TECTONIC ASPECT OF CLIMATE CHANGE

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review

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- **ABSTRACT**

The climate change has been a continuous, constant process since 3 billion years but nevertheless has witnessed certain hitherto inexplicable abrupt variations due to chemical weathering, latitudinal shifts, intense continentality, eustasy or emission of major greenhouse gases including CO_2 at the sites of magmatic eruptions among other reasons. The extension of land masses over a large latitude such as the drift of Antarctica to the south pole altering oceanic currents and heat transfer 14 million years ago, is among the early events of climate change due to plate dynamics. Consequently greater surface of ice bearing polar earth gave ways for increased albedo effect therefore cooling the earth significantly from Eocene to Snowball Earth till the present remnants of it in the form of polar ice. The closing of Paratethys ocean and development of the Southeast Asian monsoon, the uplift of plateaus surrounding the East African Rift and even the Ice Age have all been direct consequences of the plate movements. Our objective is to demonstrate the global climatic effects that tectonic movements have over the years and to predict the same for future by the current climate change due to its possible influence on the tectonic process cyclically.

We Evaluated several published researches on plate tectonics and climate change which provided us cues of a significant correlation between the two natural operations in the past and to an extent at present while some researches indicate how can a change in climate can extend to earth's crust, equivalently influencing the tectonic processes.

We found that the climates in past have been in effect of plate tectonics and in turn climate change affected the plate tectonics making this an irresistible cyclic process that in the wake of current climatic disruptions can be expected to hit the global dynamism of natural phenomena yet again ahead in the near future. Conclusively this article will give an understanding of the broad range effects of each of the two discussed phenomena on each other as well as on the entirety of global natural processes. This is also important for climate change studies as the researches summarized in this manuscript indicates an opening of yet another chapter of possible devastation climate change can bring and this time through the crust of the earth.

Keywords: Climate Change ,Green House Gases, Plate Tectonics, Earth's crust

- **INTRODUCTION**

Climatic processes and changes are fundamentally derived from a balance of influx and outflow of radiations or the absorption, reflection and transport of energy flux by the surfaces of either oceans or continents distributed at various latitudes. Meanwhile atmosphere and clouds play their parts accordingly before the rays could irradiate the underlying crusts or upper layers of oceans and also make their contribution by barricading the reflected out-flowing solar heat. Any change altering atmosphere will affect directly the outgoing radiations making disruptions in the energy balance. Hence the configuration and nature of crust distribution becomes vital in maintaining an overall climate balance. On the other hand originated in theoretical form under oceanic geology, plate tectonics has largely developed in understanding through continental crust. It resonates between continental drifting, sea-floor spreading and crust subductions. Fundamentally two kinds of lithospheric motions exists : a horizontal and a vertical. Both involves direct and indirect climatic consequences. Latitudinal shifting of continental crusts and opening/closing of major oceanic gateways are among the effects of horizontal displacements. Similarly vertical displacements through uplifts, terrains, volcanoes and sea-floor spreading etc. have been effective in blocking atmospheric flows, causing aridity through rain shadows, strengthening monsoons and most of all significantly cooling the earth to create certain paleoclimates. The indirect links are through eustasy, geochemical cycling and emissions of major greenhouse gases at the sites of magmatic eruptions.

In this paper along with presenting possible and available evidences or instances of climate change driven by plate tectonics we have also covered the tectonic evolutions by processes such as surface erosion, a result of climate change at large. Supported by abruptly increasing rates of climate change, for example a 20 times increment in the rate of climate change for the next century is predicted by Earth Laboratory (NASA,2019), we speculate an accordingly greater and quicker impact on tectonic events as well which in turn are the most influential agents for climate change. Thus a cyclic functioning to perceivable extents can get created which, though existed for millions of years, has not witnessed an abruptness equivalent to the current one.

- **PALEOCLIMATES AND LATITUDINAL SHIFT**

The fundamental idea of climate change due to varying latitudinal distributions of land and ocean was first proposed by Lyell in 1830 conducting study of rock records. Wegener (1912, 1929) and Kreichgauer (1902) are among other scientists to attribute the movement of continental blocks to the cause of climate change. As we shall see further certain properties like surface albedo and specific heat formulate the basis for these shifts to induce climatic variations. Accordingly the warm periods in earth's history are said to be partially banked on the extent of continental existence on polar and equatorial latitudes. Paleoclimate studies using Global Climate Modellings (GCMs) also explored the potential global impacts of latitudinal shifts in land area (Barron et al., 1984; Hay et al., 1990a) and the northern hemispheric glaciation is even considered to be an induction of increased concentrations of land areas in northern latitudes (Crowell and Frakes, 1970; Donn and Shaw, 1977). Studies and simulations as early as by Lyell (1830), though roughly, estimated that increased land mass in equatorial regions would've principally be the reason behind higher temperatures of earth during Cretaceous and other paleoclimates of extreme hot (see climate and albedo). Contrastingly an earth with a polar land mass would expose the otherwise underwater ice on poles elevating both the albedo and cooling. In fact polar regions with their land distributions are considered as the climatically most sensitive areas of earth and centering of land on poles as an essential requirement for the glaciation by Crowell and Frakes (1970). Lyell also proposed that land distributions were different in past and this difference is responsible for the great contrast between today's and Carboniferous climate. Similarly did the Robinson (1973) by accounting the continental motion in northern hemisphere for the warmth of Mesozoic and cooling since Eocene.

- **CLIMATE AND ALBEDO.**

Techniques like earthshine measurements and devices like Albedometers on observation satellites orbiting the earth are used to gauge certain properties of extreme importance to climate, tectonics and relation between them such as the Albedo—measure of the total solar reflections back from the surface of earth. The surface absorbs the solar radiations only in cloud-free regions for the clouds and atmosphere being major role players in reflecting about 85% of the total insolation back to the darkness of space. Rest about 65% of the electromagnetic radiations let free by clouds and atmosphere are either absorbed by the surface or radiated back to the atmosphere through longwave radiations or fluxes of latent and sensible heat (Fig.1). Objects can have albedo values ranging between 0 and 1 and the average albedo of earth is 0.35. The surface having higher albedo like ice-free land as oppose to ice-free ocean is supposed to transfer much of the falling energy back to atmosphere through diabatic heating, for example if a warmer continental body is below a cooled atmosphere it will irradiate the atmosphere and form a hot ball of air rising upwards called thermal (see monsoonal circulations below). This way climatic effect is resulting from albedo of a surface whose movements are derived from plate tectonics–Latitudinal shift. (Deconto, 2009).

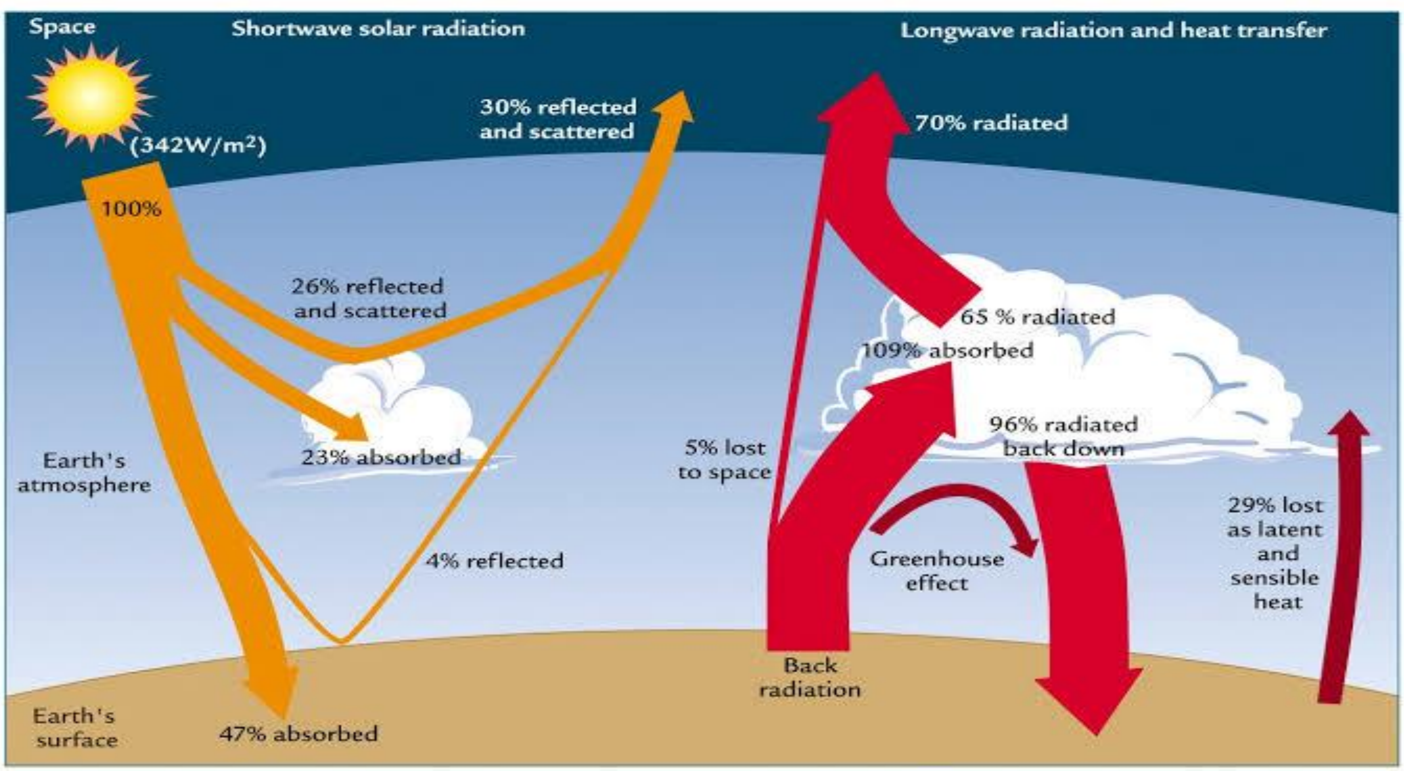


Fig.1 Showing the energy transferred to the surface and its reflection back to the space. About 79% of the radiations reflecting back from clouds and atmosphere are depicted by orange vectors. The rest of the mechanism through fluxes of latent and sensible heat is shown by red vectors (image credit: Zolushka for Earth)

Now there is a mechanism of heat transport through oceans deriving out of this effect. The energy received by the tropical waters of Pacific and Indian oceans is transported in northward direction through North- Atlantic ocean towards the poles by thermohaline circulations, it is called "Poleward heat transport"– determined by the magnitude and direction of solar irradiance on tropics, and therefore is also a function of albedo (Pielke, Lamb : Climate, Britannica 2019). It can be said henceforth that since the differences of radiations absorbed due to variations in albedos on the parts of globe on different latitudes, determines the overall heating of the planet, it decides magnitude and direction of the pole ward heat transport as well–carried out mostly by mid-latitudinal currents. Land distribution (latitudinal shift) eventually is inducing fluctuations in climate by means of albedo.

- **LAND-SEA THERMAL VARIATIONS**

  The other important effect comes from the differences of thermal properties between land and sea such as specific heat. Like albedo specific heat is also different for land and oceanic parts. The water surface has low albedo value and a higher specific heat. It is also well mixed by winds and convection, at least the upper layers (10-150 m), which facilitate the temperature changes to impact, though slowly but 'comparatively' deeper down the sea surface because these seasonal changes are unable to penetrate deeper than a meter down the rocky hard surface or soil in case of continents. Beside specific heat, the mobility of the water medium in a circular manner also delays heating of water bodies as this allows distribution of heat to a greater volume of ocean compared to conduction.

  Exemplifying the applications of the aforementioned property it can be said that regardless of temperature scale, during daytime, land temperatures might change by tens of degrees, while water temperature changes by less than half a degree which shows its poor response towards temperature swings as water's high heat capacity prevents rapid changes in its temperature. During the night as well, while land temperatures may drop tens of degrees, the water temperature remains relatively stable (NOAA ESRL, student sheet 2019). On the other side the continental surface due to its property of low specific heat has developed an adaptability to temperature swings and these thermal responses constitute the basis of well-known monsoon circulation patterns–extremely crucial for earth's climate, these are also indicative of a palpable interconnection between tectonics (latitudinal shift) and climate(monsoon).

- **Monsoon Circulation System**

By now it is clear that oceanic regions will scarcely vary their commonly warm temperatures, instead the continental temperatures will either surpass or fall behind the oceanic ones creating a seasonal temperature as well as pressure, gradient for the circulation. This gradient in pressure drives the movement of air from high to low pressure zones i.e. making moist winds blow from cooler, high-pressured sea surface towards continental margins and beyond to rain down in summers and from cooler continents towards warm sea surface during winters (Fig.2). These winds also drive huge oceanic and heat currents as they move.

Fig.2 Depicts the movement of air from high pressured surfaces to low pressured ones. Since the oceanic temperature swing is rare the continental temperature varies according to the radiations it receives. (image credit: North Carolina Climate Office).

A paper (Deconto, 2009) exemplifies the entire process as "The best example on today’s Earth is the Asian monsoon system. Over central Asia, seasonal mean temperature differences can exceed 50 degrees Celsius. During boreal winter, cold (dense), sinking air contributes to high atmospheric surface pressure (the Siberian High). Lower atmospheric pressure over the warmer Indian Ocean produces a meridional pressure gradient and northeasterly flow over southeastern Asia, Indonesia and the northern Indian Ocean. During the summer months, continental heating reverses the pressure gradient and the regional wind field. The resulting southwesterly winds (Southwest Monsoon) bring moisture-laden air and rain northward across

India, the foothills of the Himalaya, and parts of China and Indonesia. This seasonal reversal of the wind field also produces dramatic changes in the dominant Indian Ocean currents."

- **EUSTATIC SCALE CLIMATE CHANGE**

The immersion and ascent of continents through water depending on the mean sea level arising out of the consequence of plate tectonics is referred to as eustasy. The properties such as of albedo and surface atmospheric heat along with differences in vapor exchange by subaerial and water covered surfaces are the fundamental aspects for eustatic-scale climate change. A long time in earth's history witnessed an eustasy processed by tectonic-scale changes on the volume of ocean basins (Hays and Pitman, 1973). Sea level rise thereafter was partially attributed to the low-density oceanic crust produced out of tectonic processes like sea-floor spreading, "increase in total length of mid-oceanic ridges & emplacement of large igneous provinces (LIPs)" (Fig.3) (Deconto Robert, 2009).

Now the climatic impact as mentioned earlier arises out of some properties of the surface. Taking surface albedo for example where reflection power of water covered surface is considerably less than that of exposed land mass or continents. At a time in past when more than 20% of the present day continental crust was submerged under water (Hay et al., 1999) and average water levels were as risen as 100m compared to the present levels, a considerable decline in the overall reflection of solar rays would have surged the mean global temperature (Haq et al., 1987; Larson, 1991). Paleoclimates such as cretaceous period therefore were partially a result of these eustatic changes beside latitudinal shift. An aspect of CO_2 emission and its contribution to the atmospheric reservoir of carbon by diverging plate displacements is also considerable for climate (see geo-chemical cycling), especially the warmer periods, although such links are under debate in some academic circles (Conrad and Lithgow-Bertelloni, 2007; Rowley, 2002). Robert Deconto (2008), collecting the three effects, described above writes "Climate modeling studies (Barron et al., 1993; Otto-Bliesner et al., 2002) have shown that the combination of high greenhouse gas concentrations, continental positions, and high sea levels all contributed to the overall warmth of the Cretaceous".

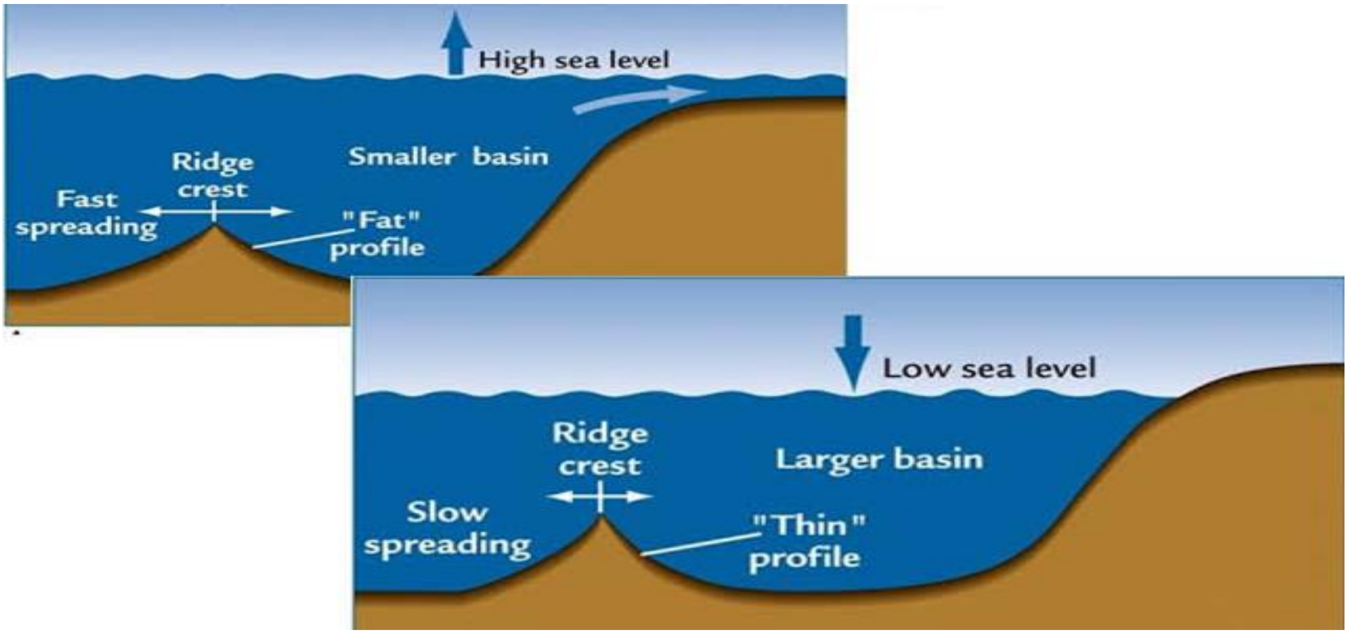


Fig.3 The diagram represents eustatic impacts of sea-floor spreading. As the spreading begins the mid-oceanic ridge widens reducing the basin which counter displaces the water upwards (image credit: Rebecca Clotts (2016), University of St Thomas Tsunamis)

- **ITCZ AND CONTINENTS**

A belt of low pressure encircling the earth just beside the equator or conventionally, the region of "low level convergence" and "convective precipitation" of trade winds is defined as inter tropical convergence zone (ITCZ) which doesn't have a fixed latitudinal position seasonally. Its mean inclination toward either of the two hemispheres is dependent upon warmth therein or ultimately the extent of land mass available, while seasonal shift is decided by weather temperature of the hemisphere.

Summers witness a northward while winters a southward shift because apparently the northern winter implies a summer in southern hemisphere (Fig.4). Presently as we know northern hemisphere has a large proportion of the continental mass due to the historic latitudinal shift in a certain fashion, ITCZ on an average lies in the north (Deconto Robert, 2009).

Since southeast and northeast trade winds are to be converged on the ITCZ it is more likely for the southeast trade winds to cross the equator while heading towards the northern hemisphere bringing major consequences on the equatorial ocean currents and the asymmetric "zones of oceanic convergence, divergence and upwelling" with respect to the equator (Gill, 1982). Which ultimately evinces a disruption in heat transport and oceanic currents, particularly the "mid-latitudinal storms".

Monsoon troughs on the other hand are convergence zones too shifted nearly 10 degrees away from the equatorial line. However the flow of converging winds isn't necessarily derived from a strong land-sea thermal contrast (Chao and Chen, 2001). Rotation of earth has mainly to do with monsoonal winds rendering land sea contrast less significant in this regard. Evidencing this, mathematical modellings and simulations of Asian, Australian and Indian continents confirmed that the monsoonal existence was not hampered by the absence of continents (Deconto, 2009).

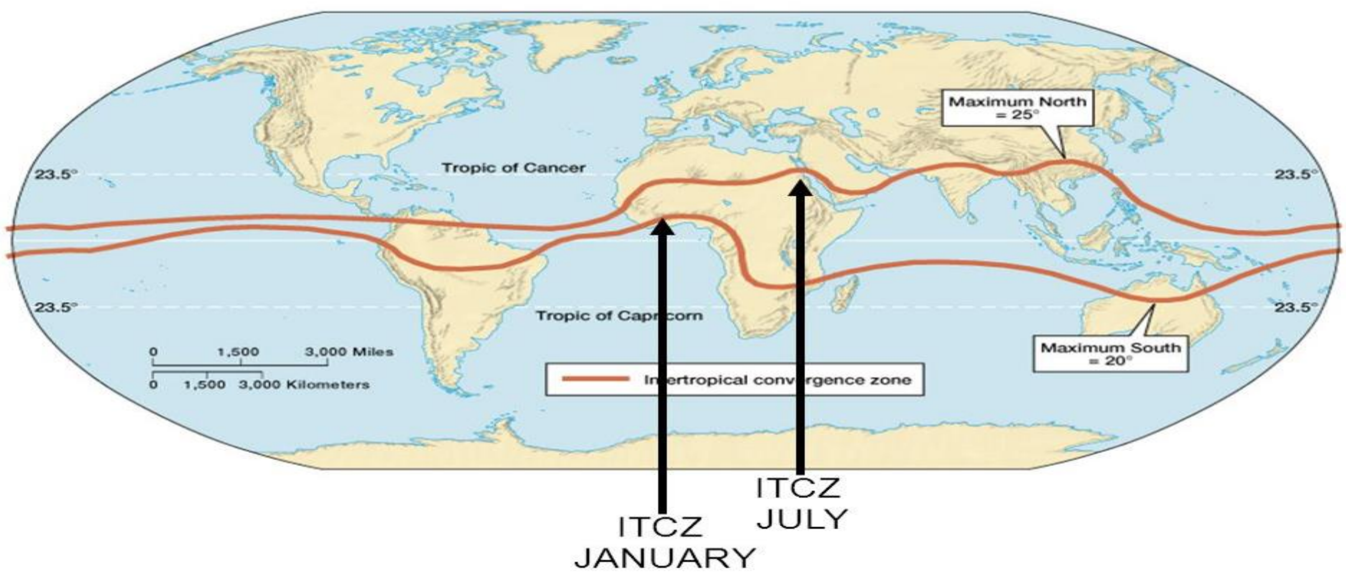


Fig.4 the maximum shift towards north is greater (25 degrees) than the maximum shift towards south (20 degrees) which justifies its average position in the northern hemisphere as the continental mass exceeds there. (image credit: slideplayer.com)

- **GIANT CONTINENTAL EFFECTS**

Extremely large continents in past have led to major climatic differences over land and oceans enhancing continentality, aridity and temperature as a whole. Formation of mega continents or supercontinents, Pangaea for example which lasted from late Carboniferous to mid Jurassic, about 480 million years ago when a giant continent called Laurasia collided with several micro-continents to form Euramerica that eventually combined with Gondwana, integrated the most of continental mass creating Pangaea beside the rest of oceanic zone, the Panthalassa Ocean. This had two major consequences :

1) The extremity in temperature swings over supercontinents coupled with a rise in average continental temperature

2) Increased aridity over the entire interior of the continent.

Now that we know, low specific heat of continents along with higher sensitivity towards seasonality can be among the explanations of (1). Aridity arises due to lack of influence of the oceanic regions over the continental interiors given the continents are large enough to diminish any links between its interiors and ocean in surrounding. This is also because there is no monsoonal circulation system in process to drive wind flow from ocean towards the main bodies of continents or vice versa except at the margins where all moisture-laden air loses the water content to precipitation becoming more arid.

This had far reaching consequences including on the habitat of living organisms as moist and temperate climate is vital for the formation of living organism and primary cells while dry weather and arid regions resist the favor of macro evolutionary changes. Convincingly the supercontinent of Pangaea had no considerable rainfalls from coastal to interior land resulting in elicited aridity (Anne-Claire, Sepulchrea et al.,2014).

Evaporation by rising continental temperature also contributed significantly to aridity. In central Pangaea, average summer temperatures were at least 8 degrees Celsius warmer than today’s continental interiors, with maximum daytime temperatures reaching even 50 degrees Celsius in some locations (Crowley and North, 1996). This was due to intense seasonality differences as during summers they quickly adapted the changing temperature as oppose to today's summers where there are considerable ocean bodies in between the continental fragments making the monsoonal circulation system more effective through the movements of moist winds up to the interiors.

- **PANGEAN MEGAMONSOONS**

The continental rise in temperature would've naturally provoked intense distinctions in thermal state of land and sea–enhanced continentality, subsequently developing severity in gradients of pressure as well and eventually leading to an intense version of monsoon called mega-monsoons.

(Kutzbach and Gallimore, 1989). These megamonsoons intensified as the continents converged and attained maximum strength during Triassic, the period of maximum continental integration. In general megamonsoons led to immense aridity along the interiors making them entirely uninhabitable with extreme hot days and frigid nights–as evident from the response of continents towards temperature swings. However seasonality was maintained by rainy and dry conditions along the coastal belts only. This stems from a distinct monsoon circulation over Pangea mentioned ahead.

The axial tilt of earth during summers in the northern hemisphere would've made Laurasia face direct solar irradiance. The atmospheric pressure over the continent lowered since diabatic heating rose the temperature of overlying air currents. This was contrasting with the southern hemisphere hosting Gondwana where the atmospheric pressure was comparatively high due to its axial tilt away from the sun. While moving from Gondwana towards the costs of Laurasia the air currents loaded moisture from the Tethys ocean and eventually through surface convergence caused huge precipitations along the Laurasian coastal belts. Simultaneously the atmospheric flow over southern hemisphere was directed away from the Gondwana high-pressured system. Hence surface winds would have been diverged and subsidence dominated creating extreme aridity throughout the southern hemisphere. (Parrish, 1993)

Later on continental drifts leading to the dispersion of supercontinent into fragments modified the sources of rainfall throughout the continent. Smaller land masses involve a more widespread distribution of precipitation over the continents due to multiple moisture sources. Therefore, the formed humid climatic continents provided new external conditions for ecological expansion of living organisms and their diversification as well.

- **UPLIFTS AND CLIMATE**

The orogenic uplifts arising out of continent-continent plate collision led to the formation and distribution of certain major terrains of high altitudes–mountains and volcanoes including Himalayan ranges. The converging Indian and Eurasian plates collided some 50 Mya to give rise to certain exceptional terrains of unique topography rarely found in any other paleoclimate throughout the geological history (except during Pangea formation). The Pamir Mountains, Tian

Shan, Altai, Hindu Kush, etc. are among other examples of mountain belts constructed out of this collision (Le Fort, Patrick : Evolution of the Himalaya (n.d))

At present the overall uplifting orography of earth is to a large extent unique with respect to the normal orographic features of the geological past and most scientist holds these uplifts accountable for the relative cooling of late Cenozoic era–high altitudes and their low pressure directs for atmospheric temperature to drop and subsequent cooling to enhance albedo by accumulating snow. There exist therefore a tangible connection between the increasing uplifts and subsequent cooling after the warmth of Mesozoic and early Cenozoic eras.

There are direct and indirect ways for this orography to influence the climate. The direct effects includes hampering smooth atmospheric flow, rain shadows (see rain shadow effect) and disruption in energy balance through varying albedos–for example the albedo upsurge with the rise of plateaus (Deconto Robert, 2009 and references therein).

In other words the higher altitudes because of their low temperatures (low pressure) are often covered by snow, their albedo is significantly high maintaining the cooling effects described above. Other tectonic reactions such as orientation of surface slopes or presence of bare lands have indirect consequences through their control on certain topographic features such as vegetation. Vegetation of a landscape decides atmospheric moisture, land roughness and thereby albedo along with the diabatic heating of the atmosphere. (Dickinson and Henderson-Sellers, 1988). A comparison of bare land or soil with a land of greater vegetation (of low albedo) shows that bare land is more often covered by winter snow as opposed to the warmth of vegetated regions.

- **Rain shadow effect**

Under natural conditions during the continental heating as the pressure gradient intensifies, monsoonal circulation system operates and the moisture-laden winds from high pressured zones starts blowing towards continental interiors, meanwhile existence of an uplift can have serious climatic consequences on some parts of the continent.

A mountainous uplift hampers the moist winds from oceans to cross its peak since the prevailing conditions for the air reaching continental margins are to rise upwards due to diabatic heating, attain a high altitude and adiabatically cool to get condensed and rain down, this compels the precipitation only on the windward side of the mountain resulting in dry, sinking air crossing the mountainous peak to become warm and arid eventually creating dry conditions on the leeward side of the mountain (Fig.5). The eastern side of the Sahyadri ranges on the Deccan Plateau including: Northern Karnataka and Solapur, Beed, Osmanabad, the Vidharba Plateau and the eastern side of Kerala (in Tamil Nadu) are among the examples of this effect on Indian climate.

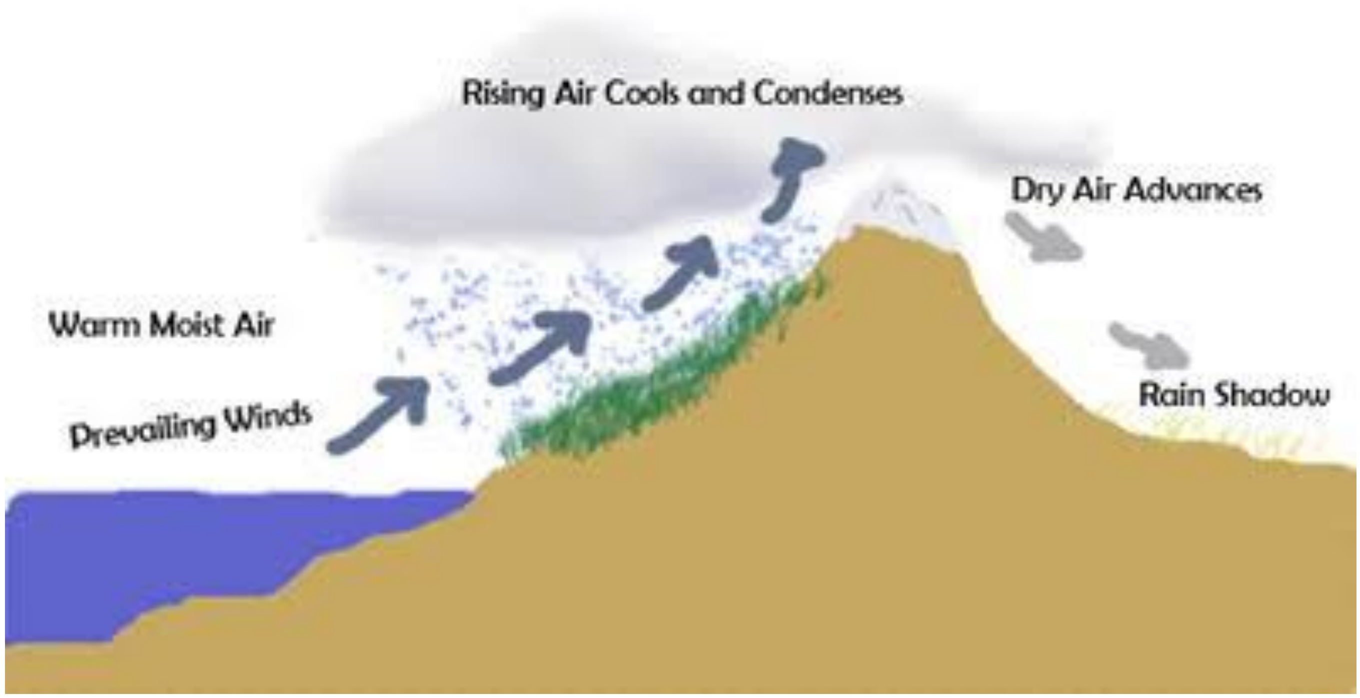


Fig.5 the prevailing winds during summers for example rises upwards to precipitate before they could cross the peak and the remaining currents crossing the peak would get sink down the leeward side of the mountain. (image : part of the public domain)

- **Monsoon strength and mountain uplift**

  As discussed the atmospheric pressure at uplifted plateaus is less and air density is low. This less dense air amplifies the rising and sinking air currents of monsoonal circulations in summers and winters respectively, intensifying their storms, strengthens the monsoon. Since monsoon circulation system runs through zonal and meridional flow of air the resulting effect on it is also natural. This can also be explained as, the effect that greater area of terrains exposed-out due to uplifts have, that is intensifying the thermal contrast between land and oceans which Earth Observatory, NASA (2006) described as, anything that increases the difference of land-ocean temperature is bound to strengthen the monsoon since monsoon is derived from these thermal variations only. For example the strength of Asian monsoon is linked with the Tibetan uplift about

50 million years ago when a collision of Indian sub-continent with Asian plate took place. Numerical studies have also shown that an uplift equal to half of those of Himalayan-Tibetan elevation is required to create a strong south-east summer monsoon over India clearly evidencing not just a correlation but a coexistence between high altitudes and strengthened monsoons. (Kutzbach et al., 1993).

- **Evidences, isostasy and cause of Cenozoic cooling**

Several evidences can be attributed to the existence of mountainous uplifts beside the visible continental slopes or structural and geomorphological features. These include sediment studies confirming continental denudation in the accumulating layers and occurrence of $^{87}Sr/^{86}Sr$ (an indicator of chemical weathering) (Richter et al., 1992). Moreover techniques including identification of fossil vegetation and presence of oxygen isotopes in carbonate rocks can also help proving a mountain uplift.

There exist as we know an isostatic balance on the surface of earth which if disturbed through erosional effects leads to a depression or elevation of continental mass in order for an isostatic balance to be maintained. Examples can be given of Alps and Himalayas where loss in mass of fluvial and glacial valleys accounted for more than 25% of the uplift in mountains (Deconto Robert, 2009).

Describing the influences that climate change may have on tectonics, (see second order effect) Molnar & England, 1990 disapproved the notion of Cenozoic cooling due to mountain uplift, instead they proposed that the recent anomalous uplifts could've been themselves the results of Cenozoic climate change. This proposition was based on the fact that erosions are derived from a combination of surface relief (Isostasy) and climatic operations such as seasonality, precipitation, and glaciation. So climate change would've caused the erosion which was countered back in the form of plateaus of unusual orography by isostasy.

- **GEO-CHEMICAL CYCLING**

Apart from sources of carbon like respiration, organic burial, fossil-fuel emissions and industrial processing outputs, one which is concerned directly with earth is focused in this entry. There are stores of carbon beneath the surface of earth in the form of either limestone rocks or organic mass burials. The metamorphism of limestone $CaCO_3$ in the presence of silica (SIO_2) at subduction zones due to shear stress and high pressure and temperatures yields carbon dioxide (CO_2) which is drawn-out by volcanic out-gassing through mantle convection (Fig.5.1). There are fundamentally two reservoirs of CO_2 in the mantle below the crust getting drawn to much of the out-gassing carbon dioxide

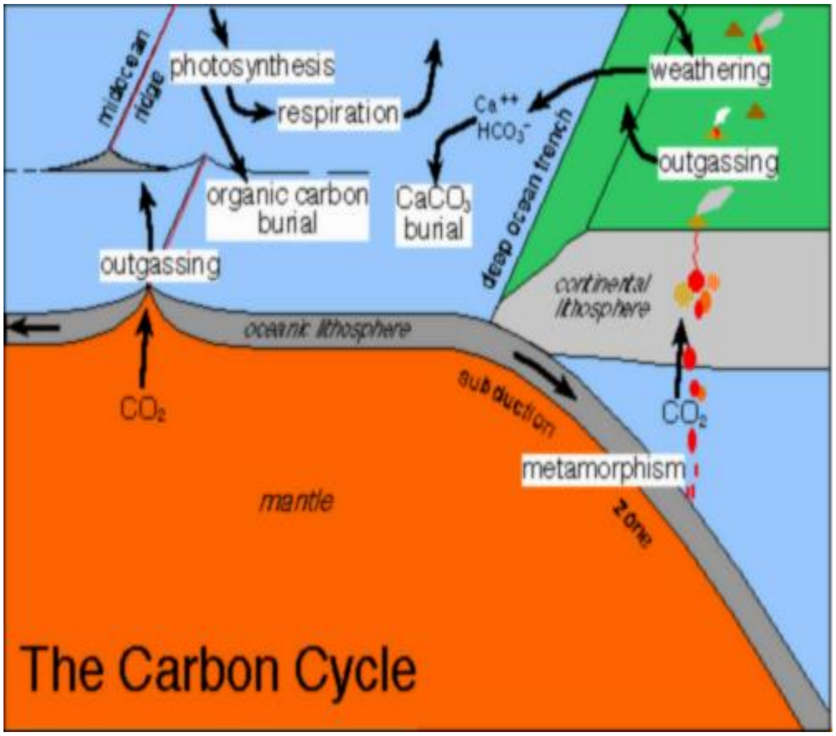
a) the primordial source which is present ever since the earth was born

b) the metamorphic outcome of carbonate rocks.

Organic burial is another carbon storage below the surface. The carbon composed in buried organisms including plants and animals when exposed by erosional mechanisms is taken up for respiration and photosynthesis, this way contributing back to the atmospheric cycle (Fig.5.1). The ocean absorbs around 30% of the annual anthropogenic emissions of CO_2 alleviating the additional warming but at the cost of altering the acidity of ocean. In fact there has been an overall increase in acidity of 26% since the beginning of the industrial revolution. The carbon dioxide and other dissolved gases in water remains in equilibrium with their atmospheric constitution. CO_2 in presence of water produces a weak carbonic acid (H_2CO_3) through reversible reaction. Carbonic acid can stimulate chemical weathering of rocks lying on the oceanic crust (Fig.5.2)

The H^+ component of carbonic acid, in the presence of water reacts with silicate and other minerals of underlying rocks. This yields divalent ions like Ca^{+2} which readily reacts with the other component of carbonic acid that is HCO_3^- forming $CaCO_3$ which stores the CO_2 in the layers of limestone until it is out-gassed by the process of metamorphism in suitable places and conditions like orogenic belt or subduction zones (Fig.5.2).

There are various well known effects of the CO_2 on temperature, atmosphere and climate as a whole. Green house effect is one of them. Also it caused long term impacts such as the Ice-Age period and Snowball earth. Apart from the notions presented earlier regarding the reasons of Cenozoic cooling, the CO_2 drawdown is also considered significant there. In fact the Himalayan-Tibetan plateau is related to cooling and glaciation through enhanced weathering rates (scarcity of CO_2) and drawdown of CO_2 from the atmosphere (Chamberlin, 1899; Fillipelli, 1997; Raymo et al.,1988) apart from the albedo.



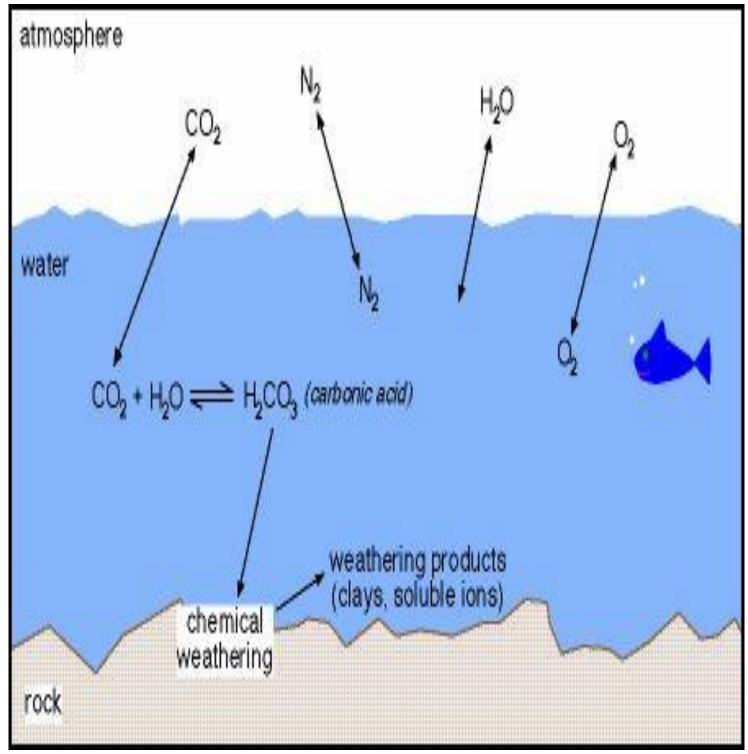


Fig.5.1 Fig.5.2

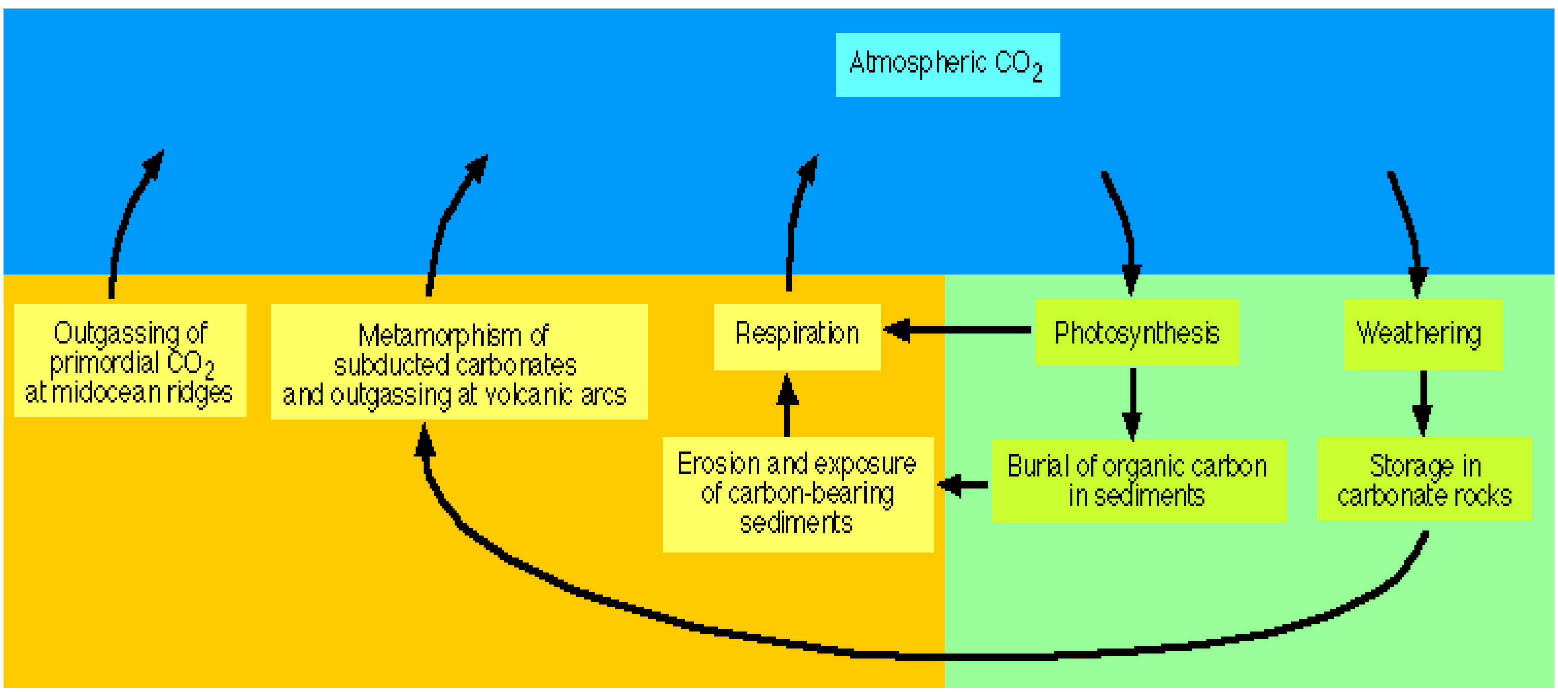


Fig.5.3. The first figure shows the the carbon cycle through mantle and crust of the earth while the 5.2 depicts the equilibrium between water and atmospheric levels of CO_2 and other gases, besides H_2CO_3 weathering the limestone to store CO_2 in the form of calcium carbonate is also depicted. Now 5.3 summarizes the mechanism involved in above depictions. (image credit: Columbia education)

- **TECTONIC EVOLUTION BY CLIMATE CHANGE : A SECOND ORDER EFFECT**

Now that climate change has been demonstrated as a result of plate tectonics it is crucial to understand it as a cause for the same as well. Climate and tectonics have conventionally been linked in one way. In this entry some studies focusing on the opposite are also considered. Possible devastations by climate change extends from acceleration in the rates of shrinking ice, melting glaciers and sea level rise to alarming increments in ocean heat and acidity, tropical cyclones, disastrous hurricanes and drought-driven wildfires releasing tens of Megatons(Mt) of CO_2 to the atmosphere such as the latest bush fire which emitted about 250m tons of CO_2, half of the annual carbon footprint of Australia.

Since we are talking about an action (tectonics) having a consequence (climate change) and each consequence triggering subsequent consequences, we can also describe it as a second order effect. A single action initiating a series of cause-and-effects which we might not have control on is what this effect is all about. Henceforth we speculate that some of the climatic outcomes described above can cyclically process with other tectonic events, the rise in sea level for example masking a great continental area decreasing albedo. Other examples are such as tectonic uplifts and subductions by erosional cyclones and sediment depositions respectively (isostasy). A fundamental idea comes from the recent alarming rise in sea levels where almost 21 pacific islands and 97% of the islanders are vulnerable to eustasy by glacial melt for example. This increased eustasy along with its direct effects of flooding and cyclones would also mean a decreasing albedo and a consequent upsurge in temperature indirectly. The same goes for erosional and depositional cyclones, floods and other disasters which as cued by the recent rates of climate change will also take a boosting surge.

Evidencing Studies

There are studies correlating two processes such as the propositions of Molnar & England, 1990 where as oppose to the consensus of significant uplifts provoking climate change they considered anomalous tectonic uplifts, a result of Cenozoic cooling rather than a cause. The proposition of Cenozoic climate change as a possible cause for the rise of Andes mountains in South-America is another example. Lamb Simon & Davis Paul (2003) published a study in Nature suggesting a causal link between the heights of Andes and shear stress in the subduction zones and a buoyancy stress contrast between the trench and highlands. As shear stress depend upon the amount of subducted sediments, the dynamics of subduction it was proposed, are controlled by erosional and depositional processes or ultimately the climate. Similarly the buoyancy stress contrasts in the Andes can only be supported because of the role of climatically controlled trench sediment fill. The paper writes "we believe that the global cooling of the climate and deep ocean must be considered as another important effect on the tectonic evolution".

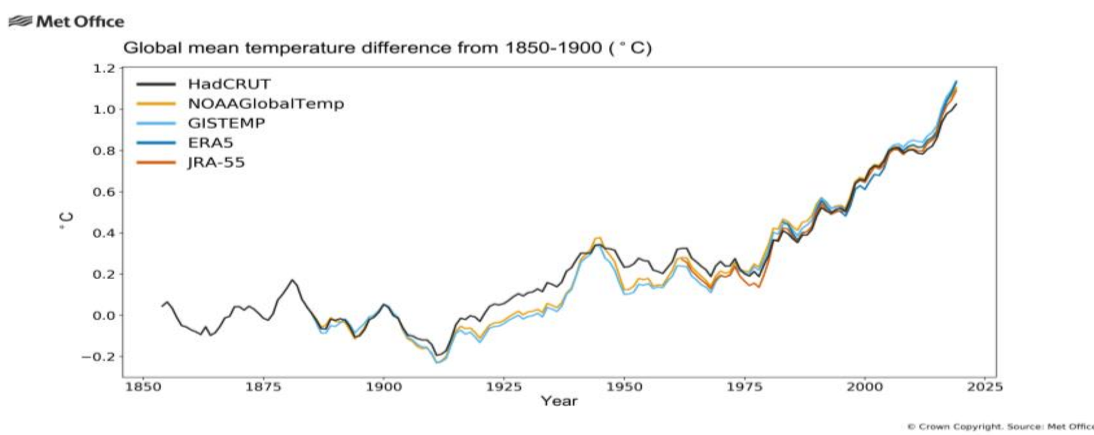
Described here are briefings of mechanism through which climate change affected tectonics, detailed in the paper (Simon & Paul, 2003). The cooling of the Peru-Chile current system created an increment in aridity during the Mio-Pleistocene along the coast of South-America that resulted in hyper-aridity for the last 3-4 Myr. Enhanced aridity was necessary to reduce the supply of sediments to the trench decreasing the lubrication at plate interface and enhancing shear stress to the levels required to push up the high Andes. In this way mountain ranges of Andes restricted to regions of suitable & right climatic conditions. Simultaneously the climate by promoting or inhibiting sedimentation directed the plate-driving forces to act on cramped portions of subducting plate boundaries and raise the local shear stress for pushing up mountain belts of elevations, close to 3 km maximum.

So does the other papers highlight the role of surface erosions in tectonic evolution (Stephan & Brown,2019)

These cycles have processed well in past too but with negligible rates. The correlation similarly is irrelevant at present since the operational period is large enough (thousands of years or more) to be neglected. However the frequency or time duration required for such cycles to create considerable repercussions can become feasible enough in the near future to create amplified devastations if the current acceleratory rates of climate change continues.

- **Current Climatic Rates**

The most recent statistics of surging rates given by the World Meteorological Organization (WMO) indicates a climate causal disproportionate rise in the frequency and extremity of following events. Surface temperature for example has witnessed a 0.5 degrees Celsius rise above the long-term average (1951-1980) in the beginning of 21st century. The earth is warming at a rate ten-times faster than even the Ice-Age recovery period. According to NOOA data, overall global annual temperature has increased at an average rate of 0.07°C (0.13°F) per decade since 1880 and at an average rate of 0.17°C (0.31°F) per decade since 1970. Moreover, 2015-2019 have been the warmest five years on record according to WMO whose reports on the global climate in 2015-2019 released to inform the United Nations Climate Action Summit, said that the global average temperature has increased by 1.1°C since the pre-industrial period, and by 0.2°C compared to 2011-2015.

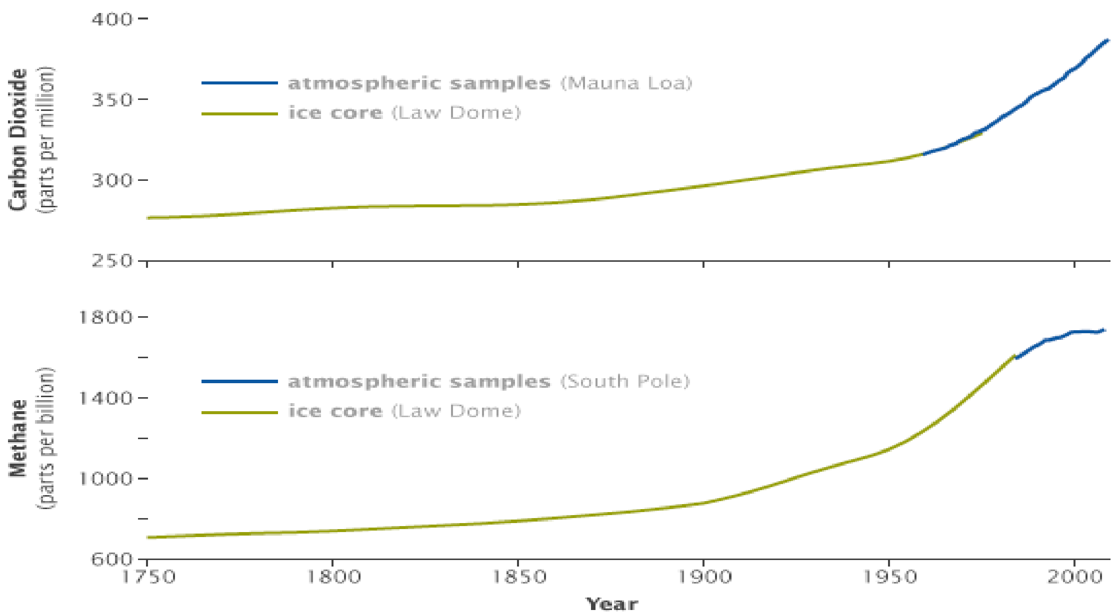


Five-year running average of global temperature anomalies (relative to pre-industrial) from 1854 to 2019 for five data sets: HadCRUT.4.6.0.0, NOAAGlobalTemp v5, GISTEMP v4, ERA5, and JRA-55. Data for 2019 to June

As more than 90% of heat caused by climate change is stored under oceans, the rate of global mean-sea level rise over the five-year period, May 2014 -2019, amounted to 5 mm per year, compared with 4 mm per year in the 2007-2016 ten-year period which is substantially faster than the average rate since 1993 of 3.2 mm/year, is an alarming threat of elevating eustasy and of other tectonic impacts such as uplifts and erosions to in turn hit back the disrupting climate. The amount of ice lost annually from the Antarctic ice sheet increased at least six-fold, from 40 Gt per year in 1979-1990 to 252 Gt per year in 2009-2017. Even more evidences of rapidity comes from the indications of World Glacier Monitoring Service (WGMS) reference glaciers for

2015-2018, of an average specific mass change of −908 mm water equivalent per year, higher than in all other five-year periods since 1950. Coming to the greenhouse gases like CO_2, growth rates during 2015-2019 have reached as high as 20% since the 2011-2012 and concentration has reached over 410 ppm by the end of 2019.

These examples among others are core evidences proving the flying rates of operations in the major climatic processes and consequent quick tectonic impacts that this change may cause or a rapidity that pacing climate change could bring in the coming years over hitherto slow tectonic processes and evolutions cyclically.



- **SUMMARY :**

Direct and indirect correlations exists among tectonic and climate events, for the most fundamental changes in the earth's climate history are triggered by tectonic events. The tectonic control of surface dynamics determines the overall albedo, and as a result global energy flux. Besides the site and intensity of land-sea thermal contrast which create intense effects like mega-monsoons is also under the domains of plate movements. ITCZ's orientation based on the continental availability and seasonal shift mobilizing the equatorial oceanic currents and resulting heat transports are among other intelligible representations. Drawing more scientific attention towards this study were the uplifts blocking atmospheric passage, causing Cenozoic cooling and amplifying the monsoons to explicitly establish an indispensable link the two processes functions with. However the aspect of reversal operation of the same mechanism is yet to be appreciated and studied to unambiguity. Hence further research can be predicted in this domain. Studies have begun already by the likes of Andes/Himalayan-Tibetan uplifts and will increase if the threat of these cycles becoming tangible enough are confirmed by the speeding rates in current climate change. This is essential to highlight as it represents an overlooked and ill-researched domain of climatology and plate tectonics. Furthermore resulting time-gap, can be predicted to shorten with as much rate as the climate change itself, capable to project a repeating, cycling and constantly uprising amplified outcomes.

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