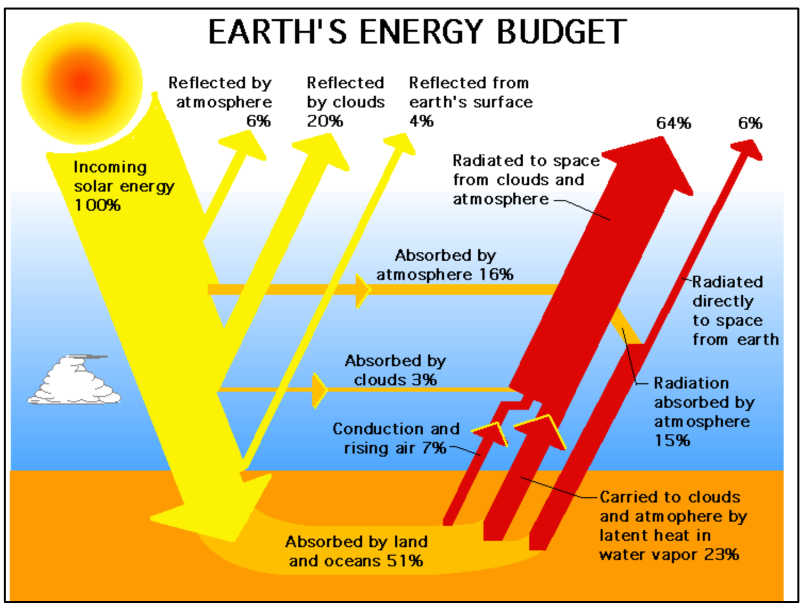
## A Primer of Earth's Climate and Sea Level Change
### The Earth as a Greenhouse Planet

## Excerpt from *The Shiva Encounter* by Doug Cook, 2020

If the Earth had no atmosphere, its effective temperature would be 255° K, that's -18° C! The Earth would more aptly named *Ice without* the atmosphere and clouds holding the balance of incoming solar radiation and outgoing heat radiation in balance and maintaining the average surface temperature 33 degrees warmer at 288° K (15° C) at this time in geologic history. So, the normal greenhouse effect on Earth is 33 degrees. Any change in the effective heat trapping greenhouse gasses, average cloud cover, or insolation of Sun's energy from cyclicity of Earth's orbital parameters will change the Earth's average temperature. Over geologic time, the Earth's average temperature has been colder and warmer. This has the dramatic effect of making glaciers wax and wane and making sea level conversely fall and rise.

Venus offers an extreme analogy. Being closer to the Sun, it receives nearly twice as much solar radiation but reflects 80 percent back into space with its thick sulfuric acid cloud cover.




The Earth's Energy Budget chart shows what we know now about the parts of the Earth's temperature controls. All the energy comes from the Sun. An equal amount of energy must go back into space or Earth's temperature will change.[1]

Because of this, Venus' effective temperature at the surface would be 220° K ( -53° C) were it not for the extreme greenhouse efficiency of its primarily $CO_2$ atmosphere to trap the heat that makes it through the clouds. The greenhouse effect on Venus is 510 degrees so that its average surface temperature is 730° K (457° C)-- hotter than the melting point of lead!

[1] "The Role of Clouds", NASA, Web accessed 16 December 2018, https://www.nasa.gov/audience/forstudents/5-8/features/F_The_Role_of_Clouds.html

**Sea Level Change in the Geologic past**

Take a look at some objective evidence of natural sea level change. Geologists and archaeologists can document that sea level was at least one hundred meters lower than today at the full extent of the last glacial maximum, about 21,000 years ago. This maximum advance is marked by glacial terminal moraines of rock and soil debris gouged and pushed by the glaciers. These moraines are found down to 40° N latitude in the norther hemisphere. The glaciers gouged out the Great Lakes. The great continental ice sheet began retreat about 19,000 years ago and the Earth has been in a warming phase since that time. Abrupt warming starting 11,700 years ago, resulted in rapid melting of ice sheets in the northern hemisphere. The melting of glaciers caused a great flood of meltwater down the Mississippi River valley and other great continental drainage basins to the oceans. This resulted in a slow rise of sea level from lows, 100 meters below present sea level, during glacial maximum.

Evaporation and precipitation are two factors that most influence the ratio of isotopes of heavy oxygen 18 ($O^{18}$) to light oxygen 16 ($O^{16}$) in the oceans and in ice records in great remaining ice sheets. When seawater evaporates, $O^{16}$ is preferentially taken up in the atmosphere because it is lighter, while the heavier $O^{18}$ is preferentially left behind in the oceans. Limestone and seashells from the oceans record these changes in oxygen isotope ratios. When the light $O^{16}$ water precipitates out as snow at high latitudes, it becomes trapped, creating glaciers and ice sheets. When Earth is cool enough year-round, the glaciers and ice sheets are long lived and the ice on Earth's surface is **enriched** in $O^{16}$ relative to $O^{18}$. Changes in oxygen isotopes are recorded in standing ice sheets in Greenland and Antarctica with deep ice cores revealing the changes. The oldest ice core dated from Antarctica is 2.7 million years old.

Geology also records sea level changes over the course of millions of years in the type of sediment laid down at a given location. A sea level rise and drowning is called a transgression. A sea level fall is called a regression. Characteristic rock layers, such as shoreline sandstone, deep water shale, and deeper water limestone may be deposited in a marine transgression and the reverse for a regression. The Grand Canyon has an incomplete record of the four marine transgressions and regression of the Paleozoic Era from 525 to 270 million years ago.

The Carboniferous Period, from 359 to 299 million years ago, is named for transgressions and regressions of coal swamps driven by high latitude glacial fluctuations. The Late Cretaceous Period greenhouse world, 99 to 65 million years ago, saw a huge rise of sea level, over 100 meters that drowned much of North America in a shallow sea. This sea level rise was driven by warm climate and tectonic plate movements.

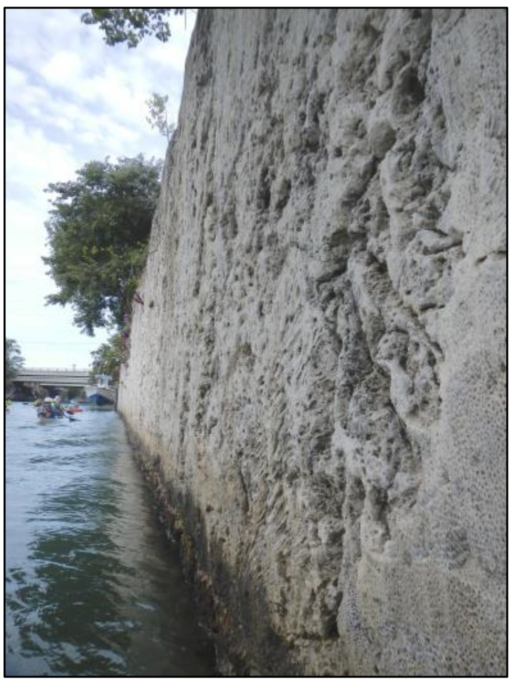
The Cretaceous warm climate was in turn driven by an atmospheric $CO_2$ rise to about 1000 ppm compared to our pre-industrial $CO_2$ levels of about 200 ppm. This natural rise in $CO_2$ is associated with plate tectonics and dissociation of methane hydrate ices. The hydrates currently are predominantly locked up in permafrost in the norther hemisphere above the Arctic Circle. Warming and melting of the permafrost and methane hydrate ices can release huge amounts of methane into the atmosphere viciously adding to global warming.

Archaeology in Europe and North America reveals human settlements up to 9000 years old that lived in moderate climate, in lower latitudes well south of glaciation, in broad plains exposed on the continental shelves. The continental shelves were exposed with the 100 meter drop of sea level during glacial maximum.

The National Historic Preservation Act of 1966, as amended, and other applicable laws and regulations, administered through the Minerals Management Service (MMS) are responsible for ensuring that archaeological resources on the Outer Continental Shelf (OCS) are not damaged or harmed by [commercial] operations. These resources may be drowned terrestrial prehistoric sites dating to the Late Pleistocene/Early Holocene period when sea levels were substantially lower than today.[2]

"Mercyhurst College seeks evidence of early Americans in an area about [two hundred kilometers] off Florida's west coast, now almost [one hundred meters] under water. Early Americans probably hugged the American coastline, congregating around freshwater rivers, before heading inland. At that time, much of the world's water was confined to glaciers, causing ocean levels to be lower and exposing more of the continental shelf. As the earth warmed and water levels rose, evidence of past settlements became submerged. "[3]

Submerged Paleolithic to Neolithic villages (9250-6600 years before present) have been discovered in the Mediterranean of the Carmel Coast of Israel south of Haifa. Atlit-Yam is the major submerged site discovered and studied since the 1980s. It is located 300-500 meters offshore, at 8-12 meters below sea level.[4]



*Our current coastal cities, towns, resorts, and homes are no less vulnerable to sea level rise than these ancient settlements.*

Geology records rises as well as falls in sea level. Geologic evidence records sea level higher than present in the 100,000 year old fossil coral reefs exposed in Adams Cut Canal in Key Largo, Florida. The top of the limestone at Adams Cut is five meters above the ocean. (Photo credit: 2geeks-at-3knots).

This is solid evidence that sea level in our recent geologic past was at a minimum five meters higher than it is today. Modern reefs in Key Largo thrive in water depths of five to ten meters, so it's reasonable from the evidence at Adams Cut that these 100,000 year old reefs may have formed in waters ten to fifteen meters higher than present. Imagine what that rise of sea level would do to today's coastal cities and coastal resort communities.

---

[2] MMS regulation: NTL No. 2002-G01

[3] "Underwater Exploration Seeks Evidence of Early Americans", Science Daily, 9 July, 2009, Web accessed 14 December 2018. https://www.sciencedaily.com/releases/2009/07/090709120654.htm

[4] Galili, Ehud, et al, "Submerged prehistoric settlements off the Mediterranean coast of Israel," Skylis, 2013, Web accessed 15 December 2018. https://www.researchgate.net/publication/271906395_Submerged_prehistoric_settlements_off_the_Mediterranean_coast_of_Israel

Today's society is resistant to the idea that sea level fluctuates. This complacence encourages unbridled development in zones only one to three meters above sea level. Shanghai, is the largest and most populous example of a modern city at risk of sea level rise with global warming. Shanghai lies on the banks of the Huangpu River at the coast of the East China Sea. Seventeen million people live in Shanghai at elevations less than five meters above the ocean waves.

Not only does geology record the evidence of past sea level fluctuations, it records the evidence that greenhouse gases such as carbon dioxide and methane have risen in lock step with warming periods of deglaciation and sea level rise. Not only are the oxygen isotope ratios recorded in Greenland and Antarctic glacial ice layers, the composition of the atmosphere and greenhouse gas levels are recorded in the accumulation of annual bands of ice.

Milankovitch Cycles of Earth's orbital eccentricity, axial tilt, and precession affect the seasonal angle of the Sun's rays and drive climate change. Earth's orbital eccentricity has a cycle period of 100,000 years. Earth's axial tilt has a periodicity of 41,000 years. Earth's axial precession, like a wobbling top, has a periodicity of 23,000 years. The three Milankovitch Cycles impact seasonality and location of solar energy heating around the Earth and so impact contrasts between the seasons and growth and retreat of glaciers.[5] Climate warming driven by astronomical orbital parameters of the Earth create a feedback loop in the biosphere raising the greenhouse gas levels and further warming the climate by trapping the Sun's heat until the Earth's orbital parameters drive climate to cooling and another cycle of glaciation.

The Earth has been in a warming phase since the last glacial period 11,700 years ago. This is undeniable from the geologic record. The rise in carbon dioxide levels in the atmosphere from industry burning of fossil fuels only serves to accelerate global warming and sea level rise.

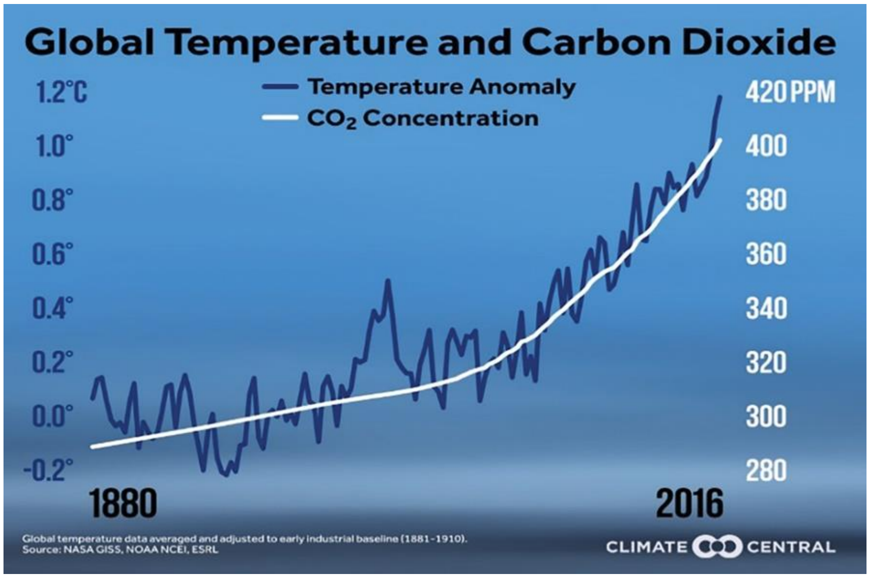
The 20th century witnessed the greatest rise in living standards in human history, supported by the energy provided from fossil fuels. Now, however, we face the consequences; the great challenge of the 21st century, which may define how we live in the future-- how to deal with a changing climate caused in large part by the emission of $CO_2$ due to the burning of these fossil fuels.

The evidence for climate change comes from three main sources: 1) The actual measurements taken from the ground, water, atmosphere, and from space in our recorded history 2) The scientific principles behind the effects of solar radiation, the components in our atmosphere and an understanding of the applicable chemistry, physics and mathematics 3) The geologic record of the past, which clearly demonstrates the changes in climate in the past and how to relate those changes with current processes.[6]

---

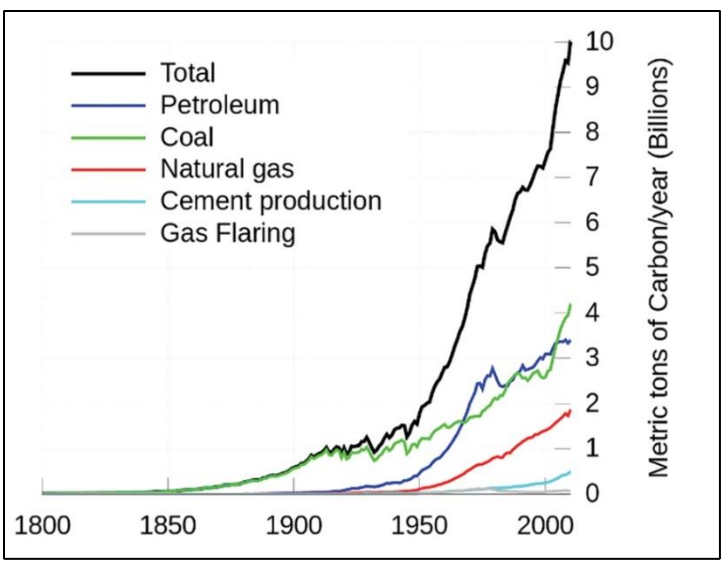
[5] "Milankovitch Cycles and Glaciation", Web accessed 15 December 2018. http://www.indiana.edu/~geol105/images/gaia_chapter_4/milankovitch.htm

[6] Leonard, Ray, "An Earth Scientist's Perspective on Climate Change," American Association of Petroleum Geologists, AAPG Explorer, October, 2018. Web accessed 18 October 2018. https://explorer.aapg.org/story/articleid/49526/an-earth-scientists-perspective-on-climate-change




Global temperature has increased approximately 1.3° C since 1880. A sharp increase in the rate of temperature rise was observed after 1950 which coincided with the increase in $CO_2$ content in the atmosphere. Atmospheric $CO_2$ content is now 411 ppm.[39]

Industrial greenhouse gas emissions are dominated by $CO_2$ (76 percent) followed by methane, $CH_4$ (16 percent) and nitrous oxide, $N_2O$, (6 percent). Eighty percent of $CO_2$ emissions come from burning of hydrocarbon fuel and related industrial processes.[39, 7] Pre-industrial levels of $CO_2$ were about 200 ppm. They have risen to about 411 ppm today. Carbon dioxide levels today are higher than any time in the last 800,000 years.




Global warming is thawing permafrost layers above the Arctic Circle. Biologically derived methane hydrate ices are trapped in the permafrost. The release of huge

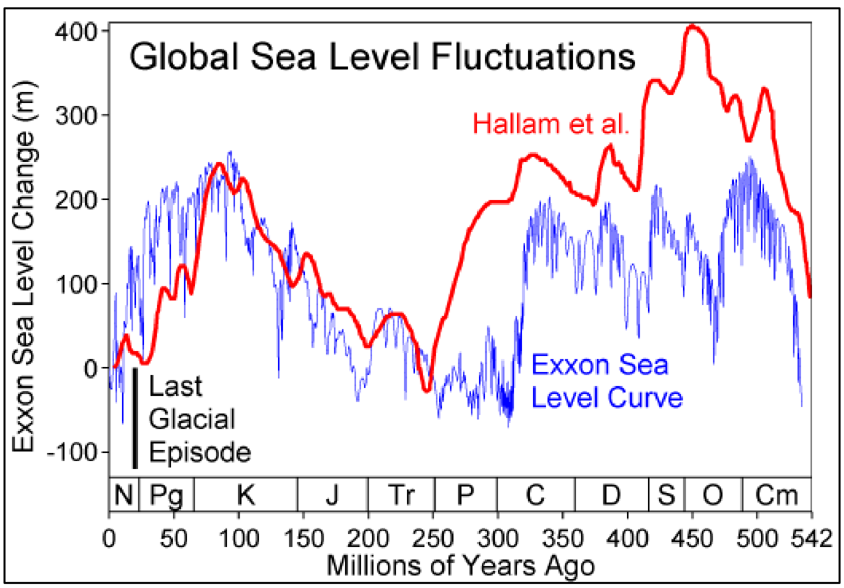
[7] EPA, 2017

amounts of greenhouse methane from the melting permafrost will further increase the rate of global warming.

Permafrost covers twenty five percent of North America and Asia mainly above the Arctic Circle. Permafrost is thawing deeper below ground every year releasing not only methane but increasingly vast amounts of additional carbon dioxide. It has been call the ticking carbon bomb that is already accelerating greenhouse warming.

The chart above shows comparative $CO_2$ emissions from different sources. $CO_2$ emissions rose steadily until 1950 when economic expansion in the "developed world" led to vastly increased emissions, with an unprecedented rate of $CO_2$ rise. The economic development of China, fueled mostly by coal, resulted in another spike. At the current increase of 2.7-3 ppm per year, consistent with the emission of 40 gigatons of $CO_2$ emitted annually, a level of 500 ppm will be reached around 2050, a level not seen since the end of the Paleogene warming period, 30 million years ago.

The geologic record indicates that it was when the $CO_2$ level dropped significantly below 800 ppm that the Antarctic ice sheet began to form; the achievable task facing mankind is to slow and then halt the rise in atmospheric $CO_2$ content and find a way to gradually reduce it so that the $CO_2$ level remains significantly below the 800 ppm level.[39, 8]

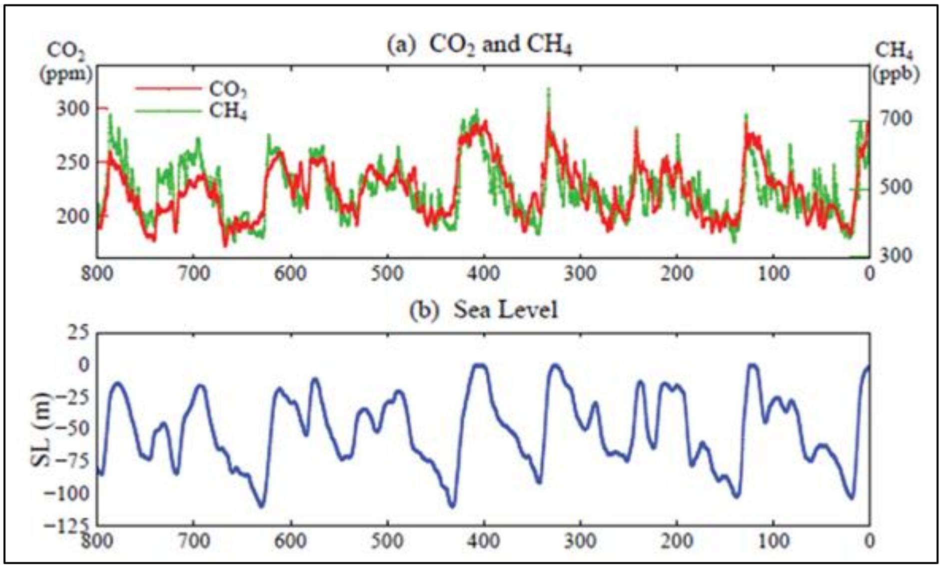



The chart above is a comparison of two sea level reconstructions for the last 500 million years.[9] The large scale changes in sea level are largely due to global tectonic plate shifts with climatic change being a secondary effect. The higher frequency sea level change in the last million years has been dominated by climate and glacial fluctuations as presented in the graph below.

---

[8] CDIAC, DOE

[9] Principles of Paleoclimatology, by Thomas M. Cronin (1999) ISBN 0-231-10955-5, pp. 381, 382




**Time Scale (Thousands of Years before Present)**

The record from ice cores over the past 800,000 years documents the range of $CO_2$ content of 180-300 ppm, the cycle time of 50,000-100,000 years, and the relationship of atmospheric $CO_2$ content with sea level rise and fall. (Adapted from Hansen et al, 2013).[39, 10] There has been a rapid rise of $CO_2$, $CH_4$, and sea level, in the last 11,000 years.

If all of the ice covering Antarctica, Greenland, and in surviving glaciers around the world were to melt, sea level would rise about seventy meters. Ninety percent of Earth's ice above sea level is locked in the Antarctic ice sheet. It has already begun to melt significantly. A melt collapse of the Antarctic ice sheet would cause a catastrophic sea level rise that would change the world as we know it.

[10] Hanse, James, et al, "Climate sensitivity, sea level and atmospheric carbon dioxide," Philosophical Transactions of the Royal Society, V. 371, Issue 2001, 18 October 2013, Web accessed 14 October 2018. https://doi.org/10.1098/rsta.2012.0294