curve may occur. This should be contrary to the physical laws of our actual sea level rise.

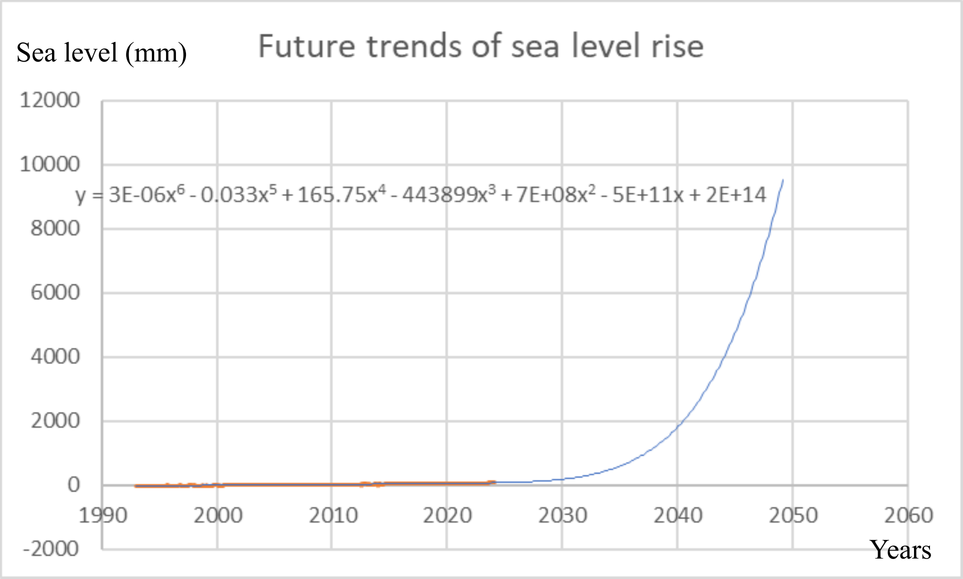

Fig. 2

Fig. 2 is a simulation of the data observed by NASA [2]. From the fitting curve in Fig. 2, we can see that the results are similar to the curve in Fig. 1. However, due to the large number of data, the error between the data will also obviously affect the prediction of the future trend of the entire curve. When the number of terms of the polynomial is relatively small, the curve of the fit is close to a straight line, and the rise is relatively small. In the fitting polynomial formula, the number of terms of the polynomial increases to five, and the abrupt turn of the curve begins to appear, such an inflection point should not be in line with the actual physical laws of sea level change, unless there is a special mechanism that causes a sudden and massive loss of seawater. However, according to our observations, there should be no such physical mechanism on Earth that causes a large loss of seawater.

In the absence of a suitable physical model, the problem of directly using existing data for fitting is of course obvious. After all, the computer doesn't know what the data means, and the fitting curve given can only roughly reflect some kind of future trend. Therefore, a more accurate approach is to build a model that conforms to physical laws of change, so as to truly reflect the actual trend of sea level rise.

4 Models of ice floes and ice sheet dissolution

4.1 Establishment of the model

The main reason for this model is to describe the tendency of the Earth's North and South pole ice floes and ice sheets to dissolve in a very simplified form. Considering that the thermodynamic mechanisms by which the ice floes and ice sheets of the entire Earth interact with other Earth's materials, etc., are so complex, very complex differential equation models may be required to describe them. The advantage of this sophisticated model is that it is possible to detail the impact of every tiny factor on the ice sheet. For example, the change of salt concentration of seawater caused by the freezing and dissolution of ice floe on the sea surface, and the change of salt concentration affects the change of temperature gradient in seawater. However, this kind of detailed description can easily lead us to pay too much attention to detail and ignore the changes at the macro level. Unlike today's geophysics, which is mainly about the fine structure of the earth, global warming is a much more macro problem. At a very macro level, if there are too many details involved, like when we use Newton's laws, you also have to consider what shape the wave function of the electron is, which can make the whole problem very complicated.

Therefore, the model used in this article will be kept as simple as possible. The advantage of a simple model is that it allows us to address climate change at a much macro level.

Of course, the simpler model also means that our model is more scalable, which means that if we find that there are various fine structure problems involved in the earth's climate change in the research process, then we can use the macro effects generated by these fine structures to make appropriate modifications to the model, so that the conclusions drawn by the model can better describe the real problems. It's like the tunneling effect of quantum mechanics, and the macroscopic effects it produces allow us to make macroscopic instruments like the Josephson interferometer.

Of course, a simple model has the advantage of being easy to modify. In other words, when we use such a simple model to solve a problem, we can easily find the problem when we encounter trouble. For example, in this model, we currently ignore the heating effect of seawater and rocks on ice floes or ice sheets. In the future, if there is sufficient evidence to prove that the heating effect of seawater or rocks on ice floes or ice sheets is very significant, then it is sufficient to add two factors: seawater and rocks to this model.

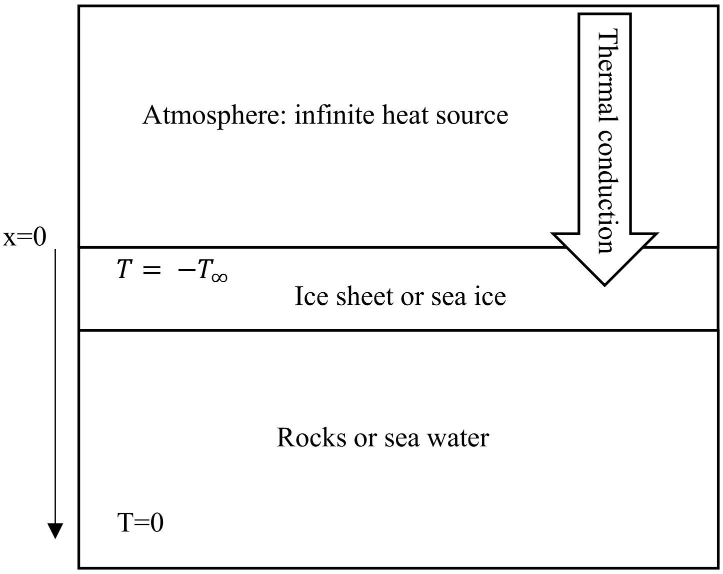

Fig. 3

The structure of the whole model is shown in Figure 3, where we can see that the atmosphere acts as an infinite heat source to provide persistent heat to the Arctic ice floes or ice sheets. The effect of this infinite heat source means that the heating of the ice floes and ice sheets in the Arctic and Antarctic will not cause the temperature of the atmosphere to drop significantly. Of course, this is a more idealistic state. Because when the global temperature rise is not very large, the ice floes or ice sheets of the Arctic and Antarctic can adjust the global climate appropriately. In other words, when global temperatures rise, the cooling effect of the Arctic and Antarctic ice floes and sheets can keep the global temperature at the right temperature. This may also be the reason why the global temperature did not rise significantly in the early days after the start of the Industrial Revolution. However, if we stretch the time span very long, to decades or even hundreds of years, then the temperature of the atmosphere will always maintain an upward trend due to the continuous heating of the atmosphere and the greenhouse effect of carbon dioxide, and it will be difficult to reverse it in a short time. The dissolution of ice floes and sheets is relatively disposable, which is why we can think of the entire global atmosphere as an infinite source of heat.

In this model, we ignore the heating effect of the sea water or rocks below the ice floes or ice sheets. Through calculations, we can find that the thermal conductivity of seawater or rock is very large, about 10-50 times that of air. In other words, the temperature is easily maintained in the atmosphere. However, if this temperature is absorbed by the ice floes or ice sheets, the heat is quickly transferred to the seawater or rocks. These seawater or rocks are connected to the sphere of the whole earth. The size of the Earth is very large, so even a 3°C increase in global temperature will not cause a significant increase in the temperature of the entire Earth's sphere. So we can think of the seawater and rocks on Earth as a thermostat. In other words, its temperature is largely unaffected by the rise in global climate temperatures. Of course, there is already evidence that the average global sea temperature is also rising rapidly. Without a continuous supply of heat and the effects of atmospheric greenhouse gases, this rise is likely to be short-lived. If there is not enough heat supply, then the heat of the seawater will spread out through the rocks on the seabed, eventually lowering the temperature of the seawater. Of course, the thermal conductivity of seawater is somewhat smaller than that of rock. The thermal conductivity of rocks is about three to four times that of seawater, which means that the temperature in seawater can be maintained for a relatively long time.

Therefore, the rise in the temperature of the seawater, especially the Arctic seawater covered by ice floe, absorbs less energy from the sun, and we think it is a passive warming process. It must heat up more slowly than the ice floes. Under conditions where there is not enough sunlight in the Arctic and Antarctic, the effect of sunlight heating the seawater will be much less. At this time, the heat in the atmosphere is mainly used to heat the Arctic ice floes by means of heat transfer, and then transfer this heat to the sea water below the ice floes.

From the results of the following calculations, we can see that such an estimate is basically reasonable.

With such a simplified model, it is easier to calculate the impact of global atmospheric warming on the melting of ice floes and ice sheets in the Arctic, Greenland and Antarctic. The fluidity of the atmosphere under consideration is very strong, so the way the atmosphere transfers heat to the ice floe and ice sheet is mainly convection. Here we can use Newton's laws of cooling to do the calculations. The parameters are also relatively easy to determine. For example, from some studies, we can find that the wind speed in the Arctic is generally about 10m/s, so the convective heat transfer coefficient can be determined to be $h = 37Wm^{-2}K^{-1}$. The thermal conductivity, specific heat capacity, and density of substances such as ice and air are all known, so the whole calculation process is very simple and straightforward. Let's start with an analysis of the dissolution of Arctic ice floe. The results of the calculations are basically consistent with the actual observations. This also verifies the correctness of this model to a certain extent. Then we applied this model to the dissolution of the ice sheets in Greenland and Antarctica. Estimate the rate of dissolution of the Greenland and Antarctic ice sheets.

4.2 The rate at which Arctic ice floes dissolve

Judging from the dissolution of Arctic ice floe, in 1988 the area of Arctic ice floes over four years old reached A=3.12 million square kilometers. By 2019, the area of ice floes with a life span of more than four years was only 89,000 square kilometers [11]. In other words, more than 3 million square kilometers of Arctic ice floes that are more than four years old have dissolved in 31 years. Calculated on the basis of the ice thickness of 4 meters, the mass of dissolved ice floe is reached

$$M = 3 \times 10^{12} \times 4 \times 1000 = 1.2 \times 10^{16}(kg)$$

We can estimate the amount of heat required to dissolve these ice floes. Taking into account the heat of dissolution of ice: $H_{of} = 3.341 \times 10^{5} J/kg$

The heat needed is $Q_{of} = MH_{of} = 1.2 \times 10^{16} \times 3.341 \times 10^{5} = 4.0 \times 10^{21}(J)$

The amount of heat from atmospheric convective heat transfer can be estimated using Newton's law of cooling

$$\frac{dQ}{dt} = hA\Delta T$$

Since the Arctic wind speed can generally reach 10m/s, a relatively large air convection heat transfer coefficient $h = 37Wm^{-2}K^{-1}$ can be used.

In this way, the time required to dissolve these masses of ice floes under the condition of global atmospheric warming ΔT = 1.5°C is

$$\Delta t = \frac{Q_{of}}{hA\Delta T} = \frac{4.0 \times 10^{21}}{37 \times 1.5 \times 3 \times 10^{12}} \approx 2.4 \times 10^{7}(s)$$

That is

$$\Delta t = 0.76(year)$$

Calculations show that at a 1.5°C global temperature rise, it would take less than a year to dissolve these ice floes. This is mainly due to the fact that the Arctic ice floe is very thin, many less than 4 meters. Therefore, the heat of the atmosphere is conducted not only to the interior of the ice floes, but also to the seawater and the interior of the seabed rocks below. This will consume most of the calories.

Below we can estimate the proportion of Arctic ice floes that absorb heat from the air. This can be calculated using the heat conduction formula.

First, let's list the heat conduction equation

$$\frac{dT}{dt} = a^2 \frac{d^2T}{dx^2}$$

As shown in Fig. 3, in order to facilitate the use of existing methods to solve this differential equation, at x=0, that is, the ice surface of the Arctic ice floe, we let the temperature $T(0,t) = -T_{\infty}$. So the temperature at infinity is 0, i.e. $T(x,t) = 0$, when t=0, $0 < x < \infty$, $T(x,0) = 0$.

It can be seen that this is a typical Cauchy problem of heat conduction, and there are corresponding solution steps. Although this equation is different from our actual Antarctic ice sheets and ice floes. But we're looking at the problem at a very macro level, so we can still use a rough approximation to estimate it. If we consider that the areas of Arctic and Antarctic ice floes or ice sheets are infinitely large, the temperature variation of these ice cubes can be approximated as a one-dimensional heat conduction problem along the direction of the thickness of the ice blocks.

This heat conduction equation can be solved

$$T(x,t) = -T_{\infty} erfc(\frac{x}{2a\sqrt{t}})$$

where *erfc* is the complementary error function and *erf* is an error function, and the relationship between them is

$$\mathrm{erf}(x) = \frac{2}{\sqrt{\pi}} \int_{0}^{x} e^{-u^2} du$$

while

$$erfc(x) = 1 - \mathrm{erf}\,(x)$$

and the thermal diffusivity coefficient *a*

$$a^2 = \frac{\kappa}{C\rho}$$

then

$$T(x,t) = -T_{\infty} erfc\left(\frac{x}{2a\sqrt{t}}\right) = -T_{\infty}\left[1 - erf\left(\frac{x}{2a\sqrt{t}}\right)\right]$$

so

$$\frac{dT}{dx} = T_{\infty}\frac{d}{dx}\mathrm{erf}\left(\frac{x}{2a\sqrt{t}}\right) = T_{\infty}\frac{2}{\sqrt{\pi}}\left(\frac{1}{2a\sqrt{t}}\right)e^{-\left(\frac{x}{2a\sqrt{t}}\right)^2}$$

It can be seen that the temperature gradient decreases rapidly over time. The greater the thermal conductivity, the smaller the temperature gradient will be. This means that the heat is transferred to the ice, the sea water and the rocks below, and the heat is quickly dispersed, leaving a very small percentage of the heat in the ice sheet.

If we ignore the difference in thermal conductivity of ice floes or ice sheets, seawater, and rocks, then the proportion of heat absorbed by the ice sheet or ice floes is

$$p = \frac{\int_0^h e^{-\left(\frac{x}{2a\sqrt{t}}\right)^2} dx}{\int_0^\infty e^{-\left(\frac{x}{2a\sqrt{t}}\right)^2} dx} = \frac{2\int_0^{\frac{h}{2a\sqrt{t}}} e^{-y^2} dy}{\sqrt{\pi}}$$

Follow the thermal conductivity of the ice $\kappa = 2.2W/mK$, and $\rho_{ice} = 1000kg/m^3$, $C_v = 2097J/kgK$. Then $a^2 \approx 1.05 \times 10^{-6}$.

If $x \approx 1000m$, , $t \approx 31year = 9.8 \times 10^8 s$, Ice floe thickness $l = 4m$

then

$$\frac{l}{2a\sqrt{t}} \approx 0.0625$$

It can be obtained using approximate or numerical calculations

$$p \approx 2 \times \frac{0.0625}{\sqrt{\pi}} \approx 0.07$$

As can be seen from the above calculations, the amount of heat left in the Arctic ice floes is about 7% of the total heat transferred by the atmosphere. This also means that it will take about 11 years to dissolve three million square kilometers of four-year-old Arctic ice floes, according to the formula above. Considering that the rise in global temperature since 1988 has been a relatively slow process. In 2020, the temperature rose by about 1.3°C, so it will take longer to dissolve these four-year-old ice floes. The results of this estimate are relatively close to the actual observations [11]. Therefore, the credibility of this model is relatively high.

In fact, from the above estimation process, we can also find that the heat transfer from the air to the ice floe is very shallow. In ice blocks that are about a few tens of meters thick, the heat transferred from the air has basically been absorbed by the ice.

4.3 Estimation of the rate of dissolution of the Greenland ice sheet

We can borrow the dissolution model of the Arctic Ocean ice floes to estimate the rate of dissolution of the Greenland ice sheet. This is because the Arctic ice floes are underneath seawater, while the Greenland ice sheet is rocky underneath. Except that seawater can flow and is therefore able to transfer heat by convection, the other properties are basically the same. In addition, considering that the Greenland ice sheet is more than 1,000 meters thick, it can be seen from the above estimates that the heat in the atmosphere is basically only consumed in the ice sheet, and is not transferred to the rocks below.

The amount of heat from atmospheric convective heat transfer can be estimated using Newton's law of cooling.

$$\frac{dQ}{dt} = hA\Delta T$$

Since the surface of the Greenland ice sheet is not completely flat, the actual surface area is A_s larger than that covered by the Greenland ice sheet. Take $A_s = 1.3A$. From the empirical formula of air convective heat transfer coefficient, we can obtain air convective heat transfer coefficient h=37. (Reference: https://www.engineeringtoolbox.com/convective-heat-transfer-d_430.html)

Among them, the Greenland ice sheet covers an area of $1.834 \times 10^{12} m^2$

Ice volume in Greenland is $2.75 \times 10^{15} m^3$

In this way, according to the global atmospheric warming of 1.5°C, the heat brought by the air can be reached

$$\frac{dQ_{air}}{dt} \approx 37 \times 1.3 \times 1.8 \times 10^{12} \times 1.5 \approx 1.3 \times 10^{14} (W)$$

Therefore

$$\Delta Q_{air} \approx 1.3 \times 10^{14} \Delta t$$

Considering that the total mass of the Greenland Ice Sheet is $M = 2.75 \times 10^{18}$, the time required to dissolve the entire Greenland Ice Sheet is

$$\Delta t = \frac{MH_{of}}{\Delta Q_{air}} = \frac{2.75 \times 10^{18} \times 3.341 \times 10^{5}}{1.3 \times 10^{14}} \approx 7.07 \times 10^{9}(s) \approx 224(years)$$

This seems to be a long time. However, considering that only 1/10 of Greenland's ice sheet can cause global sea level to rise by 0.7 meters, that is, Greenland's ice melt will cause global sea level to rise by about 0.7 meters in about 22 years. This also means that by around 2046, global sea levels could rise by nearly one meter since the Industrial Revolution as a result of Greenland's melting ice. This is a considerable increase. And we are not taking into account the possible exponential rise in global temperatures here. If global temperature rise accelerates in the future, it means that the Greenland ice sheet will dissolve faster. However, these estimates are based on a 1.5-degree rise in global temperatures, with the temperature difference between the atmosphere and the ice sheet remaining unchanged. But in fact, when the ice sheet dissolves to a certain extent, the temperature difference between the atmosphere and the ice sheet will gradually shrink and reach an equilibrium, at which time the ice sheet of the Arctic and Antarctic will no longer melt and grow, and the sea level will stabilize.

It is estimated that the resources occupied by humans in modern society are equivalent to those of two giant dinosaurs in the age of dinosaurs [12]. If this comparison is appropriate, it means that there are now more than 16 billion giant dinosaurs on the planet. This should be more than the number of dinosaurs during the peak period of the Dinosaur Age. The available archaeological evidence also shows that the global temperature rose by about 3°C during the age of the dinosaurs, and if the amount of resources occupied by humans far exceeds that of the dinosaurs, it means that the global temperature will rise by more than 3°C in the future.

4.4 Dissolution trends of the Antarctic ice sheet

The area of the Antarctic ice sheet $A = 1.24 \times 10^{13} m^2$, the total mass of the ice sheet is $2.45 \times 10^{19} kg$, and the global temperature warms by 1.5°C, taking $A_s = 1.3A$.. Take the air convective heat transfer coefficient $h = 37 W m^{-2} K^{-1}$, according to the above calculation formula, the annual heat conduction of the atmosphere to the ice sheet is

$$\frac{dQ_{air}}{dt} \approx 37 \times 1.3 \times 1.24 \times 10^{13} \times 1.5 \approx 8.95 \times 10^{14} (J)$$

The time it takes for the Antarctic ice sheet to dissolve completely

$$\Delta t = \frac{MH_{of}}{\Delta Q_{air}} = \frac{2.75 \times 10^{19} \times 3.341 \times 10^5}{8.95 \times 10^{14}} \approx 8.4 \times 10^{10} (s) \approx 266 (years)$$

Since the total dissolution of the Antarctic ice sheet can raise sea levels by about 60 meters, over a period of about 27 years, sea levels may rise by about 6 meters due to the dissolution of the Antarctic ice sheets.

Combined with the dissolution of Greenland's ice sheet and the dissolution of other continental glaciers, it is still very likely that global sea levels will rise by about 7 meters by about 2050.

Based on the rise in sea level after the end of the Last Glacial Maximum, a global temperature rise of 1.5 degrees means that the limit of sea level rise is about 15 meters. This means that when the global sea level reaches about 15m, the dissolution of the ice sheets in Greenland and Antarctica will reach a dynamic equilibrium, and excess meltwater will no longer be discharged into the ocean.

5 Response

According to our findings, the rise in global temperature has a very large impact on sea level rise. More importantly, the current rise in global temperature is caused by human activities, so it has a huge release of heat, a fast rise rate, and strong concealment at the beginning. In other words, because the global temperature is rising so fast, the ice sheets in the Greenland and Antarctic are unable to respond in time, which leads to a delayed effect of sea level rise. It is precisely because of this delay effect that it is easy to overlook the very serious consequences of rising global temperatures. As can be seen from the above analysis, if the global temperature rises by 1.5°C, then the Greenland and Antarctic ice sheets will melt by about 20 percent if the temperature rise can be maintained. This 20% or so of ice melt will cause the sea level to rise by more than 15m. This increase is staggering and catastrophic for some coastal cities and islands.

For example, for island countries such as the South Pacific, there are some countries with very low altitude and small area, and in the process of such a large sea level rise, the whole country may be submerged. There shouldn't be many ways to deal with it at the moment. Assuming that sea level is only a steady-state rise, then it is possible to consider evacuating the population to higher altitudes on the one hand. On the other hand, coastal dams could be considered. The dam doesn't need to be very high in the beginning, and as the sea level continues to rise, the height of the dam can follow suit. But if sea levels rise too quickly, this can easily lead to nonlinear changes in climate and ocean physics. For example, El Niño and so on are nonlinear climate changes. It can also cause catastrophic problems such as tsunamis. There must be a limit to what humanity can do to deal with these catastrophic problems. But whether the conclusions of this paper are correct or not, the acceleration of global warming and the acceleration of sea level rise is already a global change with very good evidence. Even if the rate at which sea levels rise by 1 meter every 100 years after the end of the Last Glacial Maximum, humanity should be well prepared to deal with the various disasters caused by sea level rise.

Specifically, along the coast of China, the middle and lower reaches of the Yangtze River Plain, as well as the North China Plain, their average altitude is very low. And we believe that in an earlier period, such as tens of millions of years ago, it was probably a sea. This means that when global temperatures rise high enough, the sea can completely inundate these areas. Now the development of science and technology has made it possible to artificially change this passive situation, for example, China can build a dam about 1 km wide along the entire coastline. Given that China had already successfully built the Great Wall during the Qin Dynasty, the construction of such a 10,000-mile-long dam would not be a huge problem with the support of modern technology. Judging from the current trend, we will have about twenty or thirty years to go. So it's time to at least start planning now, and if possible, it's best to build dams that can hold back a meter of sea level rise. In the future, as the sea level gradually rises, it will be possible to gradually raise the dam every year. It is believed that even if all the ice sheets in the North and South Poles are dissolved and the sea level rises by 70 or 80 meters, the Great Coastal Dam should be able to build up to 100 meters high, which is enough to cope with the extreme rise in sea level.

Of course, the amount of work in this project should be very large. First of all, the planning of the whole project requires a long enough time to invest a lot of manpower and material resources. Although we now have a lot of geological and hydrological data on China's coastal areas, these sites and hydrological data were not collected for the construction of such a very large dam project, so a lot of geological data needs to be recollected and explored. Once the entire dam has been planned, it can be constructed. The construction process is facing many problems. The first is whether there is enough construction team to build such a large dam. On the other hand, whether is there enough financial resources and technology to build a sufficiently strong dam? Therefore, it is indeed a very urgent matter to start preparing for this work now. Even very conservative estimates suggest that in about 100 years, with sea levels rising by only 1 meter, much of China's coastal areas will be submerged. Therefore, the construction of such dams is very necessary.

Of course, this coastal dam can actually have a lot of additional functions. For example, high-speed railways and highways can be built next to dams. This can also solve the problem of coastal land transportation in China or other countries and regions.

6 Conclusions

Available data confirm that global temperatures are now rising ten times faster than they have since the end of the Last Glacial Maximum. This also means that the rate of sea level rise could now also increase by a factor of 10. After the end of the Last Glacial Maximum, the sea level rise of 1 m every 100 years corresponds to the current sea level rise of 1 meter per 10 years. The rate of sea level rise is very fast. If a person's life expectancy is 80 years old, then he can see the entire sea level rise of 8 meters in his 80-year-old life. Surely why aren't we seeing such a large sea level rise now? In fact, available data suggest that the current rise in sea levels since the Industrial Revolution is only nearly 30 centimeters. This should have something to do with the thermodynamic mechanism of the Antarctic ice sheets. Because the Greenland and Antarctic ice sheet is very massive, a large part of the heat is used to raise the temperature of the Greenland and Antarctic ice sheet itself as the temperature rises. On the other hand, the rise in global temperature since the Industrial Revolution has been relatively stable, not suddenly rising to 1.5 degrees. This means that in the process of gradual accumulation of temperature, it will not be able to have a more serious impact on the

Greenland and Antarctic ice sheet immediately. On the contrary, the Antarctic ice floe and ice sheet can also regulate and stabilize the temperature of the global atmosphere to a certain extent. That's why sea levels aren't rising as fast at the moment. However, for some nonlinear physical phenomena, if certain critical points are breached, a very large and rapid sea level rise process may be imminent. Such a rapid rise in sea levels would be catastrophic.

From the estimates in this paper, it can be seen that at a global warming of nearly 1.5°C, it could melt away a tenth of the Greenland and Antarctic continental ice sheets in about a few decades. This rate of melting is at least ten times faster than the rate at which ice sheets dissolve after the end of the Last Glacial Maximum. Given the rapid rise in temperatures since the Industrial Revolution, this conclusion is reasonable.

Of course, there is a premise for this conclusion to be true, that is, if the global temperature in the next few decades can maintain the current 1.5°C increase compared to the pre-industrial revolution, according to the dissolution of the ice sheet during the last glacial period, the sea level corresponding to the limit dissolved ice will rise to about 15 meters and stop rising. However, in view of the current acceleration of the global temperature rise, it is believed that the global temperature will rise by more than 3 degrees Celsius in the future, which is also a very high probability. In this case, it is also possible that all the ice sheets in the Greenland and Antarctic will melt due to uncontrolled warming. Naturally, the challenges to human society will be greater.

Compared with other studies, the advantage of our model is that it is very simple, so it is easy to expand and check out the problems. Of course, this article only makes it clear that tackling the accelerating rise in sea levels is an urgent task facing humanity, and that we need to start acting now. This may involve very large migrations of people, or it may involve the construction of very large coastal dams. However, we believe that no matter which plan it is, it should reach the stage where it can be implemented immediately.

The shortcomings of this study are also obvious. The first shortcomings of this study are whether it is appropriate to compare the current rate of sea level rise with the amount of sea level rise after the end of the last glacial maximum. If there is a nonlinear relationship between the rise in global temperature and the rise in sea level, it may involve more complex physical laws. Secondly, the curve fitting is only based on the existing observation data, which is not supported by physical laws, and may be quite different from the actual situation. Finally, there are more complex factors that cause sea level rise, leading to a more severe impact on simple models of ice floes and ice sheets in the Arctic and Antarctic sea and lands.

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