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Research Article

Some Factors Affecting the Level of the Seas

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Abstract

Sea level changes cause severe problems along coastal areas today. There are places undergoing rising sea levels but other coasts show the sea levels to be stable or falling. There are also differences in rates of change with time from place to place. Causes of sea level change can be divided into three groups, viz., endogenic, exogenic and anthropogenic processes. Endogenic processes include changes in the Earth's rotation rate and orbit while movement of plates and mountain building alters the size of the ocean basins and the ratio of land to water. Vulcanicity in the oceans displaces water, adding to rise in sea levels but is partly offset by isostatic changes in response to changes in loading of the crust, e.g., by the growth and retreat of glaciers. Exogenic processes include cycles of climate change resulting in major changes in the landscape and sea level. There is a 100-ka cycle controlled by the eccentricity variations of the Earth's orbit and by the 23-ka precession cycle that has been operating for the last 800 ka B.P. These result in periods of c.85 ka of cold (glacial/permafrost) events separated by 10-15ka warm interglacials resulting in spectacular changes in the landscape. Anthropogenic processes include the man-made climate changes resulting in changes in erosion rates on land and slope instability, sedimentation rates in the sea, erosion and deposition of rivers, changes in vegetation cover due to climate changes or fire, or the growth and stranding of coral reefs. Heat storage in parts of the ocean causes its expansion and sea water temperature cycles. Cyclic growth and melting of ice sheets can all occur without the influence of Man There is negligible evidence for CO2 being the cause of the changes in climate either now or in the past, despite the claims of IPPC. Instead, variations in the Milankovitch cycles have been closely tied to the cold climatic events during the last 800 ka B.P., while cycles of abrupt but more limited warming and cooling of parts of the Atlantic Ocean have occurred roughly four times as often without the influence of humans, probably due to the 23ka precession cycle.

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Introduction

Changes in sea level are widely blamed on Human induced climate change by both environmentalists and climate scientists, e.g., by the IPCC [1]. The basic argument is that anthropogenic activities are producing an abnormal change in climate resulting in coastal flooding of low lying areas around the world. Little consideration is given to the effect of natural changes that have been occurring throughout the past when humans were not around to interfere with the other natural processes. Sea level changes certainly complicate the landscape as well as the continuity of human settlement, especially in the case of sea level rise in areas of high population density [2]. Many large port cities such as New York, New Orleans, and Rotterdam were built on the mouths of rivers assuming that the sea level would remain the same. Unfortunately, rising sea levels are now creating a major problem. The streets of Venice now flood at high tide but did not do so when the city was founded around 400 A.D. It is now primarily a relatively minor tourist attraction rather than an important port as it was in Roman times. In the Pacific Ocean, atolls were a favourite location for the boat people moving east from Asia to find new places to live. Now these island populations are complaining vociferously about rising sea levels. Reduction in sea level relative to the adjacent land can expose large areas of the shallow continental shelves, *e.g.*, in the China Sea and North Sea, greatly adding to the adjacent land mass but preventing warm ocean currents in the Tropics from bringing heat and moisture that can modify the monsoonal air mass passing over it [3]. This was involved in a substantial reduction in mean annual air temperature to both Northeast China, North America and to Western Europe during the last major cold event. Similar modifications can occur elsewhere in the tropics especially along coasts with extensive coral reefs. The lower sea levels in the Caribbean and Yucatan Peninsula during the Wisconsin glaciation exposed large areas of former coral reefs as new land while reducing the area of sea from which the Gulf Stream originates. The public view rising sea levels as resulting from climate change brought about by greenhouse gases causing warming of the climate following the reports of the International Panel on Climate Change [1]. Specific effects are viewed as being thawing of glaciers causing sea level rise, together with higher air temperatures and reduction in precipitation resulting in droughts and increased incidence of catastrophic fires in areas with a Mediterranean climate such as California and Spain, Portugal, and France. In contrast, rainfall in Monsoon areas such as Pakistan, southern United States and the lower Fraser River valley in British Columbia have greatly increased in the last two years. This paper examines the distribution of sea level change around the world and its main controls. The latter can be divided into several groups, some being dependent on endogenic processes within the Earth, while others are the result of exogenic processes acting on the surface

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of the Earth such as erosion and changes in vegetation. The effects of the advent of human settlement, the explosion of human populations, and the enormous modifications to many landscapes resulting from anthropogenic activities are also discussed It will be shown that the controls of sea level are far more complex than envisioned by the public and IPCC.

Distribution of Sea Level Change

Sea level change is not constant along the coasts of the World. Thus, Emery & Garrison [4] showed that the Atlantic Shelf sank faster than the Texas Shelf between 20ka and 7ka, while Grant [5] found that the Bay of Fundy was currently sinking at a rate of 24 cm/100years compared with 9 cm/100years along the southern coast of Nova Scotia [6-8] (Figure 1).

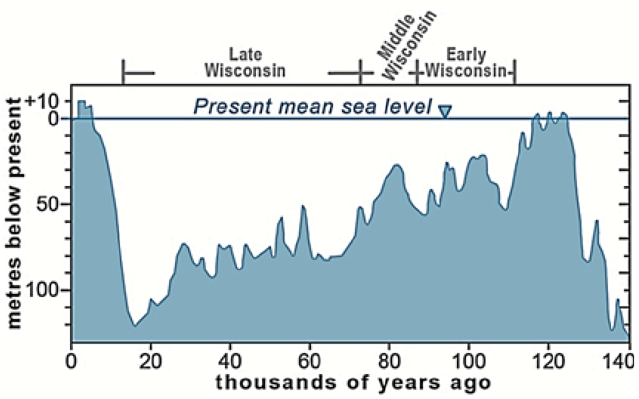

Figure 1: Mean sea levels during the last 140 ka B.P.

Figure 1 depicts the average variation in sea level over the last 140 ka according to NASA. It is very similar to that reported from Southeast Asia by Voris [9] but differs considerably from the curve used by the IPCC [1] which was based on the coral sequence in Barbados. Recent studies are showing that coral growth started at different times during the Holocene even in a single group of islands. This will be discussed further below but indicates that there is no simple relationship that can easily be discerned for the effect of climate on world sea level. [10] identified 5 definite patterns of sea level behaviour on the surface of the Earth. Around the former ice caps, glacial rebound is dominant producing rising land and raised beaches. Secondly, the surrounding areas exhibit a complex of rising sea levels and rebound. Zone 3 consists of the Caribbean and Mediterranean Seas which are in collision zones of plates that are also subject to tectonic and volcanic events. Zone 4 consists of Central and South America, Southern Africa and East Asia. They are characterized by relatively simple shoreline characters apart from the results of movements along plate boundaries. Lastly are Patagonia, Cape of Good Hope, Australia, New Zealand, and Antarctica, although these exhibit differing histories. New Zealand in particular, appears to be the remnant of an additional continent which has largely foundered beneath the waves. Thus, the IPCC [1] choice for their type locality for average sea level change around the world appears to be too simplistic.

Endogenous Processes

These are processes taking place within the Earth which are largely impossible for Humans to influence. They include the potential effects of the slowing of the rate of rotation, the movement of plates over the surface of the globe, isostacy, tectonics, and vulcanicity. One theory involves possible change in diameter of the Earth.

Movement of Plates Over the Surface of the Earth

Since Alfred Wegener in 1915 first suggested that the existing continents have spilt off one by one from an ancestral land mass called Gondwanaland centered over the South Pole [11], there has been a vast amount of discussion of the idea. [12] mapped the topography of the floor of the Atlantic and Indian Oceans and discussed the tectonic fabric and continental drift. It became clear that the surface of the Earth consists of a series of plates moving about the globe. The driving force is now regarded as being convection currents under the Sial and Sima forming the outer crust so that they slide over the underlying mantle. These currents are believed to reach the surface of the seabed along the mid oceanic ridges and result in bands of new basaltic rock sliding away on either side of the mid ocean trenches on the mantle surface. The plates can include both old rocks and new as well as both ocean beds and a variety of land areas. Where the plates collide head on, the denser Simatic rocks are subducted under the less dense Sial (see the discussion of the development of the ideas in Holmes [6]. This results in deep ocean trenches along the subduction zones. Subsequent work confirms and builds on these concepts, *e.g.*, [13], and numerous paleogeographic studies supported this conclusion [14,15]. The relevance of the concept of plate tectonics to sea level changes is that it implies that the shape and volume of the ocean basins is continually changing. Furthermore, collisions can result in the elimination of large, well established ocean basins such as the Tethys Sea that existed in the early Mesozoic era due to the collision of the Indian plate with the Asian plate. This caused uplift of that part of the ocean to form the Himalayan Mountain chain, the Tibet Plateau, and the Pamir Knot, which must have caused a great amount of ocean water formerly in the Tethys Sea to go into the other ocean basins. The process of uplift is still going on at the western end of the former sea which is now represented by the Mediterranean Sea and some large, isolated lakes in Central Asia. This is the result of the northward movement of the Arabian and African plates that is causing the changes. The immediate consequence of these collisions is to displace large volumes of sea water without sufficiently increasing the available ocean basin capacity. Varying amounts of sea level rise occur after each major head on collision of plates that eliminates part of the ocean basins as noted by [16]. The amount and duration depend on the way the resulting mountain building takes place.

Isostacy and GlacialIsostacy

Isostacy is the concept of a gravitational equilibrium that determines the heights of continents and ocean floors in accordance with the densities of the materials of which they are composed [17]. The idea implies that below a certain minimum depth, the pressure of the material above will be the same everywhere. This is often referred to as the level of compensation. In the case of a series of icebergs floating in water, the pressure will be the same everywhere at the depth of the base of the highest iceberg. In the Earth's crust, this will be below the height of the highest mountain when the latter is in equilibrium with gravity, but whether it is parallel to the geoidal surface is uncertain. Note that there is usually a substantial lag between the piling up or eroding down the pile of sediment and the achievement of the equilibrium. Glacial isostacy refers to the movement of the bedrock surface because of glacial loading or unloading. [18] provides a good introduction to the postglacial uplift that we can see today. When ice caps melt, it takes many millennia before true equilibrium is reached, e.g., the Keewatin ice cap disappeared about 7 ka B.P., but the northwestern margin of Hudson Bay is still rising today after over 250 m of rebound. An estimate of the maximum height of the Laurentide ice cap exceeds 3000 m. Presumably, it takes a similar length of time to reach isostatic equilibrium during loading of the crust, although this will also depend on the rapidity of the loading/unloading and the physical properties of the rocks involved [19]. Conversely, if the ice advance is short lived and thin, the rebound will be relatively small and rapid before isostatic equilibrium is attained. In the meantime, the adjacent land will slope down towards the ice front and tends to be occupied by large lakes with pronounced shorelines marked by raised beaches, e.g., the former Lake Agassiz. Today, the uplift is nearly complete near Winnipeg where the former ice cover was thin, whereas it is still occurring further north on the northeast margin of Hudson Bay. [20] suggested two hypotheses regarding the mechanics of isostacy [18, see Figure 2]. The first was the bulge theory producing basining by outward flow of the rocks just below the crust to cause an uplift of the surface of the land under the glacial foreland. The area around an ice sheet should rise to accommodate this outward flow within the mantle. [5] noted evidence of such a former bulge along the Bay of Fundy, and there is also good evidence for this on both sides of the southern margin of the Laurentide Ice Sheet in eastern North America. However, many of the former proglacial lakes there show evidence for the former existence of hinge lines modifying the elevation and slope of their raised beaches that were formed during deglaciation, suggesting that they formed due to localised vertical movements (the punching theory) [20]. However, the results are the same as basining under ice caps involving localized outward flow of the underlying sima to achieve isostatic equilibrium. Eustatic changes occur every time there is a change in the weight or thickness of the layers at the surface of the Earth. As a result, it is involved in most changes in sea level, whether they be natural or anthropogenic. [21] list many of these changes, applying names to some of the different types and discussing the length of time needed for the layers to reach equilibrium after a given disturbance. In the case of glacial isostacy, it can take up to 10^5 years.

Tectonics

As used here, this includes all internal processes that alter the topography of the surface of the Earth. The most obvious are the large transverse fault lines separating the plates as well as the transverse faults cutting across the mid oceanic ridges. These ridges show that vertical movements of the bed of the sea occur during the welling up of the basaltic flows before the new rocks move away from the centre of the ridges in both directions. The transverse faults relieve pressures generated by the plates as they move. If the rocks predominantly move laterally past one another, they only produce earthquakes. If there is vertical movement relieving lateral pressure, highly destructive waves called tsunamis will often be generated and the size of the ocean basin may change. Where plates pull apart, a rift valley develops. This can occur inland or on the coast. In the latter case a new narrow gulf develops as in the cases of the Persian Gulf and Red Sea. These are gradually growing in width and tend to enlarge the ocean basins. The similarity in the shape of the west coast of Africa and the east coast of South America caused Sir Francis Bacon to wonder whether these two continents were originally part of a single land mass. This is now thought to have been correct. When sialic sediments are subducted, they become faulted, folded, and metamorphosed. The metamorphism may be due to the weight of the overlying rocks producing regional metamorphism or due to sufficiently deep burial or proximity to molten rock called magma, resulting in thermal metamorphism. Both processes result in causing the rock to become massive and to change in mineralogy, e.g., forming granites. These rocks commonly are less easily eroded by wave action.

Vulcanicity

The outer layers of the Earth increase in temperature with depth. Locally radioactive heat or heat coming up from below causes part of the rock to melt producing molten magma. The friction of colliding plates usually causes an arc like zone lined by pools of molten rock at depth. Fracturing of the crust in front of the collision zone due to the pressures developed during plate movements permit the magma to ascend to the surface along faults and major joints. As a result, arcs of volcanic islands tend to be located above the descending rocks in the collision zone, e.g., the Windward and Leeward Islands in the West Indies and along the coasts of the Pacific Ocean (the “ring of fire”). There are also hot spots scattered across the Pacific Ocean which produce volcanic islands or truncated guyots. These islands rise from the ocean deeps producing the highest mountains in the world when the depth of the ocean is considered, e.g., the Hawaiian and Emperor chains in the Pacific Ocean. In the tropics, they are commonly surrounded or covered by coral formations (the subsidence theory of Darwin) [22]. On young islands, fringing reefs and barrier reefs are common away from river mouths. Since the islands are slowly sinking, there is a sequence from fringing reefs to barrier reefs and finally atolls as the extinct volcanoes undergo sinking due to isostacy. [23] showed that at Bikini Atoll, the coral was over one kilometer thick over the crest of the former volcano, thus confirming the subsidence theory for some of the islands. However, if the rate of subsidence is too fast, corals are absent. Guyots consist of the truncated tops of volcanoes and are abundant in the north Pacific Ocean [24] and the Mid Pacific Mountains. [25]. These chains represent the volcanoes developed by magma from hot spots over which the plates were moving mainly in Cretaceous times. These islands were first uplifted above sea level and have subsequently been slowly sinking primarily due to isostacy. They represent the truncated tops of volcanoes that have long since become extinct and that are now in isostatic equilibrium. Vulcanism is also associated with the deep trenches along the subduction zones around the eastern Pacific Rim. The bottom of the Mariana trench was explored by a submersible craft capable of photographing the underlying sea floor and was shown to have active extrusive lava vents with a varied collection of sea bottom plants and animals using the sulphur gases for their energy sources. These may be descendants of the original life on the primaeval Earth when oxygen was not available. The location of the source of the upwelling of El Niño is also at the location of one of the deepest trenches, suggesting the possibility that that fluctuating warm current may be partly the result of heat escaping from within the Earth instead of entirely from elsewhere. The importance of vulcanism in the oceans is that it affects the volume of the ocean basins. The volcanic rocks displace substantial volumes of sea water, but during their subsidence result in falling sea levels until they reach isostatic equilibrium. They enlarge the volume of the basins to a limited extent.

Changes in the Size of the Earth and Slowing of its Rate of Rotation

[6] provides an excellent summary of the ideas on this subject]. The idea originated with [26] who suggested that the Earth had a higher density and smaller radius in the past. This could be the result of an explosive origin of the Earth resulting in gradual expansion of the dense core. [19] argued that the available paleogeographic evidence indicates a cumulative decrease in water covered areas over time. There is consi erable fluctuation over time indicating the influence of other internal processes such as

mountain building that were much more important in altering sea level than mere expansion of the radius of the Earth. However, the rate of change increases with time. These other potential processes include glaciations involving sequestering large volumes of water on land together with the thawing and movement of meltwater back into the sea, sub crustal convection, and the thermal effects of growth and consolidation of new ocean floors. [27,12] also recognized evidence for sea floor spreading. This attracted considerable debate, e.g., [28,29] If the Earth is expanding, the length of a day would be increasing slowly, as would the rate of the Earth's rotation. In fact, the increase appears to have been rather variable but averages about 2 seconds per 100,000 years. This lengthening of the day by 2 milliseconds per century corresponds to an increase in the radius of the Earth of 0.66 mm per year, which is of the same order as the estimates obtained by [16] using paleogeographic data. Wells [2] developed a method of measuring the length of day as well as estimating the number of days in a year for rotation about the sun. He found that in reef corals, the rate of secretion of CaCO3 reaches its maximum in bright sunshine and decreases at night or in darkness leaving minute ridges and furrows. There are also obvious seasonal changes. Present day corals make about 360 ridges each year, but Middle Devonian corals produced 385 410 ridges per year. This implies shorter days during the Earth's orbit round the sun. The average rate of lengthening calculated from an average of 400 ridges suggests an average increase in radius of the Earth since Middle Devonian times of 0.66 mm/a. This suggests that the length of a day in Cambrian time may have been 12 of our present day hours. Using the first 20 years of satellite data from the Inter Terrestrial Reference Frame 2008, [30] report that the data indicates an average expansion of 0.24 +/- 0.05 mm/a for the solid areas and a sea level rise of 3.2+/-0.4 mm/a. Glacial melting measured by SLR during the same period accounts for a rise of 1.8/+/-0.5 mm/a of ice water. Ocean expansion due to a temperature rise is estimated to be 1.0+/-0.1 mm/a, suggesting that the oceanic area is expanding by about 0.4mm/a. They conclude that the Earth has been expanding at 0.35+/-0.47mm/a during the period of study. This has been corroborated by [31]. Some authors argue that the accuracy of measurement indicates that expansion of the Earth is not taking place while Shen and others conclude that it is likely to be proven to be active once a longer data set is available with a smaller statistical error. [32] also demonstrate evidence for different amounts of expansions and vertical changes between the southern and northern Hemispheres during the same period, implying that the Geoid is constantly changing its shape. This is quite likely due to constantly changing positions of the plates and the nearby heavenly bodies. Recently, this theory appears to have been replaced by the theory involving plate tectonics. The importance of this discussion is that this loss of speed and expansion of the Earth over time cannot be explained by losses due to friction alone. Expansion of the Earth is the most likely cause of the bulk of the observed changes, and it has been suggested as an alternative explanation for the differential movements currently explained under the heading of plate tectonics.

Exogeneous Processes

These are natural processes acting at the surface of the Earth that can influence sea level, ocean basins, coastal erosion, volcanic eruptions, the growth of coral reefs as well as any changes in vegetation and climate They include weathering and diagenesis of sediments, and the transport of sediment into the ocean and can be greatly affected by humans. Most of these processes will be subject to isostatic movements, the consequences of movement of plates and any changes in the size of the Earth as discussed above. The two most common explanations given for natural exogenic processes currently causing rising sea levels are climate change (thermosteric sea level change and climatic cycles) and the thawing of the ice in glaciers on land. Accordingly, these will be dealt with first. It is generally agreed that we have just passed beyond the end of the Little Ice Age (LIA) and are about 1000 years into the subsequent warming period. The IPCC report [1] claims that the warming is increasing at a continuous but accelerating pace although other publications suggest that the main post LIA warming is over and the current variations in temperature are within the normal range that occurred during the past years [33]. The evidence from the Yukon suggests that the post LIA warming ceased in 1943 at places like Whitehorse and Watson Lake, based on instrumental data collected by the Canadian Atmospheric Environment Service. It was followed by a stable period until about 1980 A.D., after which the mean annual air temperature commenced an upward trend. This trend ceased about 2000 A.D. when the MAAT seemed to stabilize. [34] noted that the first stabilization occurred during a rare period of increased sunspot activity. [33] point out that there is considerable confusion over the difference between weather and climate. Some of what the IPCC and World Meteorological Office (WMO) discuss is climate, but much of it is weather. Data from approximately 100 locations do not fully characterize the globe, but it is concluded that the overwhelming trend in the data strongly suggests that the Medieval Warm Period and the Little Ice Age were widespread phenomena that affected the entire Earth. Yet other small climatic changes that affect certain parts of the Earth's surface also occur. A survey of the scientific literature shows that 79 of the 102 proxy temperature studies identified a 50 year period during the past millennium that was warmer than any 50 years on record and the course of the Gulf Stream is probably involved as well as changes in the winter extent of the Siberian High, resulting in the periodic cooling of the area extending eastwards to mid Europe. The oscillating warming and cooling of the upper part of the oceans may also be involved. During the past colder climatic events, sea level would be lowered by contraction of the ocean water (Figure 1). Evidence for the relationship between world ocean heat content and thermosteric sea level change in the upper 2000m of the oceans between 1955 and 2010 are provided by [35]. Heat storage in the upper part of the North Atlantic Ocean has been increasing during this period and probably started at the end of the LIA. It is this storage of heat in the upper portion of the oceans that may be causing the increase in MAAT in certain parts of the adjacent land areas.

Carbon Dioxide as a Cause of Climatic Change

During the last two decades, many parts of the land areas of the Northern Hemisphere have experienced increasing mean annual air temperatures together with more extreme weather. The public, media and politicians have been assuming that the warming trends seen in many places on land are the result of increasingly high concentrations of atmospheric carbon dioxide, following the lead of a panel of climatologists appointed by various European governments that produces periodic reports on the amount and causes of the presumed warming, *e.g.,*[1]. However, many scientists have disagreed citing too many causes that are closely correlated with recent major climate changes that are clearly not associated with carbon dioxide.

Note the lack of change in parts of Antarctica and the concentration of change in the Arctic. concentrations [36]. When the known carbon dioxide content of the atmosphere over the past 4000 Ma is compared to the mean annual temperature on a linear scale, the causes of their patterns of change are quite different [37]. Since the changes

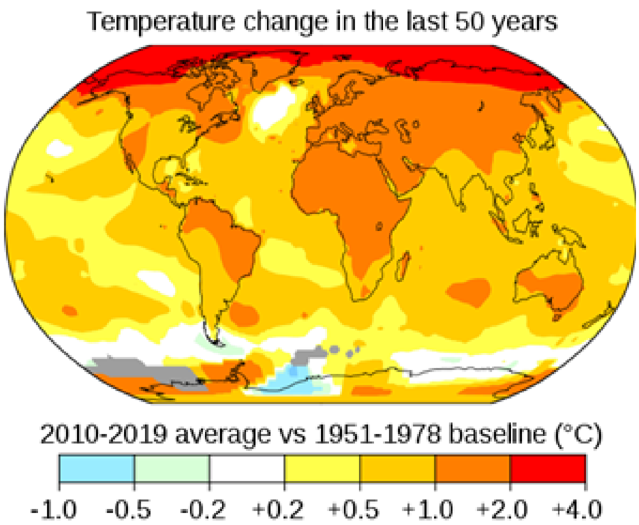

Figure 2: The pattern of change in mean annual temperature between the periods 1951-1978 and 2010-2019 (from NASA).

in carbon dioxide in the air measured in the last century lag slightly behind those of the mean annul air temperatures, the cause of these changes must be different to both. Degassing of carbon dioxide during rising sea temperatures is the most likely cause. A second indicator that carbon dioxide is not the main cause of what has been called "global warming" is provided by NASA. They compared the mean annual temperature data from weather stations around the world for 1951 1978 with those for 2010 2019. The resulting map (Figure 2) shows a very complex area of high temperature change centered on northwest North America and the Arctic Ocean with minor changes in the Sahara and the outback of Australia. There are also no clear increases in Germany nor in Eastern China and the industrial heartland of the United States. However, both IPCC and most governments claim that carbon dioxide emissions by industry are the major cause of global warming. Obviously, the pattern of change is not a global increase but suggests that the large changes are concentrated in the far north around the Arctic Ocean and decrease southwards. Obviously, the warming is not primarily controlled by the distribution of industrial plants and oil and gas installations, but it is probably due to too big a human population for the resources of the planet, *i.e.,* human activity modifying its climatic behaviour.

Solar Energy as a Source of Climate Change

The sun is the source of 99.95% of the heat energy arriving at the surface of the Earth [38]. Accordingly, solar energy also needs to be examined as a potential cause of the variations in climate around the world but is modified by the effects of local geography. The two main surfaces on the Earth are the land and sea. The oceans cover about 70% of the surface of the Earth and absorb about 5 times as much solar energy as the adjacent land areas due to water being translucent. It is also the main medium transporting heat polewards since it has a very large heat capacity (4.87 mJ/m^{3}K). However, its ability to carry heat depends on the configuration of the land and seas. Antarctica is essentially a spherical area around the South Pole with only the Falkland Islands archipelago interacting with the circular subpolar surface water flow around it. It is inevitably surrounded by a zone of cold water coming from the snow covered ice cap. In contrast in the Northern Hemisphere, the ocean currents transport heat polewards with the Gulf Stream extending north into parts of the Arctic Ocean (Figure 3). This brings enormous quantities of heat to the North Atlantic region and results in heating of the western air masses flowing east.

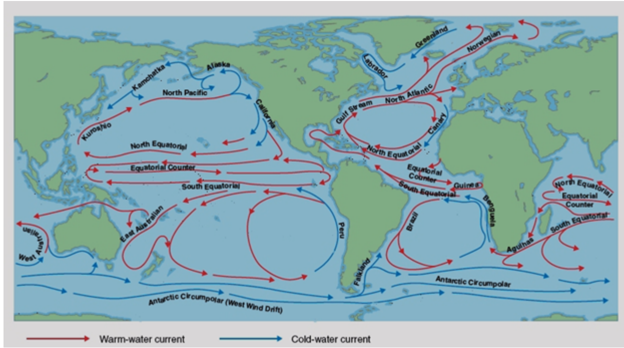

Figure 3: Ocean currents, red being warm and blue being cold.

The Gulf Stream/North Atlantic currents move the greatest amount of warm water, with the Kuroshio current moving the second most amount. Both move north towards the north pole, but there are no comparable currents heating the shores of Antarctica. Similarly, the Kuroshio and North Pacific currents move heat northeastwards in the Pacific Ocean but collide with cold meltwater from the Wrangell St. Elias mountains and are deflected back to Japan. The Bering Sea is very shallow (c. 50 m), consequently restricting water movement into that part of the Arctic Basin. As a result, there is a buildup of heat around the north Atlantic, which if not relieved in some way, causes the type of heat problems being experienced at present. In contrast, the surface of land areas heats up rapidly, but it is only slowly passed downwards into the ground by conduction. This heats the air above during the day and aids in substantial reradiation of heat by night. Air has only small heat capacity so that it is only in deserts or the centres of Oceans in the Tropics that major high pressure zones of hot air form extensive anticyclones, e.g., the Sahara and the Indian Ocean. Thus air has low carrying capacity for water in the gaseous state but the colder conditions high in the Atmosphere cause the water to change to droplets and ice crystals around suitable centres and these form dense clouds, In Hurricanes which originate over tropical oceans, the quantity of water transported in the air can be enormous and represents a substantial source of heat which travels poleward, being gradually deposited as torrential rain on the Earth surfaces along their paths of movement. Since the latter are almost exclusively northwards, this is a further source of heat in the North Atlantic and North Pacific areas (Figure 4).

This buildup of heat also leads to thawing of the ice cover in the Arctic Ocean. Cold, dry Siberian air moving eastwards across this open water picks up both heat and water vapour leaving behind relatively saline warm water which has higher density. When the density differential is large enough, the warm saline water sinks to the bottom of the ocean where it accumulates. It is estimated that at least 60% of the heat accumulated in the North Atlantic area since the end of the last Neoglacial event (c. 1915 A. D.) is held in the sea water.

The 100-ka Climatic Cycle

Inevitably this buildup of heat in the North Atlantic creates a situation which results in periodic drastic events in the oceans. Oceanographers discovered a deep water thermohaline circulation system over 50 years ago (Figure 5) [39-45]. They did not speculate

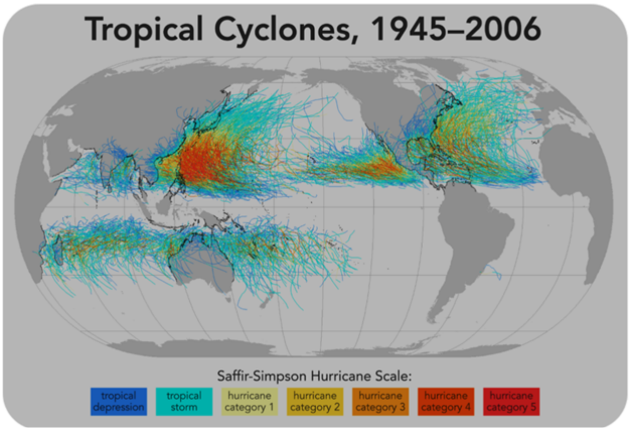

Figure 4: Distribution of tropical cyclones between 1945 and 2006 around the world (NASA).

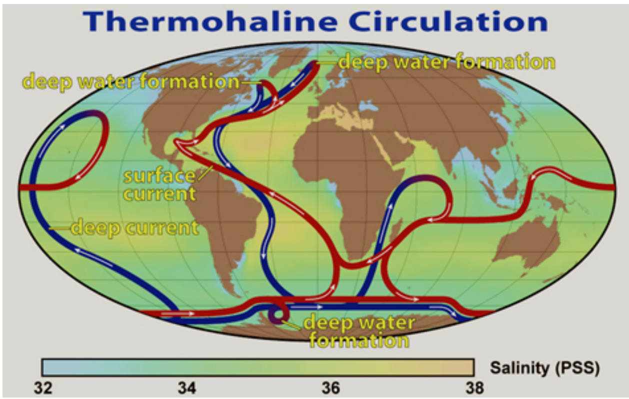

Figure 5: The thermohaline circulation (THC) and the salinity of the surface waters (NASA).

on the source of the heat but have carried out enough research to demonstrate that there is a cycle of climate change that has been occurring every 100 ka during the last 800 ka B.P. with fast moving, deep thermohaline currents (THC) that move heat down to the southern hemisphere and form part of a global thermohaline system. A return flow of cold Antarctic surface water flows north to the North Atlantic Ocean to replace it and restore the former sea level [46].

This is believed to cause a rapid cooling of the northern hemisphere with glacial advances commencing within about 12 years in Greenland and was called the "bipolar see saw" by Broecker. After this, a period of increasing expansion of cold glacial conditions takes place for about 85 ka, the sea level falling as more water is stored as ice on land (Figure 1), and the cold being punctuated by minor warming episodes about every 23 ka. It finally ends when the Arctic air mass reaches an extent such that the warming caused by the change in tilt of the axis of the Earth (precession) causes the Arctic air mass to retreat with its main flow changing from paths 2 and 3 to path 1, *i.e.*, from the northern paths to that centered on southern British Columbia (Figure 6). This produced deglaciation and an Interglacial warm period lasting 10-15ka. The Milankovitch cycles, specifically the eccentricity and the precession cycles, are believed to control the system [48].

Figure 6: Map showing the distribution of permafrost in the Arctic [47], (Figure 4.1) together with the mean surface air January isotherms (˚C) and the adjacent warm and cold ocean currents. Also shown are the three main paths (I to III) taken by the Arctic air as it moves from Asia to northern Canada, and the positions of the main warm ocean currents currently bringing heat from the Tropics.

Implications for Sea Level Changes

Currently we are close to the end of the present interglacial unless something unexpectedly changes. Any such transition to a cold glacial climate in the Northern Hemisphere would produce enormous changes in the landscape with lowering of the sea level by c. 30 m in about 25 ka, erosion along rivers mouths and estuaries. This would result in new areas of land appearing where there are now shallow seas, coral reefs becoming dry, dead coral around the present day coral islands, present day cliffs left inland, new shorelines and cliffs, docks being left high and dry, growth of glaciers and permafrost areas, as well as enormous changes in climate involving cooling, shorter periods for growing crops, changes in the biota, etc. These will be discussed elsewhere but much of the population of the Earth might view the present climate part of the "good old days".

Expansion and Thawing of Glaciers and Permafrost

The recent warming of air temperatures has caused spectacular retreat of many glaciers in the middle latitudes together with thawing of ice in the ground (permafrost). [30] reported a sea level rise of 1.8+/-0.5 mm/a based on more than 20 years of satellite data [31]. Rates of release of water from permafrost are slower and difficult to measure. [21] refer to these changes as glacio isostacy and hydro-isostacy respectively. They estimate these major changes in a glaciation to take 10,000 100,000 years to complete depending on the climatic history of the region. The amount of subsidence and rebound can exceed 300 m. During the Little Ice Age, water was sequestered in the colder parts of the landscape as ice resulting in expansion in the areas of glaciers and permafrost in the colder climatic areas and decreased runoff of water to the sea.

Other Climatic Effects on Land Areas

In all climates, modifications in microenvironments on land alter the processes involved in weathering, diagenesis, mass wasting and deposition. The two key factors involved are precipitation and temperature. Together, these control the physical and chemical processes in weathering, erosion and downhill movement towards the sea. Together, they control the physical and chemical processes operating to carry material downstream towards the sea. Removal of soluble chemical weathering products is normally greater than removal sediment in streams. They also control what vegetation can grow in each area as well as the type of soil present and its water regime and chemistry. Slope modifies the hydrology of an area. Fire can abruptly alter these environments, water retention and vegetation, often producing a fire climax replacing the original vegetation as in coastal areas of Southern California. It can quickly alter conditions in forested areas and peatlands.

Weathering and Diagenesis

When sediments are deposited on the land surface, they become subject to weathering by wind and water. They normally are relatively unconsolidated, *e.g.,* volcanic ash on the slopes of Japanese mountains. When soaked by rain and vibrated by wind or earthquakes whereupon it can flow downslope as a mudflow or simply compact allowing the excess water to drain away. Diagenesis is the weathering and compaction of the sediments to form a relatively hard relatively stable sediment which takes up less space than the original deposits. Weathering is the alteration of the sediment in situ by chemical, mechanical or biological means. These processes result in changing the composition of all surface rocks into mineral particles which are chemically stable on land in the local microenvironment, but this generally also involves breaking them up into fragments that can readily be moved by wind or water. Precipitation causes movement downslope and ultimately into the sea. This sediment displaces water and tends to cause the sea level to rise as well as lowering of the landscape being eroded. However, isostacy slowly raises the landscape being eroded and causes the accumulation of isostatic movements as being tectono sediment isostacy and suggest that they may continue for up to15 million years. The rates of erosion of the upstanding land areas depends a lot on climate and vegetation cover. The large amounts of precipitation in tropical cloud forests cause the soils to have abundant roots due to the dense vegetation cover, so minimizing runoff and providing excellent water storage in the ground Measured densities in the undisturbed surface soils in Costa Rica can be as low as 1.0 g/ cm3 [48,49] whereas after deforestation and cultivation, they exhibit densities of the order of 1.65 g/cm3. As a result, runoff and erosion is greatly increased as the soil structure becomes very poor. Elsewhere in humid climates, runoff is considerable, carrying considerable quantities of sediment downslope, into rivers and finally into the sea. Fire can destroy the vegetation and may produce similar results. In desert areas, the precipitation is rare but comes in the form of heavy rainfalls resulting in catastrophic floods. Along coasts with cliffs of relatively soft sediments, erosion by wave action can be very rapid. The more intense the storms and the greater the fetch, the faster the erosion. The presence of ground ice along coast or in the banks of streams or rivers intensifies rates of erosion and slumping [37,49,50].

Coral Reefs

Corals can grow in a wide range of conditions provided there is clear water in the local environment. However, reef building corals are currently growing primarily within the confines of the Tropics of Capricorn and Cancer apart from Bermuda and southern Japan which lie in the path of the warm ocean currents. Substantial volumes of coral reefs occur where the sea water allows sunlight to penetrate through the upper layers of the sea to a maximum of about 50 m. They do not grow where the water carries much sediment, *e.g.,* at river mouths and most living coral formations have grown since the end of the Late Wisconsin glaciation. They occur only where the rate of the rising sea level was slower than the rate of coral growth and cease to grow if the rise in sea level is too fast [51]. Many of the atolls with great thicknesses of coral masses overlying the former volcanoes were probably built on much older coral structures, *e.g.* along the Yucatan Peninsula, the west coast of the Caribbean Sea, the south tip of Florida and in the Persian Gulf. Coral reefs grow where there is tropical upwelling of nutrient rich water and represent an invaluable protection against erosion of shorelines by wave action in the sane way as mangroves. They occupy 284,300 km^2 or just under 0.1% of the ocean surface [51]. The Great Barrier Reef developed on an undulating lowland that began submergence about 20 ka B.P. It makes up 40.8% of the living coral reefs but is currently undergoing widespread damage resulting in deaths of the reef animals. The coral reefs affect sea level because they remove calcium carbonate dissolved in sea [52]. Recently, it has been found that anthropogenic aerosols damage corals [52] so that perfumes and sunscreens [53] are banned from these areas. In Indonesia, coral mining occurs [54] resulting in destruction of reefs. Dredging of mouths of rivers on coral reefs for access for ships also causes the death of the adjacent reefs due to silt and pollution. Blast fishing destroys reef ecology [55].

Fluctuations in the Height of the Ocean Surface

These are a collection of minor forces that make measuring sea level reliably very difficult. They include lunar tides that are the result of the attraction of the water surface by the moon as it moves around the Earth. They vary in amplitude according to distance from the Earth as well as the time taken to complete a single orbit. These tidal amplitudes can be modified by funnel shaped estuaries and coasts, *e.g*., the Bay of Fundy. Doubling in frequency of the tides can be found between islands, *e.g.,* near Southampton which lies between the Isle of Wight and England. Seiches and wind driven waves can raise the water level along a shoreline by up to 3m by piling up the water for up to two hours by wave action. When atmospheric air pressure changes, the height of the sea alters somewhat. Below a depression (low air pressure), the sea level rise slightly whereas beneath a high pressure cell (anticyclone), the ocean surface is slightly depressed. Satellite altimetry is now being developed and the results obtained so far show that sea level rises towards mountains and over sea mounts due to the gravitational pull of the solid earth masses. To these complications must be added oceanic planetary waves that produce small but mobile wave patterns that move across the oceans. They are part of the planetary waves system which includes the Rossby waves discovered by Chandler [56,57], now known to be present in all fluids on heavenly bodies. The overall effects of these vary randomly in most cases and present small but significant problems in the precise measurement of the Earth's mean sea level.

Summary

On land, there is a climatic cycle every 100 ka of climatic change during the last 800ka in the North Atlantic region involving a cold event with a build up of glaciers, ice sheets and permafrost lasting about 87 90 ka, separated by a warmer interglacial [36]. We are now coming to the end of one of these interglacials. There is also natural variation in sea level apparently related to variations in temperature of the upper part of the ocean. The duration of these cycles varies somewhat but occurred at roughly 30 ka intervals during the Wisconsin Glaciation. They are recorded in the ^{18}O data obtained from the shells of foraminifera in deep sea cores. Before about 850 ka, the cold events in the seas were about twice as frequent but were of lower amplitude. When the sea cooled, the sea level relative to the land dropped partly because of contraction of the mass of water and partly through the added sequestration of water on land. As a result, the shorelines retreated seawards leaving raised beaches backed by cliffs as well as causing alterations in the thalwegs and mouths of rivers that had not usually been realized. The current thinking is that the cycles of cold events during the last 800 ka B.P. were controlled by the Milankovitch Cycles. The effect of the first cold sea cycle establishes ice caps on land. It is followed by a warming sea cycle but the reflection of solar energy by the ice caps back into space prevents the complete loss of the ice in the glaciers. These then enlarge during the next cold cycle, thus growing steadily bigger until an increase in insolation disrupts the temperature balance between the Subtropical air mass and the enlarged Arctic air mass. The latter then starts moving more frequently across the North Pacific Ocean [47, path 1], picking up moisture and heat from the oceans that the air mass crosses and depositing large amounts of snow on the mountains in its path. It then descends as a chinook onto the lower land, thus altering its properties so that it joins the subtropical air mass. In this way, the Arctic air mass decreases in size until it becomes stable in its interglacial position. The retreating ice front results in the slow sea level rises due to the melting of the glaciers. Weathering, mass wasting, and the trio of erosion, transportation and deposition in the sea result in wearing down the land and infilling the ocean basins under the prevailing interglacial climatic conditions. These processes are partly compensated for by isostatic movements resulting in slowly raising the land and submerging the sediments being deposited in the coastal areas. Repeated fires can modify the processes by producing a fire climax vegetation or can aid in the establishment of a new type of vegetation cover. Wave action eats away the shores of the land areas while coral growth can displace the water in the ocean basins. These coral formations are also subject to isostacy, and all areas take part in the movement of plates and the resulting tectonic events. The available evidence suggests that the increasing carbon dioxide in the air may come from expulsion of the gas from the warming seas. There is no significant evidence that it causes climatic change, and the geological record indicates that it varies independently of the temperature of the Earth.

Conclusion

In general, sea level is determined primarily by endogenic processes, modified by exogenic processes. The latter can be seriously impacted by anthropogenic activity in contrast to the endogenic processes which Humans cannot modify at present. The effects of climate change are important but not readily affected by the works of Man. They seem to be controlled by the Milankovitch cycles, the periodic bipolar see saw 100 ka cycles of warming and cooling of the oceans in the northern and southern hemispheres during the last 8 ka, and the development and demise of glaciations. Carbon dioxide does not seem to be important despite the claims by IPCC which overly affect the opinions of the media, the public, and the resulting policies of many Governments. Instead, the carbon dioxide content of the atmosphere appears to be largely controlled by the temperature of the upper layers of the oceans, degassing occurring as the surface waters increase in temperature. Longer term (400,000,000 years) comparison of the mean annual temperature of the Earth and the carbon dioxide of the atmosphere shows no correlation [36] due to losses in the oceans due to formation of limestone. Availability of carbon dioxide in the atmosphere should aid the growth of plants which are a fundamental source of food and wood. Humans must learn to control their numbers, chose their locations for ports and settlements, methods of agriculture, waste production and its disposal and their impacts on the natural environment more carefully. While many places are very beautiful, they can be destroyed by too much inconsiderate love. The damage to coral atolls is an excellent example. Unfortunately, since the end of World War II, humans have increasingly improved their technological skills and now seem expect to be able to modify their entire environment to accommodate populations that are expanding exponentially. Instead, they need to realize that there is a finite carrying capacity on the surface of the Earth at any one time for Mankind to continue to prosper. They must also be sure to adapt to the large natural changes that they cannot either fully understand, predict or control.

Conflict of Interest

The author declares that he has no conflict of interest in this work.

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