

Review Article

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

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 decision in Paris Agreement. Current mainstream mitigation measures may be insufficient to halt sea-level rise whereas Geoengineering—which can be described as a mechanism to mitigate unprecedented sea-level rise—has garnered scientific interest in line with the present state of climate change. This paper reviews the various methods and options under Geo-engineering approach and investigates effectiveness of traditional and modern geo-engineering techniques vis-à-vis other conventional mitigation measures. It is opined that conventional and pioneering techniques can decrease sea-level rise, and those optimal results would be achieved through the co-operation of methods.

Keywords: Geo-engineering; sea-level rise; aerosol injection; marine cloud brightening; oceanfertilization

1. INTRODUCTION

Sea level rise (SLR) is a long-lasting consequence of climate change because global anthropogenic warming takes centuries to millennia to equilibrate for the deep ocean and ice sheets. A global rise of sea level exceeding 1 m is stated to be possible at the end of the 21st century and if melting of icebergs continues in a high-end scenario there can be upto 2 m rise by 2100 [1]. Due to absorption of 90% of the excess heat trapped by greenhouse gases, ocean is increasingly getting hotter and expanding. Further, due to melting of ice in Polar Regions Sea level rise is also accelerating [2].

Circulation of wind within northern and southern hemispheres (Coriolis Effect -Figure 1) has seasonal variation in climate and the effect of El Niño (the warm phase) and La Niña (the cool phase) also influences (Figure 2). Climate Change bringing in significant differences from the average ocean temperatures, winds, surface pressure etc.

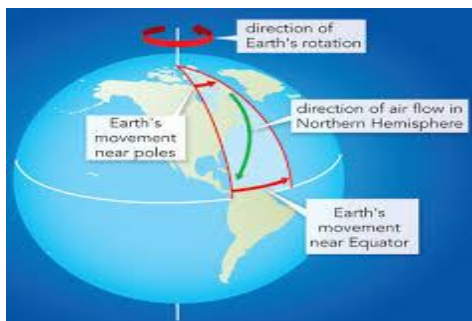


Figure -1 Coriolis Effect

Source – Island Physics

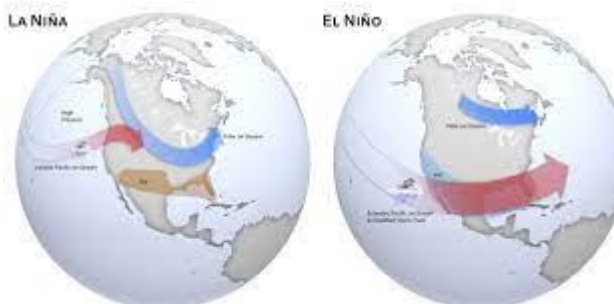


Figure -2 El Niño (Warm) & La Niña (Cool)

Source: The National Environmental Education

Foundation <https://www.neefusa.org/>

Future conditions of the SLR distribution are in fact highly unpredictable to be defined by existing models. SLR projections based on climate models, despite their large uncertainties is estimated by process-based models. However, even a modest 2°C warming may cause multi-meter SLR on centennial time scales with profound consequences for coastal areas. Global surface temperature has increased $\approx 0.2^{\circ}\text{C}$ per decade in the past 30 years as per global climate model simulations with transient greenhouse gas changes. Recent accelerated warming warns that global warming of more than $\approx 1^{\circ}\text{C}$, relative to 2000, will constitute “dangerous” climate change as judged from likely effects on sea level and extermination of species [3]. For global warming of $+2^{\circ}\text{C}$ in 2100 (RCP2.6/SSP1-2.6) relative to pre-industrial values the high-end global SLR estimates are up to 0.9 m in 2100 and 2.5 m in 2300. Similarly, for a (RCP8.5/SSP5-8.5), it is estimated up to 1.6 m in 2100 and up to 10.4 m in 2300. The large and growing differences between the scenarios beyond 2100 calls for long-term strategies for mitigation. 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 uncertain due to low understanding of the driving processes. Earlier high-end assessments focused on Marine Ice Cliff Instability (MICI) and Marine Ice Sheet Instability (MISI) mechanisms to assess the timing of ice shelf collapse but definitely in the 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 important to assess the high-end SLR [4].

In the prevalent ice dynamics during accelerated warming situation, and prevalent deep uncertainty in socio-political and economic changes 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 variations in contributing factors in the form of (SSPs) analyzed by latest climate model CMIP6, in reality the predictions are still remaining unreliable. Even in a situation, if all anthropogenic emission of GHGs is immediately stopped the self-sustained melting will continue. Models so far being based on numerical and probabilistic approaches are expected to undergo abrupt change because of the current inconsistent ice sheet dynamics and the accelerated global warming [5].

In The Paris Agreement nations agreed for a global framework to avoid dangerous climate change by limiting global warming to well below 2°C and pursuing efforts to limit it to 1.5°C along with aiming for strengthening different countries’ ability to deal with the impacts of climate change and support them in their efforts 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:

Sea Level rise due to global warming is basically a combination of: (i) Thermosteric sea-level rise i.e., the increased sea level due to the volumetric water expansion & (ii) Bary static sea-level rise i.e. the increased sea level due to adding masses of water to the ocean from the atmosphere or land areas.

The past eight years have been the hottest eight years on record globally. Oceans were the warmest on record, with around 58% of their surfaces experiencing a marine heatwave. The year 2022 was the fifth or sixth warmest year on record with the mean global temperature 1.15 °C above the pre-industrial average, Global Ocean heat and acidity levels hit record highs and Antarctic Sea ice and European Alps glaciers reached record low amounts. The key glaciers that scientists use as a health check for the world shrank by more than 1.3 m in just one year and for the first time in history, no snow survived the summer melt season on Switzerland's glaciers [7].

This has happened in spite of the rare third year of La Nina---a natural temporary cooling of parts of the 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:

A brief assessment of the mainstream mitigation measures currently underway to address sea-level rise are listed below along with their limitations and the shortcomings. Against this backdrop, mainstream approaches to addressing the issue of modern sea-level rise have primarily been confined to emissions mitigation and adaptation. The oceans' rise seems intrinsically linked to anthropogenic actions in the next few decades. The extent of emissions constraint and reduction may mean the difference between manageable disturbance and catastrophic inundation [9]. Therefore, the preferred solution would be to reduce and remove greenhouse emissions while preparing for the portion of sea-level rise that can no longer be prevented. In endeavouring to limit global temperatures to well below 1.5°C above pre-industrial levels, the Agreement adjured countries to peak GHG emissions imminently and to commit to net-zero GHG emissions to ensure that mitigation strategies would balance out anthropogenic GHGs, soil and oceans between 2050 and 2100 [10]. To achieve this before 2050, scientists confer that a GMSL rise between 0.7 and 1.2 m by 2300 can be anticipated if net-zero GHG emissions are obtained and maintained until then [9]. However, the 2015 Paris Agreement is the current single emission mitigation approach. Current mainstream mitigation measures may be insufficient to halt sea-level rise, implying that radical measures may be required.

4. Emission mitigation:

A consensus has been reached that reducing heat-trapping emissions is optimal for limiting the magnitude and rate of sea-level rise over the long term [8]. Looking towards the close of the twenty-first century and beyond, two very different scenarios are possible. If the commitments for phasing out greenhouse gas emissions in the Paris Agreement are upheld, sea-level rise may hold with a GMSL rise in the range of 50 cm. But if emissions continue at the current pace, 1 m of sea-level rise is possible by 2100 and up to 4 m by 2300 [9]. Despite 197 nations having endorsed the Agreement since its inception in 2015 and many reaffirming their commitments after that [11], progress has been heterogeneous [12]. Presently, Morocco is the only country whose emissions are compatible with the 1.5°C pathway [6]. Only a few countries are 2°C compatible, with most compliant countries remaining in the insufficient or critically insufficient categories [11], which grossly impede the ability to address rapidly rising seas through exclusive emissions mitigation pathways adequately. Therefore, combating sea-level rise may not only be successful by reduction of emission and is heavily reliant on concerted global action out of which Geo-Engineering approach is getting importance amongst scientists.

5. Adaptation measures against sea-level rise:

Current adaptive measures aim at protecting coastal regions against flooding and water damage. Among these measures are conventional defensive approaches, such as building seawalls and levees, constructing adaptive infrastructure, or reconfiguring existing buildings and infrastructure to make them more resilient (i.e., elevating and flood-proofing structures) [9]. Many communities will contemplate the costs and risks of accommodating the rising seas, withdrawing from them, or trying to defend coastal infrastructure with various protective measures (Environmental Protection Agency, 2021). Consequently, other contributions like sinking of land viz. sinking coastal megacities like Jakarta may suffer significantly from a 20-40 cm sea-level rise [9]. Maintaining or restoring natural buffers, such as replenishing sand along eroded beaches, implementing barrier islands, and regenerating tidal wetlands, help defend coastlines while providing additional ecosystem services also fall under adaptation measures. Constructing natural channels to accommodate temporary flooding and gradual inundation of low-lying areas are also current adaptive measures, with nature-based solutions also providing a suitable climate adaptation strategy [13].

Unlike emissions mitigation, whose ultimate success relies on a collective and holistic front, adaptation measures are generally enacted locally. GMSL rise on coastlines worldwide will likely be 20-40 cm by 2050 [9]. Whilst this sea-level rise may appear manageable, local drivers of relative sea-level and other extenuating factors can exacerbate the issue, meaning some locations will be more adversely affected. Adaptation wherever possible will certainly be a locally possible measure. Adaptation is necessary for the sea-level rise that is already locked in despite improbable emissions reductions.

Adaptation often involves costly operations and financial constraints, particularly in developing nations, curtailing a region's ability to construct effective defences and infrastructure. Consequently, rapidly rising seas result in large-scale impacts in coastal areas as the sea submerges them. Locations unable to bear the costs of implementing protection and adaptation measures will have to be abandoned, resulting in social, economic, and environmental losses [14]. In response, the past few decades have witnessed research into more unorthodox measures for abating sea-level rise one of which is Geo-Engineering.

6. Geo-engineering:

Geo-engineering, which can be described as a mechanism to mitigate unprecedented sea-level rise has garnered scientific interest in line with the present state of climate change. Geoengineering is the deliberate manipulation of the Earth's systems to engineering the climate to keep it in the desired state [15]. Geo-engineering basically entails - Solar geo-engineering i.e. mainly: increase in the surface albedo (reflecting more sunlight back to space) & Removal of carbon dioxide (reduce its atmospheric content) [16]. This has featured at the centre of research with a surge of niche techniques [17] emerging over the past decade [6]. Within this contextual environment after consolidated thoughts the implementation of Geo-engineering becomes a need of the hour.

Before establishing how pioneering geo-engineering techniques may assist sea-level rise mitigation, it is prudent to establish why they may be necessary. In this paper the different aspects of Geo-engineering have been attempted to collate after review.

Geo-engineering techniques can be grouped depending on three principal climate systems: atmosphere, hydrosphere, and cryosphere (Figure 3). Also, space-based geo-engineering approaches are an effective mitigative tool in abating sea-level rise. Increasing attention is being drawn to the feasibility of placing reflective or refracting glass shields, sunshades, mirror-mounted satellites and solar shields and absorbers in space and, further, to the possibility of generating dust rings around the Earth, synonymous with those surrounding Saturn. The troposphere is between 5 and 9 miles (8 and 14 kilometers) thick depending on where you are on Earth. It's thinnest at the North and South Pole. This layer has the air we breathe and the clouds in the sky. The air is densest in this lowest layer. The cryosphere is the part of the Earth's climate system that includes solid precipitation, snow, sea ice, lake and river ice, icebergs, glaciers and ice caps, ice sheets, ice shelves, permafrost, and seasonally frozen ground. The term "cryosphere" traces its origins to the Greek word 'kryos' for frost or ice cold. The stratosphere extends from 4 -12 miles (6-20 km) above the Earth's surface to around 31 miles (50 km). This layer holds 19 percent of the atmosphere's gases but very little water vapor. In this region, the temperature increases with height. Furthermore, these techniques have the operational advantage of avoiding direct changes to the atmosphere and biosphere and the need for complex land use and resource trade-offs.

Ongoing studies deduce that some, if not all, of these techniques could be a critical toolbox for climate intervention or a climate barrier [18]. The various measures considered for reducing global warming under the banner of Geo-engineering includes:

6.1 Atmosphere

- i. Stratospheric Aerosol Injection [19] = Injection of micro reflective particles into the stratosphere to reduce atmospheric temperature. Aerosol injection or a space mirror system reducing insolation at an accelerating rate of 1 Wm^{-2} per decade from now to 2100 could limit or reduce sea levels. Aerosol injection delivering a constant 4 W/m^2 reduction in radiative forcing could delay sea-level rise by 40–80 years. Aerosol injection appears to fail cost-benefit analysis unless it can be maintained continuously, and damage caused by the climate response to the aerosols is less than about 0.6% Global World Product [27]

- ii. Marine Cloud Brightening [20] = Injection of micro particles into marine stratocumulus clouds to increase reflectivity to offset atmospheric warming.
- iii. Cirrus Cloud Brightening [21] = Injection of silver iodine into cirrus clouds to thin or eliminate the clouds to allow long-wave thermal radiation to escape the atmosphere.
- iv. Microbubbles [22] = Injection of surfactants onto the ocean surface to increase surface albedo and reduce ocean heat transfer (Figure 4).
- v. Ocean Fertilization [23] = Adding micro and macronutrients into the ocean to stimulate phytoplankton growth to enhance carbon dioxide sequestration and lower temperatures. Ocean fertilization is the best studied ocean geo-engineering method and may be able to reduce both ocean acidification and global warming. It involves supporting the growth of phytoplankton, which convert CO₂ into oxygen through photosynthesis. Microscopic phytoplankton performs around 50% of the world's photosynthesis.

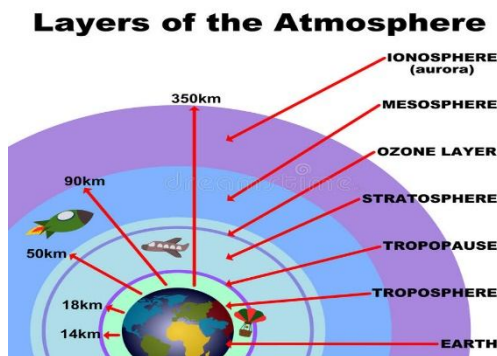


Figure 3. Layers Of the Atmosphere
Source: <https://www.dreamstime.com/>

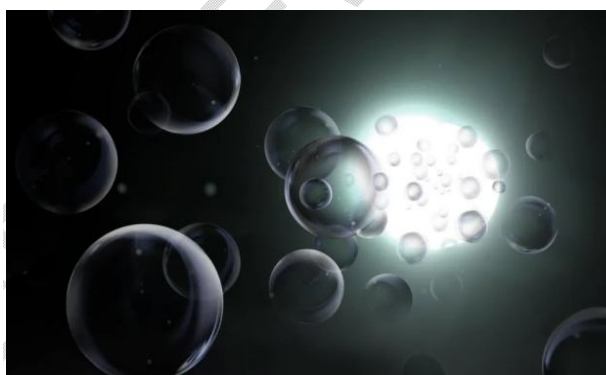


Figure 4: "Space Bubbles" – The Deflection of Solar Radiation Using Thin-Film Inflatable Bubble Rafts - Massachusetts Institute of Technology
Source :<https://scitechdaily.com/> July 24,2022

6.2 Cryosphere

- i. Glacier Geo-engineering [24] = Restriction of polar outlet glaciers (e.g. berms [16], buttressing, basal freezing, bed drying) to prevent ice mass loss.
- ii. Sea Ice Restoration [25] = Placement of floating reflective materials onto the Arctic Ocean surface to increase and thicken sea ice, increase albedo and reduce Arctic temperature.

7.0 Conclusion:

Climate change (CC) has continued to have a devastating effect on the earth's sustainability. The impact on the environment, economy and society has continued to gain significant attention among countries worldwide. One of the big reasons that climate change is so controversial is that the modelers have oversold their predictive abilities.

Current mitigation efforts and existing future commitments are inadequate to accomplish the Paris Agreement temperature goals. In light of this, research and debate are intensifying on the possibilities of additionally employing proposed climate geo-engineering technologies, either through atmospheric carbon dioxide removal or farther-reaching interventions altering the Earth's radiative energy budget. Although research indicates that several techniques may eventually have the physical potential to contribute to limiting climate change, all are in early stages of development, involve substantial uncertainties and risks, and raise ethical and governance dilemmas. Based on present knowledge, climate geo-engineering techniques cannot be relied on to significantly contribute to meeting the Paris Agreement temperature goals [28]. It is felt that improved recognition of these processes is necessary to identify achievable mitigation actions, avoiding excessively optimistic assumptions and consequent policy failures. The targets will depend of future scenarios of emission which again will depend on policies of different nation, which is a global issue. Geo-engineering has been proposed as a feasible way of mitigating anthropogenic climate change, especially increasing global temperatures in the 21st century. The two main geo-engineering options are limiting incoming solar radiation, or modifying the carbon cycle. While Geo-engineering is an overall approach to climate change, the feasibility and effectiveness is yet questionable and need to be established. Now, research from the Harvard John A. Paulson School of Engineering and Applied Sciences (SEAS) finds that solar geo-engineering may be surprisingly effective in alleviating some of the worst impacts of global warming. While pretty much no one is claiming solar geo-engineering could replace planet-warming pollution cuts and solve climate change, supporters argue it could have a big planetary cooling effect for a relatively small price tag. A 2018 Harvard study estimated it would cost around \$2.25 billion a year over a 15-year period [26]. 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 order of their technical feasibility and economic viability which may appear if implemented holistically.

UNDER REVIEW

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