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A Contemporary Review on Geo-engineering Techniques for Mitigation of Accelerated Rise in Global Sea Level in the Past Eight Hottest Years

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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Review Article

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ABSTRACT

Because of extreme heat during the last few years, absorption of heat in ocean water is continuously on the rise and due to additional melt water from icebergs the phenomenon of sea level rise is gradually coming to an alarming level. The present scenario based on the proposed mitigation measures to restrict the rise in temperature hardly commensurate with the decisions in Paris Agreement. Currently although geo-engineering, which is a mechanism to limit extraordinary sea level rise, has attracted scientific interest as per the current state of drastic changes in climate change, standard mitigation measures may not be enough to stop sea-level rise. This paper examines the various approaches. and options under Geo-engineering and compares effectiveness of traditional and modern geo-engineering techniques vis-à-vis other conventional mitigation

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measures. It is opined that conservative and groundbreaking techniques can decrease the ongoing rise in sea-level, however most befitting results would be accomplished through the combination of approaches.

Keywords: Geo-engineering; sea-level rise; aerosol injection; marine cloud brightening; ocean-fertilization.

ABBREVIATIONS

SLR	*: Sea Level Rise*
RCP	*: Representative Concentration Pathway*
SSP	*: Shared Socioeconomic Pathways*
MICI	*: Marine Ice Cliff Instability*
MISI	*: Marine Ice Sheet Instability*
IPCC AR6	*:Intergovernmental Panel on Climate Change Assessment Report Six*
CMIP6	*: Coupled Model Intercomparison Project Phase 6*
GHG	*: Green House Gas*
NOAA	*: National Oceanic and Atmospheric Administration*
ENSO	*: El Niño-Southern Oscillation*

1. INTRODUCTION

Because it takes decades to millennia for the limitless deep-sea water and icebergs to adjust to global anthropogenic warming, rise in sea level is a continuing effect of changes in the climate. The quantum of rise in sea level is stated to be exceeding 1 m at the top of the century and if melting of icebergs continues in a high-end scenario there can be rise upto 2 m by 2100 [1]. Due to absorption of 90% of the excess heat trapped by greenhouse gases, ocean is increasingly getting hotter and is expanding. Further, also due to melting of ice in Polar Regions, Sea level rise is accelerating [2].

Circulation of wind within northern and southern hemispheres (Coriolis Effect – Fig. 1) contributes to seasonal variations in climate and the effect of El Niño (the hotter phase) and La Niña (the cooler phase) also influences (Fig. 2) the process. Climate Change is bringing in differences in the average ocean temperatures, winds, surface pressure etc. quite significantly.

In reality, it is quite problematic for the current models to anticipate the future conditions and their impacted SLR distributions. Despite significant uncertainty in accuracy of the climate models' estimates, SLR projections as of now are obviously based on the presently available climate models only. According to simulations of global climate models with transient greenhouse gas fluctuations, the average increase in global surface temperature over the past 30 years has been 0.2°C each decade. The havoc of recent rapid warming shows a rise in temperature above 1°C compared to that in 2000, because of the likelihood of its effects on sea level and species extinction, is considered as "unsafe and risky" changes in the climate [3]. Having risen the temperature above 2°C by 2100 (for scenarios RCP2.6 or equivalent SSP1-2.6) relative to pre-industrial values, the high-end global SLR projections are 0.9 m by 2100 and 2.5 m by 2300 out of ongoing and speculated global warming. Similar estimates are made for high end scenarios (i.e., for RCP8.5/SSP5-8.5), which might raise SLR upto 1.6 m in 2100 and 10.4 m in 2300. Long-term methods for mitigation are necessary, given the significant and expanding gaps between the scenarios beyond 2100.

The process of melting of icebergs, which adds to sea level rise- particularly, how fast these are going to melt and in how much quantity, is highly ambiguous due to low-slung knowledge of the entire procedures. Earlier high-end assessments focused on mechanisms of Instabilities in the Marine Ice Cliffs (MICI) and in the Marine Ice Sheets (MISI) to assess the judgement of ice shelf breakdown. But definitely in past eight hottest years, because of continuous rise of temperature, the melt water has accumulated more than envisaged. Obviously, understanding both, i.e. the melting process and control in emission scenario are equally important to assess the high-end SLR [4].

In the prevailing circumstances of so-called phenomenon of ice dynamics during acceleration in the ongoing warming situation, and prevalent deep ambiguity in socio-political and financial deviations amongst nations, model hierarchy for the complex science of climate change is quite a challenging task. Even in terms of forecast by IPCC AR6, in 2022 the differences in contributive influences in the form of (SSPs) analyzed by latest climate model

CMIP6, in reality the predictions are still remaining unreliable. Even then, in a state where all human-caused GHG emissions say if instantly terminated, self-sustaining melting will still occur. Because of the current unpredictable ice sheet dynamics, models that have been built on numerical and probabilistic methodologies are predicted to vary drastically and the acceleration in global warming remains difficult to be ascertained [5].

In the Paris Agreement nations agreed for a worldwide agenda to avert unsafe and risky changes in climate by restricting rise in temperature under 2°C and hunting for attempts to retain the rise within 1.5°C, as well as trying to recuperate the capacity of various nations to handle the effects of changes in climate and aid them in their exertions with appropriate strategies [6]. A review of the ongoing situation reveals that the restriction of rise in temperature does not fully commensurate with the desirable status.

2. THE CURRENT SCENARIO

Global warming impacted Sea Level rise is basically a combination of: Rise of sea level due to (i) Thermosteric i.e., increase in the water level of sea because of volumetric expansion of aquatic mass & (ii) Bary static rise in sea-level i.e. the increase in level of water at sea for addition of water to the sea from other sources (like meltwater from glaciers).

Globally it is recorded that the past eight years have been so far the hottest. Oceans were the warmest on record, with around 58% of their surfaces experiencing a marine heatwave. With the rise in the mean global temperature by 1.15 °C from pre-industrial time, year 2022 was the fifth to sixth warmest year. Globally heat and acidity levels in Ocean have hit record highs and glaciers in Alps in Europe and ice in Antarctica ice touched record low volumes. For the first time in history, none of the snow on Switzerland's glaciers survived the summer season, and the main glaciers that scientists use as a health check for the planet has decreased by more than 1.3 m in just one year [7].

This has happened in spite of the rare third year of La Nina---a natural temporary cooling of parts ofthe Pacific Ocean that changes weather conditions worldwide. According to definitions by NOAA, El Niño and La Niña are opposite phases of a natural climate pattern across the tropical Pacific Ocean that swings back and forth every 3-7 years on average, that can affect weather worldwide. Together, they are called ENSO (pronounced “en-so”), which is short for El Niño-Southern Oscillation. The ENSO pattern in the tropical Pacific can be in one of three states: El Niño, Neutral, or La Niña. El Niño (the warm phase) and La Niña (the cool phase) and contributes to significant changes in the average ocean temperatures, winds, surface pressure, and rainfall. Neutral indicates that conditions are near their long-term average.

3. CONTEMPORARY MITIGATION APPROACHES

The main mitigation strategies being used to combat sea level rise are briefly discussed here, along with any drawbacks they may have. In light of this, major solutions to the problem of contemporary sea level rise have mostly been focused on emissions control and adaptation. In the coming decades, anthropogenic activities will play a significant role in the rise of the oceans. Occurrence of a moderate disturbance or a catastrophic flood depends on how much emissions are constrained and reduced [8]. The finest path of achievement would therefore is to curtail and eliminate greenhouse gas emissions, while combating the rise in sea level rise, which as a matter of fact, is no longer preventable. In order to restrict rise in temperatures globally within 1.5°C above preindustrial period, nations are required to control their peak GHG emissions under the Agreement.

a. Emission Mitigation

It is already agreed and determined decrease in emissions is the predominant best strategy to mitigate long-term sea level rise [9]. Two incredibly distinct futures are conceivable as we look towards the end of the twenty-first century and beyond. If the Paris Agreement's pledges to gradually phase down greenhouse gas emissions are reserved, the rise in the Global Mean Sea Level may be limited within 50 cm. However, if releases keep increasing at the prevailing rate, the sea level might rise by up to 4 m by 2300 and by 1 m by 2100 [8]. Although 197 countries have approved the Agreement since it was established in 2015 and many of them have reaffirmed their commitments since then [10], progress has been uneven [11]. Morocco's emissions are now the only ones that are consistent with the 1.5°C route [6]. Only a

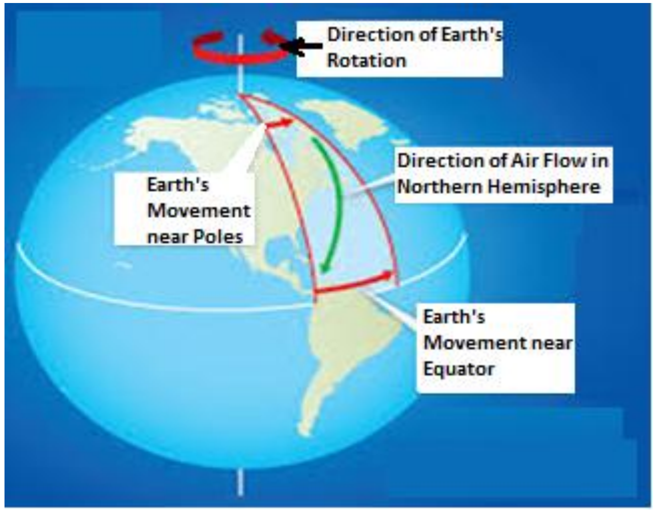

Fig. 1. Coriolis Effect
Source – Island Physics (Image: Prentice Hall)

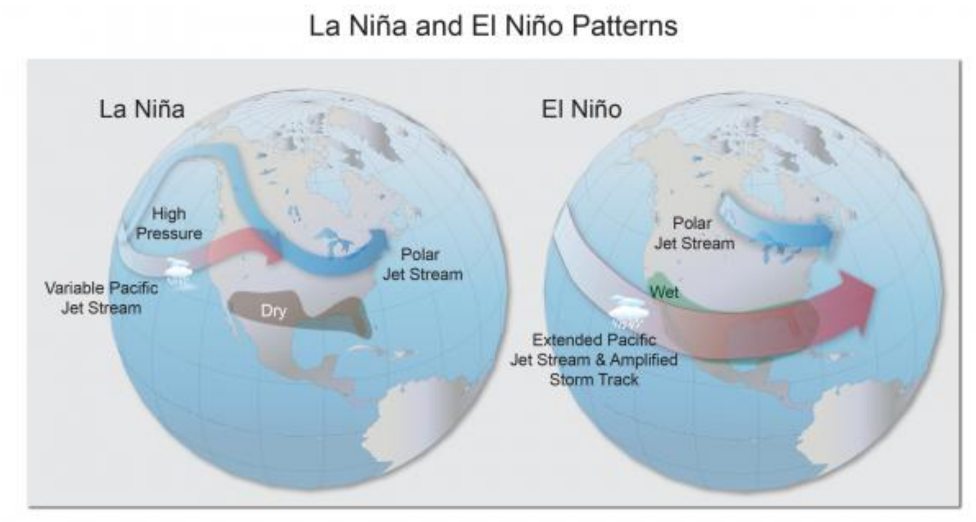

Fig. 2. El Nino (Warm) & La Nina (Cool)
Source: The National Environmental Education Foundation https://www.neefusa.org/

small number of nations are 2°C compatible, and the majority of those who [10] nevertheless fall into the inadequate or critically deficient categories, thus impeding efforts to appropriately address fast rise in sea level through restricted paths for mitigation of emissions. Therefore, preventing sea level rise may need more than just reducing emissions; it also necessitates coordinated global action, of which the geo-engineering method is gaining popularity among experts.

b. Adaptation Measures against Sea-Level Rise

Protecting coastal areas from floods and water damage is the main goal of current adaptation methods. Traditional defensive strategies, for example erecting sea-walls and levees, creating adaptable structure, or repurposing present structures to be more robust (e.g., elevating and flood-proofing structures) are some of these methods [8]. Numerous communities will weigh the dangers and costs of adjusting with sea's rise in general, leaving those as it is, or attempting to protect coastal structures with multiple defences (Environmental Protection Agency, 2021). Due to additional factors, such as sinking soil, coastal megacities like Jakarta may experience considerable damage from increase of sea level spanning from 20 to 40 cm [8]. Sustaining or repairing natural barriers like adding sand to seashores that have eroded, constructing barrier islands, and restoring wetlands in tidal zones, helps protect coasts along with providing more ecological services [12]. Adaptation techniques are typically implemented locally, in contrast to mitigation of emissions, the ultimate success of which depends on effectiveness of many measures in a collective manner. By 2050, it is predicted worldwide the rise in Global Mean Sea Level on beaches will at least be around 20 to 40 cm [8]. Even while the sea level increase may seem acceptable, regional contributions and other mitigating factors may make it worse in the form of rise in relative sea level, making some areas more severely affected. Whenever it is feasible, adaptation will be a viable option. Despite unlikely emissions reductions, adaptation is also vital to prevent the rise in sea level that has already been locked in.

Particularly in underdeveloped countries, adaptation frequently entails expensive procedures and conflicts with budgetary constraints, which limit a region's capacity to build efficient defences and infrastructure. As a result of the coastal areas being submerged by the sea, fast increasing waves have significant effects on them. A place will have to be abandoned if it cannot afford the expenses of putting protection and adaptation measures in place, which would cause social, economic, and environmental losses [13]. In response, research into newer and more unconventional strategies in slowing rise in sea level has increased over last few decades. One of these strategies is Geo-engineering.

4. GEO-ENGINEERING

For monitoring the current state of climate change, geo-engineering has attracted interest of the scientific community, as a technique to mitigate exceptional sea-level rise, Geo-engineering, often known as climate engineering, is the thoughtful modification of nature's systems to maintain a particular climate [14]. Geo-engineering mostly involves solar geo engineering, which requires atmosphere to be free from carbon dioxide and increasing the albedo from the earth's surface to reflect more sunlight back into space [15]. This has been the focus of research as a wave of specialized methodologies [16] have emerged over the last ten years [6]. Following solidified thinking in this situation, the application of geo-engineering becomes urgently necessary. Before determining how innovative geo-engineering techniques may aid in sea level rise mitigation, it is crucial to first determine why they may be required. In this paper the different aspects of Geo-engineering have been attempted to collate after review.

Geo-engineering approaches are classified according to the three major climatic systems: atmosphere, hydrosphere, and cryosphere (Fig. 3). Furthermore, space-based geoengineering technologies are a powerful tool for mitigating sea-level rise.

The viability of engaging reflective or refracting shields of glass, developing of sun-shades, satellites mounted with mirrors, solar buffers and heat absorbers in space, as well as the option of generating rings of dust around the Earth, analogous to those available around Saturn, are gaining attention. Dependent on position on the Earth, the depth of troposphere varies within a thickness of 5 to 9 miles (8 to 14 km) .The Poles at the northernmost and southernmost point of the earth have the minimum thickness of ice (thinnest). This layer contains the densest layer of air we breathe as well as have maximum clouds in the sky.

Snowflake, sea frost, freshwater and river frost, Icemass, glaciers and frost caps, frost sheets, ice tables, permafrost, and seasonally ice-covered land comprise ‘cryosphere’. Etymologically “cryosphere" descends from "kryos," a Greek word which means ice. Above the Terrain's face this zone of stratosphere extends upto around 31 miles (50 kilometers) starting from about 4 to 12 miles (6 to 20 kilometers). This layer contains very little water vapour and about 19% of the atmospheric gases [17]. In this location with altitude the temperature rises.

According to ongoing research, some, if not all, of these strategies could constitute an important tool-kit for climate intervention or a climate barrier [18]. Furthermore, these strategies have the practical advantage of not requiring complex planning at land and also avoids direct changes to the atmosphere. Under the banner of geo-engineering, the following measures are being studied for mitigating global warming:

a. Atmosphere

i. Injection of Aerosol at Stratosphere [17] = The injection of reflective particles of micro size into the stratosphere for lowering atmospheric temperatures. From now onwards till 2100, injection of aerosol or installation of a mirror system at space can reduce thermic fever with an accelerating rate of 1 W/m2 per decade which inter-alia could control rise in sea levels.

ii. Injection of Aerosol with a radiative forcing decrease of 4 W/m2 may well interrupt rise in sea-level rise in coming 40-80 years. Injection of Aerosol seems to fail in benefit of cost analysis without indefinite sustainability and the harm produced by the macroclimate reaction to the misters is lower than 0.6% of the global world product [19].

iii. Brightening of Marine Cloud [20] = The microparticle infusion into maritime stratocumulus clouds in order to increase reflectivity and thereby counterbalance the warming in atmosphere.

iv. Brightening of Cirrus Cloud [21] = Silver iodine injection into cirrus clouds can weaken or else eradicate the clouds and allows exit of long-wave warm air fallout from troposphere.

v. Microbubbles [22] = Injection of Surfactant on the surface of ocean can improve albedo from surface and decrease transmission of hotness (Fig. 4).

vi. Ocean Fertilization [23] = The addition of nutrients (in both micro and macro forms) to the sunlit upper layer of oceanic bulk mass for boosting growth phytoplankton through photosynthesis can confiscate carbon dioxide which culminates towards temperature reduction. Ocean fertilization is the most researched ocean geo-engineering technique, and it has the potential to mitigate both ocean acidification and global warming. It entails promoting the growth of phytoplankton, which use photosynthesis to turn CO_2 into oxygen. Around 50% of the world's photosynthesis is performed by microscopic phytoplankton.

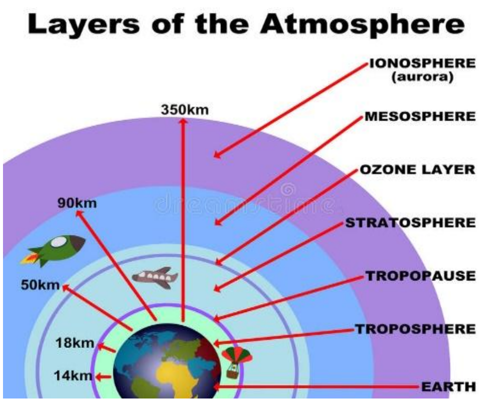

Fig. 3. Layers of the atmosphere
Source: https://www.dreamstime.com/

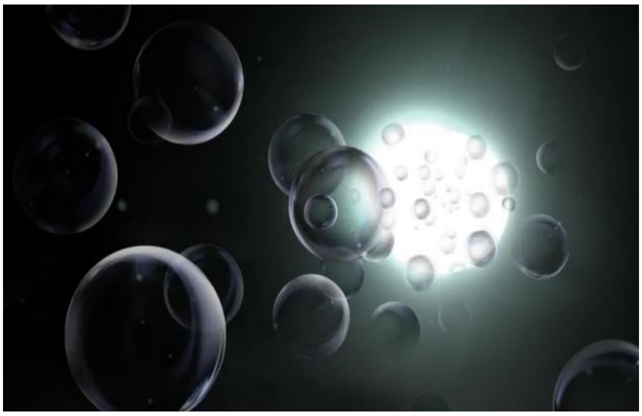

Fig. 4. “Space Bubbles” – The deflection of solar radiation using thin-film inflatable bubble rafts - Massachusetts institute of technology
Source :https://scitechdaily.com/July 24,2022

b. Cryosphere

i. Glacier Geoengineering [24] = Polar outlet glacier restriction (e.g. submarine embankments [15], building up barriers like submerged berm breakwater, restricting the basal freezing temperature to restrain the pressure melting point, contribute towards natural basal drying to slow ice streams as liquid water lubricating flow warm-based glaciers fast) to avert forfeiture ice mass.
ii. Restoration of Sea Ice [25] = The application of floating materials to the Ocean surface for improving reflective power to lower temperatures for retaining ice.

5. CONCLUSION

- Climate change (CC) has continued to wreak havoc on the planet's sustainability. The influence on the environment, economy, and society has continued to garner substantial attention from governments throughout the world. One of the major reasons that climate change is so contentious is because modelers overestimated their prediction ability.
- Contemporary moderation exertions and imminent promises appears as inadequate to match the temperature goals of Paris Agreement. As a result, research and debate on the potential use of wished-for macroclimate geo-engineering technologies, either through removal of atmospheric carbon dioxide or more far-reaching intercessions modifying the balance of radiative energy of earth, are intensifying. While investigations shows that numerous strategies might someday have the real ability of mitigating changes in climate, research is now in the premature stage with significant ambiguities and hazards.
- Climate geoengineering approaches, based on current knowledge, hardly can be relied upon to pointedly underwrite towards attaining the temperature goals decided in the Paris Agreement [26]. It is believed that enhanced detection of these processes is required in order to identify feasible mitigation activities while avoiding too optimistic assumptions and subsequent policy failures. The targets will be determined by future emission scenarios, which will be determined by national policies, as this is a global issue. Geo-engineering has been advocated as a viable method of reducing anthropogenic climate change, particularly rising global temperatures in the twenty-first century. While geo-engineering is an overall strategy to climate change, its feasibility and effectiveness are still debatable. Restraining inward solar energy or changing the cycle of carbon is broadly the two basic geo-engineering methods. According to new research from Harvard's John A. Paulson School of Engineering and Applied Sciences (SEAS), solar geo-engineering could be unexpectedly effective in mitigating some of the worst effects of global warming. While no one claims that solar geo-engineering can substitute pollution cuts and resolve climate change, it is stated that it can have a significant planetary chilling effect within a comparatively low cost. According to Harvard research (2018), it would roughly cost 2.25 billion $ per year over a period of 15-year [27,28]. In view of the foregoing, it is opined by the authors of this paper that the afforested measures under the banner of Geo-Engineering may be undertaken in the order of their technical feasibility and economic viability which may appear if implemented holistically.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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