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Effects of Variations in Earth's Gravitational Force Fields on Climate Change

Uzoma Oduah[1], Emmanuel Joel[2], Josephat Izunobi[3], Olubunmi Nubi[4], Samuel Popoola[4], Nnaemeka Njoku-Achu[5, 6], Oluwaseun Ajileye[7], Daniel Obiora[6], Augustine Chukwude[6] & Babatunde Rabiu[7]

[1] Department of Physics, University of Lagos, Lagos, Nigeria

[2] Department of Earth Sciences, Anchor University, Lagos, Nigeria

[3] Department of Chemistry, University of Lagos, Lagos, Nigeria

[4] Nigerian Institute for Oceanography and Marine Research, Lagos, Nigeria

[5] National Space Research & Development Agency (NASRDA) Centre for Basic Space Science, Nsukka, Nigeria

[6] Department of Physics & Astronomy, University of Nigeria, Nsukka, Nigeria

[7] African Regional Centre for Space Science and Technology Education - English (ARCSSTE-E), Obafemi Awolowo University, Ile-Ife, Nigeria

Correspondence: Josephat Izunobi, Department of Chemistry, University of Lagos, Lagos, Nigeria.
E-mail: jizunobi@unilag.edu.ng. ORCID: 0000-0002-6315-4969

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Abstract

World climate continues to deteriorate at varying rates in spite of different anthropogenic mitigative and adaptive interventions. Conversely, the gravitational force fields of the sun and moon hold Earth in orbit, amongst others. Herein, we explore the impacts of changes in these gravitational fields on global climate and examine their influences on natural events, such as ocean tides, volcanoes, geomagnetic storms and movement of tectonic plates. Beyond reports on greenhouse effect and mass transport, we discuss the influence of gravity on tidal bulges, melting glaciers, condensable atmosphere and other events, such as El Niño and La Niña, and correlate their typically subtle impacts on climate worldwide with variations in Earth's gravity. The intention is to highlight other causative factors implicated in climatic change without diminishing the contributions of greenhouse gasses and other factors, which are currently regarded, by specialists and lay-public alike, as the major culprits of climate change. We submit that the shifts in Earth's gravitational fields to sustain equilibrium and remain in orbit can manifest as perturbations of atmospheric temperatures, pressures and air concentrations as well as volume changes and ion effects; in hydrological bodies, and are some of the non-anthropogenic agents driving changes in global climate. We surmise, therefore, that the influence of changes in gravity, albeit subtle, on climate change is significant. It is envisaged that highlighting these subtle agents of change would intensify efforts toward ameliorating and/or eliminating drastic and deleterious changes in climate as well as at embracing adaptive measures at local and international levels.

Keywords: atmospheric circulation, climate change, geomagnetic storms, gravity, greenhouse effect, ocean tides, SDG-13

1. Introduction

The adoption of the 2030 agenda for sustainable development goal 13 (SDG-13), amongst 17 others, to 'take urgent action to combat climate change and its impacts' (UN, 2015) by all United Nations Member States in 2015 was aimed at strengthening the global response to the threat of climate change by keeping this century's global temperature rises below 2 ^{o}C above the pre-industrial levels of 1850–1900 (Rhodes, 2019; IPCC, 2021). Dishearteningly, however, some of the sustainable development goals (SDGs); including SDG-13, are off-track (UN, 2021), more than seven years from the resolution. Moreso, with the emergence of the corona virus disease 2019 (COVID-19) pandemic, progress in many other vital areas and targets, including lowering carbon emissions, have either stalled or reversed (UN, 2021). It is notable that despite the global economic slowdown of 2020, the concentrations of major greenhouse gases have continued to increase; with the global average temperature estimated to rise to about 1.2 ℃ above pre-industrial levels (IPCC, 2021; UN, 2021). This is in spite of the 4–10% drop, albeit temporarily, in greenhouse gas emissions in 2020 due to COVID-19-related travel bans and economic slowdowns (UN, 2021).

Nonetheless, the decision of the Royal Swedish Academy of Sciences to award the 2021 Nobel prize in Physics to Syukuro Manabe, Klaus Hasselmann and Giorgio Parisi for laying 'the foundation of our knowledge of the Earth's climate and how humanity influences it as well as revolutionizing the theory of disordered materials and random processes' (NobelPrize.org, 2021) underpins the significance of climate change and spotlights the need to move the discussions from 'talk' to 'walking the talk' (Barnard, 2021; Wanless, 2021).

Our world is faced with the global challenge of gradual, deteriorating and deleterious changes in our climate evidenced by the abnormal variations in earth's temperature, humidity, air pressure, cloud systems, wind and hydrology, over time (IPCC, 2021). Understanding the causes of worldwide climate change that has persisted for decades, and proffering solutions, remain issues of urgent scientific interests and demands as well as policy and practice; not only because of the potential life-threatening risks to humans but also due to the potential damages it presents to the environment. It is well-known that changes in the climate can be attributed to anthropogenic and natural events' activities (Knowles & Cayan, 2002). These include man-made activities, such as the burning of fossil fuels and deforestation, which lead to the emission of greenhouse gases, release of toxic and obnoxious wastes, and reductions in carbon sinks (Duchemin, 2022). In contrast, contiguous natural events include volcanic eruptions, shifts in tectonic plates, variations in the sun's intensity, gravitational force fields and geoid heights as well as the albedo effect, El Niño and La Niña, etc. (Lamon *et al.*, 2009; von Schneidemesser *et al.*, 2015). Significantly, denudation and geomorphic processes, for instance, which involve the transfer of solid and/or dissolved materials by different agents, such as continental and ocean waters, ice, air, plants, animals and humans, from one part of Earth's surface to another under the influence of gravity, and wind and water currents, are reported to be at least one order of magnitude greater due to human-triggered land surface alterations than nature-induced denudational processes (Cendrero *et al.*, 2022; Eekhout & de Vente, 2022).

Greenhouse gases, such as carbon dioxide, methane and water vapor, are implicated in the greenhouse effect, which regulates global temperature and is, therefore, essential for life on Earth. Greenhouse gases absorb harmful radiant energy, such as infrared radiation, and subsequently release it to the environment thereby heating up the surrounding air and ground (Rose, 2021; Tuckett, 2021). Interestingly, water vapor is the most persistent greenhouse gas but it is controlled by the hydrological cycle unlike carbon dioxide (CO_2), which is, largely, subject to anthropogenic controls (Rose, 2021). Notably, atmospheric water vapor is dependent on temperature, which is dependent on CO_2 concentrations (Zhai & Eskridge, 1997). Simply put, the more the CO_2 in the atmosphere, the warmer it gets and the larger the amount of water vapor that can be held in the air. Consequently, the higher the concentration of atmospheric water vapor, the higher the temperature rises. Pertinently, about 93% of the atmospheric warming caused by these temperature rises are transferred to the water bodies; with concomitant rises in surface temperatures (Wanless, 2021). A consequence is the accelerated melting of the polar ice, which results in the rise in global sea levels. It is noteworthy that when CO_2 levels drop, water vapor condenses; cooling the atmosphere, with attendant reduction in temperature.

Relatedly, Manabe and Wetherald (1967; 1975) had previously shown that changes in atmospheric CO_2 impacted temperature and surmised that temperature rises were attributable to increases in CO_2 levels since rising temperatures were observed closer to the ground, with relatively higher CO_2 concentrations, whereas the upper atmosphere, with lower CO_2 concentrations, exhibited decreasing temperatures. They, therefore, concluded that solar radiation variations were not responsible for the observed increases in temperature as the upper and ground atmospheres would exhibit similar changes in temperature if the converse were the case.

Globally, researchers and policymakers have continued to focus on controlling and managing anthropogenic activities with a view towards mitigating climate change as stocks in the atmosphere are forecasted to stabilize in 100–300 years (Ma *et al.*, 2010). The approach is to categorize the interventions into mitigative and adaptative solutions. The mitigative interventions tend to proffer solutions to annul or reverse causative factors of climate change whereas adaptative interventions adjust human practices with improved technologies; to be able to evolve and fit into the dynamic environment, to reduce climate change vulnerabilities.

It is instructive that a major part of the mitigative interventions has been channeled towards reducing greenhouse gas emissions. These include the introduction of renewable energy transfer devices with enhanced efficiencies, electric and solar cell-based transportation, fuel switching and other practices geared at preserving and expanding the carbon sinks (Rosenzweig *et al.*, 2007). A post-Kyoto climate regime was also introduced to monitor global compliance to climate change policies in developed and developing nations to ensure a balanced, fair, equitable and acceptable emission reduction levels in order to avert dangerous changes in the climate (Vanderheiden, 2011). Similarly, adaptative interventions are hinged on planned large-scale models that inform policy choices and the coping strategies of communities and individuals; in order to reduce their vulnerabilities to climate change. Such adaptations include irrigation, seasonal climate forecasting, water resources' management, agricultural productions and the diversification of livelihoods as well as the implementation of various disaster monitoring/alerting technologies and flood warning systems.

Interestingly, a study of the variations in the sea levels and climate of the Ordovician period suggests that the icehouse conditions and fall in sea levels as well as other major faunal turnovers were triggered by the extraordinary amounts of Earth-cooling dust veils therein (Melki *et al.,* 2009). The foregoing, therefore, reinforces the potential level of impact of natural phenomena on climate change. Consequently, and on the backdrop of the just-concluded 27th Conference of the Parties (COP 27), held in Sharm el-Sheikh, Egypt; which not only sought to reaffirm the resolution of COP 26 (Glasgow, UK) to 'put the world on a path to aggressively cut greenhouse gas emissions and slow Earth's warming' but to, more pertinently, 'actively move toward local and global adaptations to the inevitable impacts of climate change' (UNFCCC, 2022), we examine the influence of the earth's gravitational force field on natural events, such as ocean tides, tectonic plates' shifts, volcanoes and geomagnetic storms, as well as the moon, sun and other associated agents on climate change. The intention is to highlight other causative factors implicated in climatic change without diminishing the contributions of greenhouse gasses, and other factors, which are currently regarded, by specialists and the lay public alike, as the major culprits of climate change. The objective being to attempt to draw the attention of researchers and policymakers toward these other subtle agents of change with a view to ameliorating or, perhaps, eliminating drastic and deleterious changes to the global climate; and where tenable, embrace adaptive measures at both local and international levels.

2. Impacts on Climate

2.1 The Impact of Gravity on Ocean Tides

It is common knowledge that the earth's atmosphere is maintained by its gravitational force fields, which keep it in orbit (Kivelson and Russell, 1995). It also causes ocean tides (Helm *et al.*, 2010; Sumich, 1992). Accordingly, Newton's law of universal gravitation stipulates that every particle exerts a force of attraction on every other particle in the universe with a force of magnitude F, which varies directly with the product of their masses, M_1 and M_2, and inversely as the square of their distance R apart (Ducheyne, 2009). Mathematically, the gravitational force is described as:

$$F = G\left(\frac{M_1 M_2}{R^2}\right) \quad (1)$$

where M_1 and M_2 are the masses of two different bodies with a distance of R apart. G is the gravitational constant.

This implies that forces of attraction exist between the earth and its moon and sun, respectively, based on their individual masses and distances apart. Figure 1 illustrates the estimation of the magnitude of the gravitational force field producing the tidal bulges due to the gravitational force of attraction between Earth and its moon. R designates the radius of Earth and r is the orbital separation between Earth and its moon. G is the gravitational constant. The higher mass within the sublunar creates high tide.

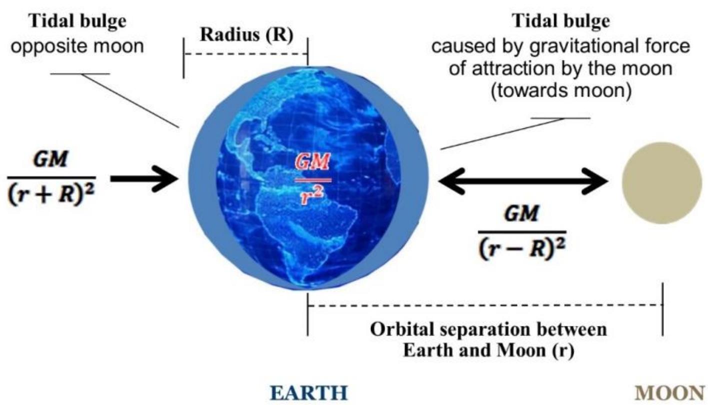

Figure 1. Estimation of the gravitational force field between Earth and its moon (The sun's is not shown)

Consequently, changes in Earth's gravitational field will have strong implications on its hydrological cycle. This is evidenced in the strength of the gravitational forces of attraction from the earth's moon and sun on its oceans, which generate tidal waves and allied storms (Sumich, 1992). Furthermore, depending on the trajectory locations of the sun and moon with reference to Earth, the magnitude of the gravitational pull producing the ocean tides and bulges can fluctuate (Kennish, 2019; Munk & Revelle, 1952), leading to commensurate changes in the tidal currents. So, the stronger the gravitational pull, the larger the tidal bulges and vice versa (Kennish, 2019). Additionally, a relatively small change in water levels could trigger large changes in the return period and more perturbations and rises in sea levels (Thurman, 1994). It is worthy of note that the magnitude of ocean tides can be also influenced by the shape of the shoreline as well as local wind and pressure systems (Keeling & Whorf, 1997). The rise and fall of tidal waves play crucial roles in our natural world and can have marked effects on the climate and environment, especially maritime.

Tidal action has been suggested as a possible cause of periodicities in temperature wherein it has been proposed that abnormally great ocean tides modulate the amount of warm water entering the Arctic, Bering and Baltic seas (Keeling & Whorf, 1997). Contrarily, weak but persistent north–south tidal currents, which reverse over an 18.6-year nodical cycle, may also be capable of periodically changing ocean surface temperatures (Keeling & Whorf, 2000; Royer, 1993). Establishing a relationship between tidal forcing and temperature is, therefore, significant because the oceanic tide-raising forces can, predictably, vary in strength over a wide range of time scales and should temperature, on any time scale, prove to be influenced by tidal action, it could explain the variabilities in temperature on other time scales; even millennial and longer, and climate change (Ward *et al.*, 2012; Washington *et al.*, 1980).

Likewise, mass shifts have been linked to the melting glaciers in Antarctica, for example, which is a major contributor to the variations in Earth's gravitational field. This is reported to influence ocean tides (Ward *et al.*, 2012). Mass transport in the Antarctic is caused by drifting snow particles, which are propelled by different wind systems; sometimes leading to sublimation. The melting of ice glaciers is also attributable to the rises in global surface temperatures (Seo *et al.*, 2015). Besides, in their investigation of the causes of the Greenland ice sheet surface melt of July 2012, Hanna *et al.* (2014) concluded that it was atmospheric. They connected it with the natural variabilities of the summer North Atlantic Oscillation (NAO), Greenland Blocking Index (GBI) and polar jet stream, which favor southerly warm air advection along the western coast. They also agreed with Goelzer *et al.* (2012) that the mass balance of the Greenland ice sheet would likely be a dominant contributor to global sea-level changes over the next century or millennium years. In addition, reports show that, between 2002 and 2017, 60% of the total mass loss in Antarctica and Greenland was due to enhanced ice melts, in response to Arctic warming trends, while the increased ice flow into the oceans constituted 40% (Tapley *et al.*, 2019). It is instructive to note that sea levels are expected to continue rising even after the human-induced climatic warming of Earth has been stabilized (Goelzer *et al.*, 2012). This underscores the significant impact of natural causative factors in climatic change.

Greenberg *et al.* (2012) also reported, based on data from the Bay of Fundy and Gulf of Maine, that the existing trends in mean sea levels and changing tides, which can result in rises in sea levels are related as their analysis of long-term sea level records showed that, independent of global warming-related climate change, sea levels and tidal ranges have been rising in the system. In the same vein, Frederikse *et al.* (2020) surmised that the sum of the contributions to sea-level changes from ice-mass loss, thermal ocean expansion and changes in terrestrial water storage is consistent with the trends and multidecadal variability in global sea level, and suffice to explain the observed changes since 1900. Figure 2 depicts change in global mean sea levels from 1900 to 2018; with data derived from coastal tide gauge and satellites. The factors responsible for the increases and decreases in mean sea levels are designated with positive (+) and negative (–) signs, respectively, and displayed at the times they caused the changes in sea level (NASA, 2021).

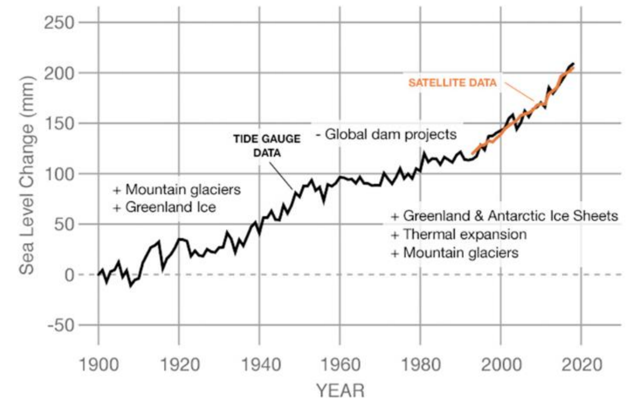

Figure 2. Change in global mean sea levels from 1900–2018 (Frederikse *et al.*, 2020; NASA, 2021)

It is also noteworthy that the effect of tides on the pathway of the North Atlantic Current (NAC), for example, and the resulting changes in the sea surface temperature also impact the ocean–atmosphere heat flux. Müller *et al.* (2010) implemented an explicit forcing of the complete lunisolar tides into the ocean part of a coupled atmosphere–hydrology–ocean–sea ice model and showed that this climate model was significantly affected by the induced tidal mixing and non-linear interactions of the tides with low frequency motion. Interestingly, the largest changes occurred in the North Atlantic where the ocean current system experienced large-scale changes. The modification of the pathway of the NAC yielded improved sea surface temperature fields, of up to 50 W/m^2, in comparison to the non-tidal runs. Therefore, it is plausible to infer that the climate simulations, which resulted in an improved NAC had strong implications for the simulation of the Western European Climate, particularly, with amplified temperature trends between 1950 and 2000, as these simulations were closer to the observed natural trends (Müller *et al.*, 2010).

It is said that the story of gravity causing tides dates back to the Newtonian era but it appears that, today, the tides are an intricate part of the story of climate change, as is the history of the lunar orbit (Wunsch, 2000). Tides transport sand and sediment and oftentimes help to shape shorelines and affect other aspects of maritime life, such as feeding, reproduction and removal of pollutants. Tidal currents have also been exploited in hydroelectricity and renewable energy (Leary & Esteban, 2009). Ocean tides also endue more habitable climatic conditions by mixing Arctic waters, which do not experience much sunlight, with warmer waters from the Tropics thereby regulating the earth's temperature.

2.2 The Ecological and Chemical Impacts of Ocean Tides

Tidal changes can often lead to the accumulation of aquatic fauna and flora in localized areas with limited resources whilst causing dearth of same in other areas (Barendregt & Swarth, 2013). The former typically results in periods of rapid growth in which large amounts of nutrients and dissolved gases are expended. In addition, bioactive natural products, which may be stored in plants, are generated and released into the environment or broken down, during decomposition (Van Alstyne *et al.*, 2015). The large-scale use, depletion and/or production of organic and inorganic compounds under such conditions commonly have detrimental impacts on other proximal organisms and their environments (Ye *et al.*, 2011).

With algal 'green tides', for example, as the blooms develop and expand, the algae take up inorganic nutrients, such as nitrates and orthophosphates, which may limit the availability of these nutrients to other photosynthetic organisms (Van Alstyne *et al.*, 2015). Additionally, the algae's uptake of dissolved inorganic carbon for photosynthesis can cause localized spikes in the ocean water's pH during the day with concomitant drops in the pH at night, when the algae are respiring (Van Alstyne *et al.*, 2015). Essentially, these macroalgal blooms can have harmful effects on other organisms by altering the concentrations of the dissolved gases and nutrients in the aqueous environment as well as produce and release allelopathic compounds. The instance of the deaths of one horse and thirty wild boars, attributed to effervesced hydrogen sulfide gas, from the decomposition of the blooms, calls to mind (Smetacek & Zingone, 2013). Many of the allelochemicals are also used by plants to mediate ecological interactions, such as deterring feeding by herbivores and reducing the growth of pathogens, competitors and fouling organisms (Van Alstyne *et al.*, 2015).

Moreover, the agglomeration of aquatic fauna and flora by tidal currents as well as the anthropogenic inputs of nutrients and carbon dioxide (CO_2) into the oceans and atmosphere can alter the chemistry of the ocean waters (Van Alstyne *et al.*, 2015). For instance, CO_2 dissolved in sea water not only generates hydrogen ions (H^+), in a series of reversible reactions (*cf*. eqn. 2), which can cause a decrease in ocean water pH as the concentration of aqueous CO_2 increases (Doney *et al.*, 2009) but also depletes the calcium carbonate ($CaCO_3$) sources (*cf*. eqn. 3). $CaCO_3$ is an important building block in corals, shells and exoskeletons of many aquatic animals. It is also worthy of note that whilst plants are net generators of oxygen gas (O_2), as they photosynthesize with CO_2 and grow, they can also cause hypoxia in periods of reduced photosynthesis (Diaz, 2001). Crucially, atmospheric and aqueous CO_2 are predicted to increase by 2100 AD; resulting in a 0.3–0.4 decrease in the average ocean pH (Orr *et al.*, 2005).

$$CO_2\,(g) \rightarrow CO_2\,(aq) + H_2O\,(aq) \rightleftharpoons H_2CO_3\,(aq) \rightleftharpoons H^+\,(aq) + HCO_3^-\,(aq) \rightleftharpoons 2H^+\,(aq) + CO_3^{2-}\,(aq) \qquad (2)$$

$$CaCO_3\,(s) + CO_2\,(aq) + H_2O\,(aq) \rightarrow Ca^{2+}\,(aq) + 2HCO_3^-\,(aq) \qquad (3)$$

It is pertinent to point out that though other factors influence these reactions on a variety of time scales and that these processes do not occur in isolation, the impacts of these processes, on a local scale, on the pH and dissolved inorganic carbon (DIC) concentrations of the ocean water, for example, may be larger than the impacts of atmospheric carbon dioxide (Duarte *et al.*, 2013). Nonetheless, changes in O_2 concentrations are expected to have more adverse effects on the aquatic fauna as low O_2 concentrations can cause high mortality and sublethal stress in marine animals as well as alter the structures of marine communities (McAllen *et al.*, 2009). Instructively, the impact of the Paleocene-Eocene Thermal Maximum (PETM), which was associated with global warming, acidification and oxygen stress (hypoxia), on shallow marine molluscan faunas has been analyzed (Ivany *et al.*, 2018); indicating that the long-term impact of PETM on these shallow-water benthic communities was minimal. On the contrary, changes in the climate, which result in expanded benthic habitat, less ice cover and higher light availability may also lead to more detrital carbon in the system thereby dampening the quantitative importance of the seasonal pulses of phytodetritus to some Arctic seafloor communities (Morata, 2020).

It is notable that differences in the pathlengths of light through the ocean water column can decrease the attenuation of light at low tides but increase it at high tides (Nelson & Waaland, 1997). It is therefore reasonable to conclude that the chemical and ecological impacts of changes in the gravitational field vis-à-vis the rise and fall of ocean tides can be significant on the earth's hydrosphere.

2.3 The Impact of Gravity on Tectonic Plates and Volcanoes

Tectonic plates are the pieces of Earth's crust and uppermost mantle, which form the planet's lithosphere, and its movement shapes Earth's surface. It has also been established that gravity drives the motion of tectonic plates, generating mass transport (Coltice *et al.*, 2019). The kinematics and stress of the movement of tectonic plates are seen as active sliding and sinking in different models, which demonstrate vertical components downwards from the ridge crest to the ocean floor and extend into the asthenosphere and mesosphere beneath the Earth (Bercovici, 1993; Davies, 1989). Gravitational spreading has been identified as the cause of extensional deformation in the Tibetan plateau and the formation of subduction zones (King *et al.*, 1992). In similar vein, Vasanthi and Santosh (2021) provided insights into the thinning lithospheric architecture and extensive decratonization of the North China Craton; underlining the presence of a positive residual gravity anomaly (+90 mGal) over a differentiated 15 km-thick layer of lower crustal and upper-mantle magma, emplaced below the Jizhong depression. Moreover, the interactions of tectonic plates have led to the formation of mountains and valleys and the occurrence of fault lines whereas the releases of energy at the fault lines have caused earthquakes (Mahmud, 2019).

Mitsui and Yamada (2017) examined earthquakes of < 7.5 magnitude and found, using correlation analysis, that a moderate positive correlation existed between the amplitudes of the annual gravity changes and the shallow background seismicity rates at the worldwide subduction zones (*cf*. Figure 3). Figure 3 shows the monthly changes in gravity as equivalent water thickness and the number of earthquakes per month (in grey lines) at a grid of longitude 275° and latitude 5°. Gravity change was equated to water thickness because changes in gravity are congruous to the hydrological water mass movements around Earth's surface (Mitsui & Yamada, 2017); as changes in hydrology are also affected by climate warming (Yao *et al.*, 2022). Besides, the mass transport, energy exchange and gas emissions generated by earthquakes are part of the agents of climate change. Gravity drives the movement of the tectonic plates, which produces the earthquake event. Also, mass shifts have been linked with the motions of the tectonic plates, which are influenced by the gravitational pulls from the moon and sun thereby amplifying the climate change cycle. Not forgetting geomorphic processes, which affect landscapes and are known to result in transfers that could include relief reductions, by way of volcanism and tectonic or isostatic uplifts, and the deposition of eroded materials in different sedimentary environments (Cendrero *et al.*, 2022).

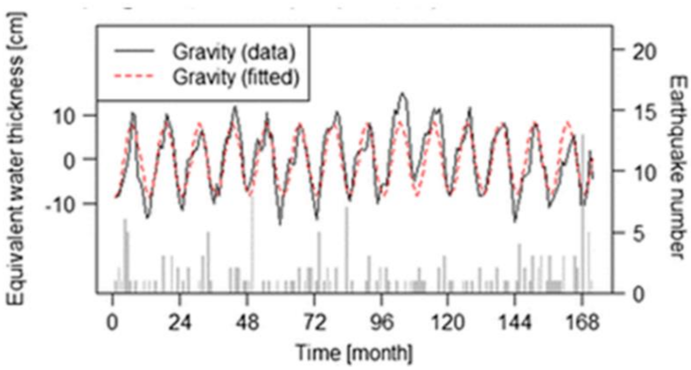

Figure 3. Monthly change in gravity (water thickness) superimposed on monthly earthquake numbers, from April 2002–March 2016 (Mitsui & Yamada, 2017)

Volcanoes have been reported to erupt in locations with relatively high concentrations of magma, which is synonymous with greater mass and higher gravity; monitoring changes in the gravitational field of active volcanoes can, therefore, provide insights into volcanic activities (Poland & Carbone, 2016; Yan, 2016). Volcanoes typically occur as a combination of seismic activities and gas emissions, with the eruptions creating surface deformations (Compton *et al.*, 2015; Crowley *et al.*, 2015). Besides, volcanoes and phreatomagmatic eruptions eject lava flows, which increase temperature and discharge harmful gases, such as carbon dioxide, sulfur dioxide, hydrogen sulfide and hydrogen halides (Tuffen, 2010).

It is instructive that less volcanic activities were observed in Iceland when glacier covers were more extensive; suggesting that the melting of glaciers triggers more volcanic activities (Swindles *et al.*, 2017). Congruously, rapidly receding glaciers and ice sheets at locations of active volcanoes are causing more ice-melts and rises in global sea levels, which are, in turn, driving climate change. Furthermore, the freezing of the world's ocean waters in ice sheets during glaciation also causes submarine eruptions as it reduces the ocean's pressure on the floor thereby allowing magma to escape from Earth's mantle (Pearce, 2015). On the coastal planes, on the other hand, the melting of ice relieves the pressure on the rocks beneath thus allowing them to erupt upwards. Notably, the generation, storage, pressure and eruption of magma at stratovolcanoes are dominated by gravity (Greco, 2020). Gravity can also transfer the effects of volcanoes to other agents of climate change with amplified ripple effects. Therefore, the mass transport, energy exchange and gas emissions associated with rapidly increasing events of volcanoes contribute significantly to climate change.

The foregoing was reinforced by Crowley and co-workers (2015) who, through a detailed analysis of the topography of the seabed of the southern (Australian–Antarctic) ocean, buttressed the connection between climate change and volcanism and, by extension, gravitational field by showing that the eruptions coincided with phases of orbital wobbles known as Milankovitch cycles, which trigger ice ages. They explained that locking up the world's water in ice sheets on land, for example, can lower sea levels, which can in turn reduce the ocean's pressure on the seabed to permit the escape of magma (Pearce, 2015). Cyclically, therefore, changes in gravity can drive the movement of tectonic plates, which can result in earthquakes and volcanic eruptions; leading to mass shifts and, consequently, climate change. In other words, earthquakes weaken the earth's geosphere; with concomitant damages whereas volcanic eruptions release noxious gasses. Glaciations and deglaciations may also trigger submarine eruptions and magma outflows, respectively (Pearce, 2015), or much more but all with deleterious consequences on the climate.

2.4 The Impact of Gravity on Geomagnetic Storms

A geomagnetic (or solar) storm is described as a temporary disturbance of the earth's magnetosphere by a solar wind shock wave and/or cloud of magnetic field, which interacts with the earth's magnetic field (Gonzalez *et al.*, 1994). Acoustic-gravity waves (AGW), in contrast, are compression-type waves propagating with amplitudes governed by the restoring force of gravity (Kadri, 2014). They are, therefore, generated and propagated during geomagnetic storms. AGW are also generated by underwater (deep ocean) earthquakes, explosions, landslides and other mechanisms, such as surface waves and meteorites (Lal, 2006). A variation in gravity can generate strong perturbations in AGW and cause them to travel thousands of meters in oceans, transport materials and create regions of extreme temperatures. Besides, these immense deep-ocean waves can rapidly transport millions of cubic meters of water; carrying salts, carbons and other nutrients around the globe in a matter of hours (Kadri, 2014).

Previous reports show a strong geomagnetic–weather relationship and that AGW of oceanic origin have an observable impact on the upper atmosphere (Godin *et al.*, 2015). AGW influences the tropospheric acoustic gravity waves triggering variations in weather conditions. Similarly, high correlation coefficients have been found between geomagnetic activity, sea-level atmospheric pressure and surface air temperature (Bucha & Bucha, 1998). These correlation coefficients were positive in middle and southern Europe, south-eastern North America and western Atlantic but negative sign in northern Atlantic and Canada (Bucha & Bucha, 1998). The impact of geomagnetic storms on atmospheric waves is, therefore, characterized by variations in wind speeds and atmospheric density and pressure; all of which induce climate change.

Likewise, geomagnetic storms reportedly bring about a high-pressure weather system, which can alter Earth’s gravitational force field and result in variations of the elastic Earth’s shape by up to 2 cm (Subedi *et al.*, 2017). Geomagnetic storms equally induce small but measurable fluctuations in the earth’s rotation pattern, which are evidenced from polar motions and changes in the duration of daylight (Laštovička, 1996). The fluctuations in Earth’s rotation can trigger a block pattern that interrupts the westerly winds causing extreme weather conditions, which can also affect tidal bulges and gravity. Researchers have also demonstrated that the impacts of geomagnetic storms are consistent with a weakening of the earth’s magnetic field. They posit that the weakening magnetic field allows cosmic rays to stream more freely through Earth’s magnetosphere into its atmosphere with reduced resistance (Arnold & Robinson, 2001; Woodbridge, 1971) thereby impacting on the global climate.

2.5 The Impact of Gravity on Atmospheric Circulation

Atmospheric circulation is usually used to depict the large-scale movement of air by which heat and moisture are distributed on Earth’s surface. The strength, direction and steadiness of prevailing winds dictate the vagaries of climate and are likely to have profound influences on global ecosystems and societies (Ogutu-Ohwayo, 2016). The changes in the structure of atmospheric circulation and its associated winds are best described as poleward displacements of major wind and pressure systems in the atmosphere. These include changes in tropical and extratropical circulations, which are related to a poleward expansion of the Hadley cell and shift of the zone of high westerly winds in the mid-latitudes; also known as an enhanced positive phase of the annular modes, respectively (Reichler, 2009). The study of Zhu *et al.* (2015), on the Tibetan plateau, has documented changing climatic conditions in response to shifting atmospheric circulation since the last glacial maximum.

The sphericity of Earth and the resulting spatially non-uniform distribution of solar heating are the basic drivers of atmospheric circulation (Reichler, 2009). The tropics absorb about twice the solar energy absorbed at the higher latitudes thus creating a meridional gradient in temperature and potential energy (Ogutu-Ohwayo, 2016). Some of the potential energy is then converted into kinetic energy, which consequently manifests as wind. The winds are typically deflected under the influence of the rotating Earth to create a complicated flow pattern (Reichler, 2009). Notably, atmospheric circulation is also driven by AGW, which can be equally defined as a type of buoyancy waves that, on breaking or becoming unsteady, deposit their energy and momentum into the mean atmospheric flow (Moffat-Griffin *et al.*, 2019).

The Pacific Ocean-originating weather patterns, El Niño and La Niña, have both been indicted as two of the drivers (and not causes) of climate change (Blunden *et al.*, 2011). El Niño and La Niña describe the warming and cooling phases, respectively, of the El Niño Southern Oscillation (ENSO), which is a cyclical weather pattern that influences temperature, humidity, rainfall and winds across the globe (Wang *et al.*, 2017). During the El Niño, the pressures of the trade winds weaken, allowing warmer waters to move south of its neutral position under the influence of the Pacific jet stream but cannot flush the warm waters at the surface to enable upwelling (Weng *et al.*, 2007). Consequently, nutrients become trapped at the ocean bottom while the surface gets warmer, leading to dryer and warmer North American weathers as well as destabilized marine ecosystems and disruptions in maritime food chains (Wang *et al.*, 2017). The converse is the case during La Niña as warm waters are flushed towards Asia; enabling rapid upwelling, which brings cold waters and nutrients to the surface, and can result in droughts and wildfires in southern America as well as heavy rainfalls and flooding in Northwest Pacific and Canada (Kug *et al.*, 2009). El Niño and La Niña are reported to influence climatic conditions drastically during winter in the northern hemisphere (Yu *et al.*, 2012). Pertinently, changes in the gravitational field also influence upwelling and ocean currents, which can contribute to climate change.

Considerable scientific evidence show that key elements of the atmospheric circulation system are moving poleward. Additionally, current theories and model experiments indicate that anthropogenic activities, greenhouse gas increases and stratospheric ozone depletion are the likely culprits responsible for the trend. Nevertheless, the possibility that natural climate variabilities also play important roles cannot be ruled out (Reichler, 2009).

Furthermore, the gravitational force field on Earth also acts on the wind systems and influences atmospheric pressures based on its variation in density (Merriam, 1992) whereas the thermally- and eddies-driven gradient jet streams are directly propelled by the equator to pole temperatures and eddy currents, respectively (Lehmann *et al.*, 2015). Eddy currents are generated by the rotation patterns of Earth whereas Rossby waves are generated from eddy stream jets; which can cause blocking, leading to extreme weather conditions (Petoukhov *et al.*, 2013). Researchers have shown that the magnitude of blocking is determined by a combined effect of the speed of the jet stream's wind, and latitude and width of the jet (Kornhuber *et al.*, 2020). Besides, the Rossby waves and Monsoon circulation are both influenced by gravity. The former can cause severe weather conditions while the latter can be influenced by the gravitational force field on the wind density and pressure (Schott *et al.*, 2009); with both being capable of triggering changes in climatic conditions.

3. Conclusion

It is established that the climate of Earth is governed by its distance to its sun and moon, size, rate of rotation, obliquity, gravity and atmospheric composition, amongst others. Herein, the impacts of the Newtonian gravitational force field on some climate change-related factors in the earth's hydrosphere, lithosphere and atmosphere have been probed and salient relationships highlighted; with the surmise suggesting that variations in gravity are implicated, to some degree, in climate change. Significantly, changes in Earth's gravitational field have strong consequences on its hydrological cycle as the rise and fall of tidal waves play crucial roles in our natural world; with marked effects on sea levels, glaciers, shorelines, temperature, wind and pressure systems as well as marine flora and fauna. On the other hand, gravity generates mass transport by driving tectonic plate shifts, which have resulted in the formation of mountains and valleys as well as earthquake-causing fault lines and gas-emitting volcanic eruptions that increase temperature, on varying scales. In the same vein, geomagnetic storms affect the earth's magnetosphere and rotation (wind) patterns as well as generate acoustic-gravity waves; which can transport nutrients and other materials, globally, and create regions of extreme temperatures.

Relatedly, one of the glaring indicators of climate change remains global warming, which generally involves a temperature change on Earth. This gradual change in temperature is so insidious that the average person is somewhat oblivious to its occurrence. Nonetheless, subtle hints abound, such as the increasingly incessant reports of unusual weather patterns world-over: floodings; due to rising sea levels, droughts; caused by low precipitations over extended periods and raging wildfires; due to lightnings, pyroclastic clouds and volcanoes as well as intense tornados and hurricanes; caused by thunderstorm updrafts and more energies in the atmosphere, and unusual snowfalls; because of elevated atmospheric moisture content, dips in temperatures and changing wind systems. Incidentally, the aforementioned are reported to be culpable in the prevailing changes in global climatic conditions. The results of Bucha and Bucha (1998), however, suggest that global warming could be slowed down in the coming decades because the natural components influencing the temperature increases in the twentieth century would likely experience decreases in the next century due to the weakening external geomagnetic forcings, which are expected to modify natural meteorological processes.

Equally notable is the fact that the rates of evaporation increase with increasing global temperatures; leading to increased moisture contents in the earth's atmosphere but dried-out lands and forests as well as reduced sea levels. Different studies (*cf.* Compton *et al.*, 2015; Crowley *et al.*, 2015) have reinforced the notion that the wholesale redistribution of water that typically accompanies major changes in climate can elicit significant responses from solid earth in form of potentially hazardous phenomena, such as earthquakes and volcanic eruptions. Deep-water transport is also vital to the local and global marine ecosystems since its disruption can have dire consequences on marine life as well as produce extreme water temperatures, to the detriment of our climate.

In concluding, we hypothesize that if Earth's atmosphere obeys the hydrostatic primitive equations; which are good approximations for most terrestrial atmospheres, and contains radiatively-active, dilute condensables (such as water vapor and methane), an increase in its gravity ought to produce a cooling effect on Earth's atmosphere as the total pathlength of the water (or methane) should decrease with increasing gravitational pull (Thomson & Vallis, 2019). The anticipated upshot of the foregoing, it is proposed, would be decreases in the greenhouse effect and specific humidity, which can lead to changes in the moist adiabatic lapse rates, equator-to-pole heat transport and surface energy balances, due to the changes in the sensible and latent fluxes.

In summation, the causal factors enumerated in this article, though somewhat minuscule and typically occurring over relatively longer time scales, have been shown to be significant and should not, therefore, be discountenanced in the concerted global efforts to prevent the destruction of our planet.

'The climate they're a-changin'!'

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Competing interests

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Data Availability

The datasets generated during and/or analyzed during the current study are available upon request.

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