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Explore the factors of global mean temperature change

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Abstract:

Global warming, driven by human-induced greenhouse gas emissions and natural factors, poses a significant threat to ecosystems and human societies, necessitating a comprehensive understanding of its causes to inform effective mitigation strategies. This paper addresses the knowledge gap by providing a holistic analysis of both natural and human contributors to the global temperature rise. This paper summarizes the effects of natural forcing and human activities on global mean temperature. The research results show that fluctuations in global temperature are largely influenced by solar activity, volcanic forcing, and human-induced CO_2 emissions. Although volcanic and solar activity has different effects on climate, human action—especially the use of fossil fuels—is one of the main causes of global warming. Land degradation and desertification speed up climate change, and land use changes also have a significant impact on carbon emissions and climate control. The above factors together act on the change of global mean temperature, and further research can be conducted to more accurately understand and predict the future trend of climate change and find ways to mitigate global warming.

Keywords: Climate change; Global warming; Carbon dioxide.

1. Introduction

Global warming is the phenomenon of the Earth's surface temperature rising over time, mainly due to increased emissions of greenhouse gases such as carbon dioxide (CO_2), methane (CH_4) and nitrogen oxides caused by human activities. These gases create a layer of insulation in the atmosphere that prevents the heat that the sun radiates to the Earth's surface from being effectively lost to space, causing global temperatures to rise.

Global warming is one of the most severe environmental challenges facing human society today and in the future. The effects of global warming are widespread, including an increase in the frequency and intensity of extreme weather events, the elevation of sea levels, the decline in biodiversity, and the adverse birth [1].

According to IPCC, 2023, the global surface temperature was 1.09 °C higher in 2011–2020 than in

1850–1900, with larger increases over land (1.59 °C) than over the ocean (0.88 °C), and they are projected to continue warming over the next two decades when they will be 1.5 ° C above pre-industrial levels [2]. A significant portion of this temperature increase is attributed to global warming.

The current research dedicated to understanding the factors that contribute to the alarming trend of global warming is indeed vast and continues to expand annually, while the majority of existing studies have placed a significant emphasis on human activities, particularly the emission of greenhouse gases such as carbon dioxide, and their profound effects on global temperature and climate patterns. Despite the extensive analysis, there is a notable gap in the form of a comprehensive synthesis that encompasses all aspects of this critical issue. There is insufficient discussion regarding natural factors, such as solar radiation, volcanic activities, and other geological processes.

This paper aims to analyze and discuss the various elements responsible for the rise in global mean temperature. The factors contributing to this critical environmental issue are roughly organized into two categories: natural forcing and human activities [3]. Within the part of natural forcing, the paper considers the impacts of solar activity and volcanic activity, while the latter encompasses burning fossil fuels, which releases significant amounts of carbon dioxide and other greenhouse gases into the atmosphere, and land utilization. Furthermore, the paper delves into these factors, offering a comprehensive discussion of how they affect the global mean temperature.

2. Natural forcing

2.1 Solar activity

The relationship of solar activity with climate started to attract attention of scientists from the late 19th to the early 20th century. Solar activity is a complex scientific issue that scientists continue to study, however, there are two main obstacles to overcome [4]: 1) The fundamental cycle of sunspot fluctuations lasts roughly 11 years, however, long-term climate indices do not show any consistent 11-year cycles linked to the sunspot cycle. There are occasionally local climate indices in one or two 11-year cycles that are correlated with sunspot changes, but most of these correlations are not sustained; 2) Except for cyclical issues, it is unknown how solar activity influences Earth's temperature.

2.1.1 MWP, LIA and cold events

There are two important epochs for the global climate, the Medieval Warm Period (MWP) and Little Ice Age (LIA). Most scientists believe that natural forcing like solar activity are responsible for the MWP and LIA that occurred before the Industrial Revolution. According to Kikby [5], Fig. 1 shows temperature changes and solar activity over the past thousand years, reflecting the close relationship between solar activity, represented by the galactic cosmic rays (GCRs), and Earth's climate.

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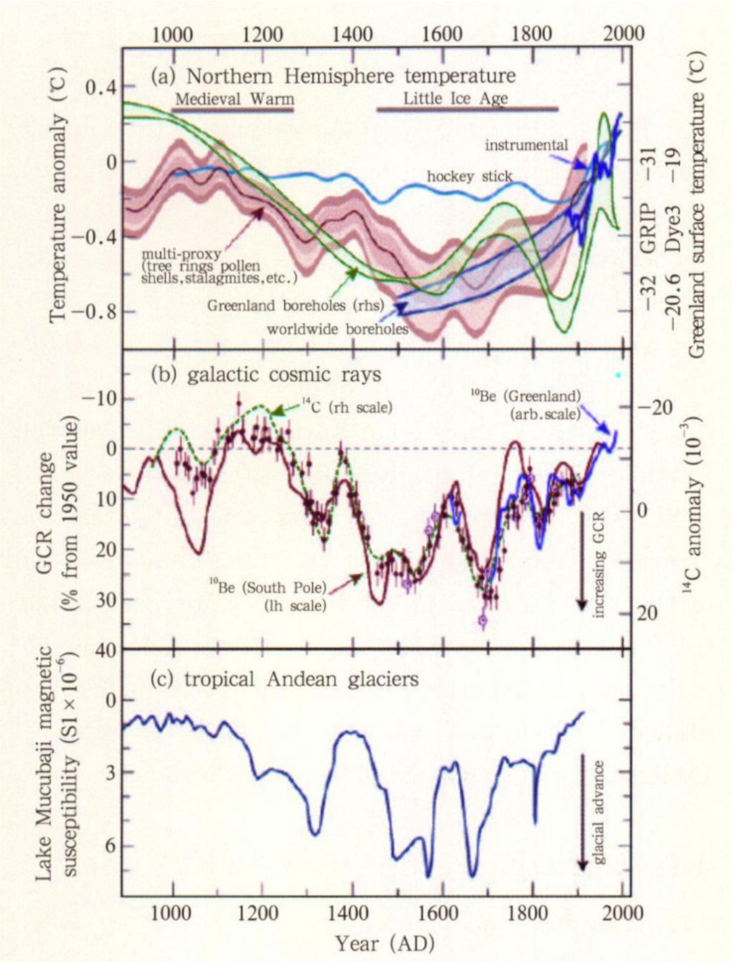

Fig. 1 (a) The surface temperature, (b) GCRs, and (c) tropical Andean glacier changes during the last millennium [5]

Based on the North Atlantic drift ice debris (IRD), Bond et al. concluded that the North Atlantic has experienced ice-rafting events (often known as cold events) 9 times during the Holocene [6]. They created a composite index with 4 sea sediment records to reflect the North Atlantic cold events during the Holocene and reconstructed the solar variations using ^{14}C and ^{10}Be records [7]. Then, these reconstructed series were filtered 70 years after being first taken out of linear trends. It is clear that there is a strong association between solar activity and the composite index(Fig. 2). 9 times cold events corresponded to the valley of solar intensity(GCRs peak), suggesting that a decrease in solar intensity may be the cause of the cold events.

2.1.2 How solar activity influences Earth's temperature

Solar activity affects the Earth's climate through three ways: Total Solar Irradiance(TSI), ultraviolet(UV) radiation, and GCRs changes.

Through the direct observations over the past two and a half 11-year cycles, it is proved that the solar constant is not a true constant(Fig. 2), but that the variation over the 11-year cycle is only 0.1% [8].

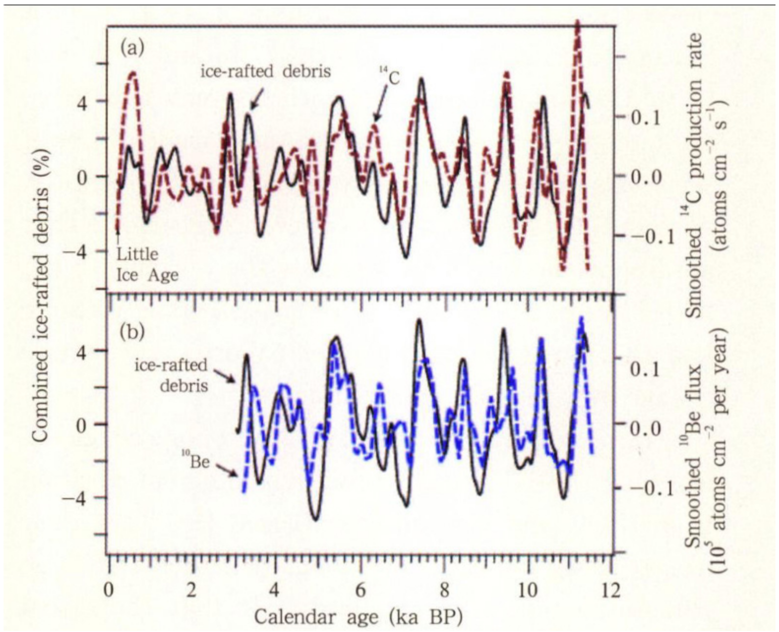

Fig. 2 Correlation of GCRs with North Atlantic cold events (ice-rafted debris events)during the Holocene [8]

That would not be enough to explain the observed climate change, as it would only result in a temperature shift of roughly 0.1 °C [9]. Therefore, a growing number of scientists no longer consider this to be the primary way in which solar activity affects the Earth's climate.

The second method of solar activity affecting Earth's climate is primarily based on the significant variations in ultraviolet (UV) radiation intensity throughout the 11-year solar activity cycle [10]. UV increases when solar activity is high, warming the stratosphere and increasing O_3. However, the physical mechanisms underlying this method are poorly understood, and the observational evidence is insufficient.

There are more research on GCR changes. Over an 11-year period, variations in GCRs amounting to approximately 15% are measured, and meanwhile, changes in low cloud quantity amounting to approximately 1.77% are noted. This corresponds to variations in radiative forcing of approximately 1 W/m^2 [4], proving that the impact of the GCR is sufficiently large. But how GCRs affect the Earth's climate is still being studied.

2.2 Volcanic activity

J. Ring et al. [11] separated radiative forcing into various sources and calculated the temperature change resulting from each forcing component during the temperature record's whole duration as well as its shorter period by using SCM. They observed that volcanic forcing produced between 0.11 ℃ to 0.13 ℃ of warming. The 1904–1944 period is linked to a decline in aerosols produced by volcanoes, which in turn is linked to the early 20th century warming because there were fewer significant volcanic eruptions during this period than during the late 19th century when there were numerous volcanic eruptions [12].

According to Stenchikov et al. [13], volcanic eruptions significantly impact the climate system, with long-term effects on ocean temperatures and shorter-lived impacts on the atmosphere, typically masked by meteorological noise within seven years. Radiative forcing from historic volcanic events lasts about three years, while temperature anomalies in the troposphere decrease below noise levels after approximately seven years. Sea ice and deep ocean temperatures, sea level, salinity, and meridional overturning circulation (MOC) respond on decadal to centennial timescales. Volcanic activity cools the climate and has slowed the growth of ocean heat content, a key indicator of global warming, by about 30%. However, it seems unlikely that the comparatively moderate explosive volcanism of the 21st century will have a major impact on the climate and is not likely to be the main reason for the last decade's climate hiatus, which is most likely due to natural climate variability.

3. Human activities

It is obvious that CO_2 from the burning of fossil fuels and land use is growing rapidly (Fig. 3). The primary factor influencing changes in the Earth's climate and air composition now is human activity [14]. The increase in atmospheric greenhouse gases (GHGs) is caused by human activity.

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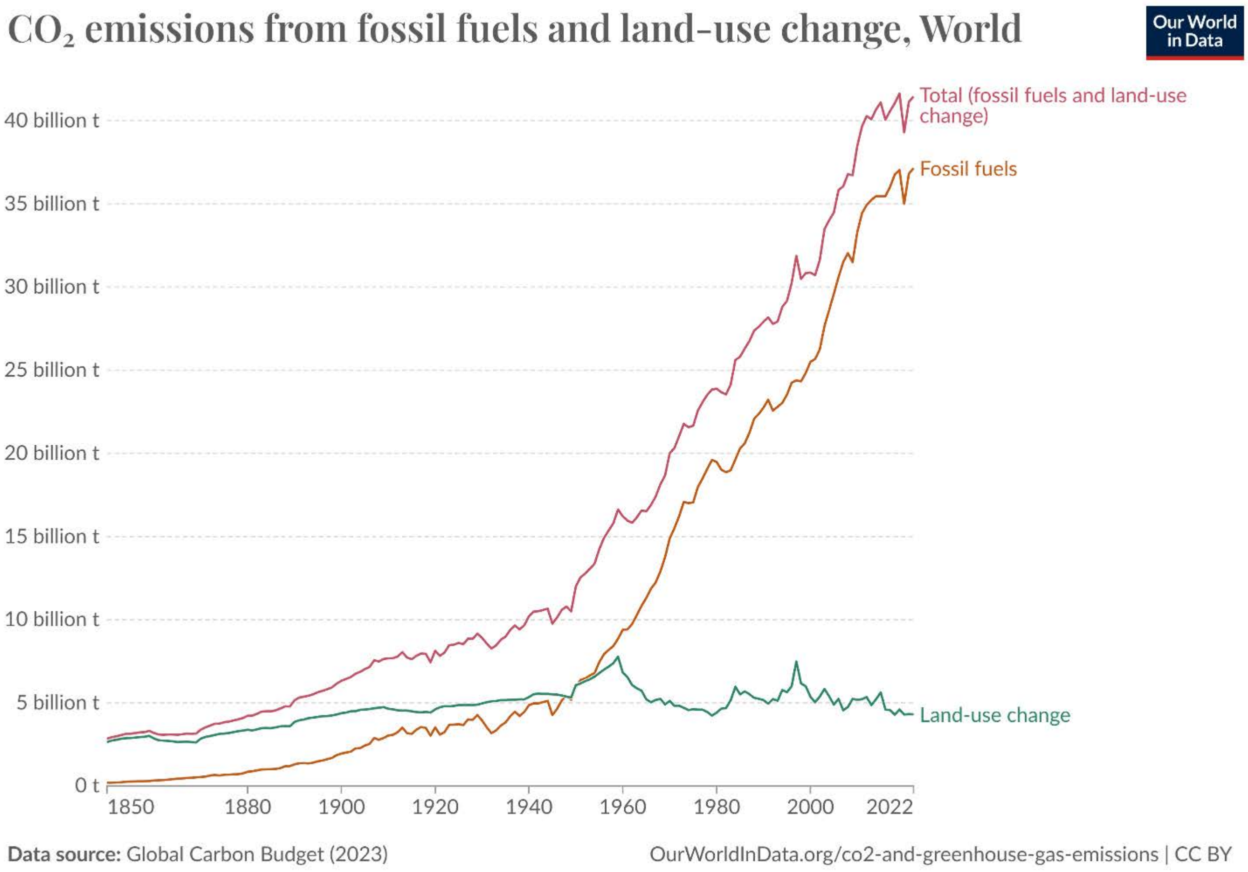

Fig. 3 CO_2 emissions from fossil fuels and land-use change, World [14]

3.1 Burning fossil fuels (coal, oil and natural gas)

CO_2 from burning fossil fuels, such as coal, oil and natural gas, is the strongest force on climate today, meaning it is the greatest enforced disruption of the planet's energy balance [15]. Burning all available fossil fuels would dramatically alter the planet, creating conditions that could be largely uninhabitable for humans. The primary driver of global temperature rise is the increase in CO_2 levels, with a significant escalation expected from an 8-fold increase in CO_2 concentration, leading to a 16°C rise in global temperatures according to simulations [16]. This temperature increase is particularly pronounced in polar regions. Furthermore, the trend is exacerbated by a 25% contribution from non-CO_2 greenhouse gases such as N_2O and CH_4. A 12 W/m^2 increase in greenhouse forcing, which is attainable with this level of CO_2 enhancement, is a major factor in this warming scenario. The resultant temperatures would be disastrous for agriculture, potentially eliminating grain production across most regions [17]. In addition, the ozone layer would be destroyed by the increasing stratospheric water vapor [18], and humans could suffer from severe hyperthermia due to the high temperatures because our bodies cannot withstand continuous wet bulb temperatures above 35°C [19, 20].

The rapid pace of human-induced climate change, projected to occur over centuries rather than the millennia of the Paleocene-Eocene Thermal Maximum (PETM), leaves little time for evolutionary adaptations that might have helped mammals survive past warming events [21]. The feasibility of reaching a 9 W/m^2 forcing through fossil fuel emissions is supported by current reserve estimates. When combined with the potential for increased CO_2 airborne fractions, it is shown that the emission of 5000 to 10000 Gt C is possible [22, 23]. According to recent updates of probable reserves, 5×CO_2 (1400 ppm) is indeed achievable. These reserves include conventional oil, gas, and coal as well as unconventional fossil fuels (such as tar sands, tar shale, and shale gas produced by hydrofracking). Similarly, total recoverable fossil energy reserves and resources estimated by GEA[24] are about 15000 Gt C using IPCC [25] emission factors. Therefore, there are more than enough fossil fuels accessible to induce a forcing of 9 W/m^2 sustained for centuries at a multi-centennial

CO_2 airborne percentage between one-third and two-thirds [16].

Coal, unconventional oil, and gas contain the majority of the carbon that remains from fossil fuels. This would have dire consequences for future generations. With the effects of burning all fossil fuels becoming more apparent, it appears unlikely that mankind will not change its energy trajectory. The future of humanity may depend on whether governments are still willing to be so naive as to permit or promote the development of all fossil fuels.

3.2 Land utilization

As a key resource, land plays an important role in regulating the climate system. Land provides vital resources, ecosystem functions and services that form the basis of human economic and social existence. However, the resources and services that land provides to the human economy and society are under unprecedented threat from climate change and human activities.

3.2.1 GHGs and carbon emission

From 2007 to 2016, GHGs emissions from agriculture, forestry and other land use (AFOLU) accounted for 13% of global anthropogenic CO_2 emissions, 44% of CH_4 emissions, and 81% of N_2O emissions [26], with AFOLU's total emissions accounting for 23% of total anthropogenic GHGs emissions [27, 28]. The global land carbon emission estimated by the global model was (5.2 ± 2.6) Gt CO_2 per year [29], while the global land carbon emission estimated by the national greenhouse gas inventory method was (0.1 ± 1.0) Gt CO_2 per year [30]. Both of these had wide uncertainty ranges and differed by tens of times. There are no definite outcomes.

3.2.2 land degradation and desertification

Land degradation means the land is getting worse due to human activities and climate change, leading to long-term loss of plant and animal life, harm to ecosystems, or reduced usefulness for people, with at least one of these losses occurring [31]. Desertification is defined as "land degradation in arid, semi-arid and arid subhumid areas caused by a variety of factors, including climate change and human activities". In other words, desertification is a type of land degradation. Dry areas are particularly vulnerable to land degradation due to scarce rainfall and poor soils, with warming twice as high as the global average surface warming. This is because a land surface covered with healthy vegetation has a lower albedo and is able to absorb more solar radiation, while a degraded or desertification land surface usually has a higher albedo and reflects more solar radiation. This change will affect the surface energy balance and cause the surface temperature to rise.

4. Conclusion

The purpose of this paper is to explore the factors of global mean temperature change. After the above summary, the following conclusions can be drawn:

(1) Solar activity impacts Earth's climate via three mechanisms: TSI, UV radiation, and GCRs changes. They've all been thoroughly examined, but more research is needed to determine the extent to which solar activity actually counteracts or enhances the effects of global warming.

(2) Volcanic forcing contributed to warming between 0.11°C and 0.13°C, particularly during 1904–1944, due to a reduction in volcanic aerosols. Volcanic eruptions have long-term oceanic effects and short-term atmospheric impacts, but the latter are often obscured by meteorological noise within seven years.

Volcanic activity has mitigated the rise in ocean heat content, a pivotal indicator of global warming, by approximately 30%. However, the 21st century's moderate volcanic activity is unlikely to significantly influence climate or account for the recent climate hiatus, which is more attributed to natural variability.

(3) Because of CO_2 emissions, using accessible fossil fuels would seriously upset the Earth's energy balance, possibly raising global temperatures and creating inhospitable conditions for humanity. The warming is made worse by non-CO_2 gases. There is not much time for evolutionary adaptation due to the accelerated rate of climate change, which is faster than previous catastrophes like the PETM. Future generations are seriously at risk from our prolonged reliance on coal, unconventional oil, and gas, and how the government handles the development of fossil fuels may have a significant impact on how things turn out.

(4) Land, a critical climate regulator, is threatened by climate change and human activities, impacting its ability to provide essential resources and services. AFOLU had a major impact on carbon emissions and greenhouse gas emissions. However, there is a significant uncertainty in global land carbon emission estimates, varying widely between different methods. A higher albedo and higher surface temperature owing to decreased vegetation are the results of land degradation and desertification, which are made worse in arid regions. This affects the energy balance and accelerates climate change.

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