Short communication

Earth Thermal Emissions and Global Warming

ABSTRACT

Although the link between increasing levels of greenhouses gases and global warming is now widely acknowledged, controversy remains as to the extent to which the greenhouse gases, in particular carbon dioxide, impact global temperature. Hubert Lamb, who founded the Climatic Research Unit in East Anglia, UK and is regarded by many as the father of modern climatology, challenged the notion that elevated atmospheric carbon dioxide could explain all the observed global warming, and instead suggested that the direct heating effects of heat production could be playing a major role in warming the earth. Despite decades of extensive climate change research, further effort is necessary to fully understand the role that earth thermal emissions may play in global warming.

A earth-human body analogy offers a useful way of moving forward. For example it is known that ~~example, that~~ 70% of the earth is covered by water and a similar percentage accounts for the amount of water that makes up the human body. A further analogy is between body fat and hydrocarbons (oil, coal and gas) stored in the earth. The main functions of the fats and fatty tissues in the human body are to keep the core body temperature constant and to store energy. Fats are hydrocarbon and the fatty cells are mainly found in the body around the middle part, prominently in the abdominal region and the brain to reduce heat losses and store energy for future use. Fats in the body are normally under the skin and around the organs but not in a separate layer. Equivalently, the fats of the earth are the fossil hydrocarbons too and mainly are made of coal, petroleum and natural gas which are called fossil fuels. They therefore must have different functions and one of them could be to sustain the earth's natural ecosystem. One of their prime functions arguably could be to prevent the underground heat of the core earth reaching the surface, i.e. they act as the natural insulators for the earth.

When fossil hydrocarbons are extracted from the earth, they are naturally replaced by a layer of water. Water has high thermal conductivity as compared to coal, oil, and gas. This will further increase the heat transfer rate from the underground in all directions but most importantly towards the surface of the earth and seas due to the greater temperature difference. Additionally, heat losses and thermal emissions from boreholes will be even higher and given that there are more than 4 million onshore hydrocarbon wells (producing and non-producing) around the world, the heat emissions could be significant. Added to this is the heat from thousands of coal mines across the world. Some recent evidence is emerging on elevated subsurface temperatures in areas of hydrocarbon extraction.

Further research is warranted to establish the extent to which thermal emissions, and in particular, heat flow from the earth's interior resulting from earth insulation loss caused by hydrocarbon removal may contribute to global warming. This requires extensive monitoring. Data on geothermal heat emissions from operational and abandoned oil and oil-gas fields needs to be collated. Sub-surface temperatures need to be monitored using bore-hole repeat temperature measurements and particular trends ascertained.

INTRODUCTION

Although not widely known, Eunice Foote is believed to be the first person to suggest that an atmosphere containing high levels of carbon dioxide would lead to a warmer world [1]. Her research findings were presented in 1856 (see [2]) at the annual meeting of the American Association for the Advancement of Science. Being a female, Foote was not permitted to present her own paper and instead, Professor Joseph Henry of the Smithsonian Institution spoke on her behalf [1]. A few years later, Foote's findings were reflected in the studies of English physicist John Tyndall.

From that period onwards, the idea of climate warming linked to increasing levels of atmospheric carbon dioxide became the subject of intense debate. *Change font here* - A few decades after the work of Eunice Foote and John Tyndall, the Swedish scientist Svante Arrhenius, in 1896, quantified the effects of carbon dioxide concentration on temperature. He estimated that a doubling of carbon dioxide would increase the global mean temperature by up to 5°C to 6°C – a value not far off from current estimates. It was not until after the work of Guy Stewart Callender during the 1930s and 1940s [3], and that of American scientists Roger Revelle and Hans Suess [4], that the idea of increasing atmospheric carbon dioxide levels leading to increase in global temperature was beginning to find greater acceptance.

Although the link between increasing levels of greenhouses gases and global warming is now widely acknowledged, controversy remains as to the extent to which the greenhouse gases, in particular carbon dioxide, impact global temperature [5, 6, 7]. Hubert Lamb, who founded the Climatic Research Unit in East Anglia, UK and is regarded by many as the father of modern climatology, challenged the notion that elevated atmospheric carbon dioxide could explain all the observed global warming, and instead suggested that the direct heating effects of heat production could be playing a major role in warming the earth [8]. Despite decades of extensive climate change research, further effort is necessary to fully understand the role that earth thermal emissions may play in global warming.

THERMAL EMISSIONS AND GLOBAL WARMING

The role played by thermal emissions in elevating temperature has been the subject of research at the global scale (e.g. [9, 10, 11, 12, 13]); regional scale (e.g. [14, 15, 16, 17]) and local scale (e.g. [18]). As noted by [15], the idea that anthropogenic thermal emissions may contribute to global warming was first brought forward almost half a century ago (see [9]) but has largely been forgotten. In attempting to better understand the role of thermal emissions in global warming, [15] investigated unexplained winter warming over northern Asia and North America. They concluded that thermal emissions are likely to be a missing forcing for the additional winter warming trends in observations.

The impact of thermal emissions from thermoelectric power plants on riverine temperature was recently quantified for the first time by [19]. In the analysis comprising 565 power stations from across the world, they found the Mississippi receives the highest total amount of heat emissions (sourced from coal-fuelled and nuclear power plants) whilst the Rhine is the thermally most polluted river in the world in relation to the total flow per watershed. One third of the total flow of the latter is found to experience temperature increases of $\geq$ 5°C on average over the year.

[12] made a case for just over a quarter of the observed warming attributable to increasing levels of atmospheric greenhouse gases, with the remainder resulting from heat emissions on Earth. They argued that heat emissions arise from fossil fuel burning, nuclear power generation, nuclear bomb tests and conventional bomb tests as well as natural processes including volcanic eruptions. [20] argue that energy generation technologies such as nuclear (fission or fusion), fossil fuels and geothermal power plants are human-made sources of heat energy which flows into Earth's climate system. They also stress that such thermal emissions contribute directly to Earth's heat budget and cause global warming.

We believe that our understanding of all the underlying drivers of accelerated global warming is incomplete and warrants further investigation. To help achieve this, it is useful to consider the human body analogy of the earth.

EARTH TEMPERATURE REGULATION AND THE HUMAN BODY ANALOGY

[21] were the first to apply the human body analogy to the earth climate change and global warming phenomena. In their study, the authors highlighted the similarities between the human body and the earth. For example, 70% of the earth is covered by water and a similar percentage accounts for the amount of water that makes up the human body. 97% of human blood plasma is made up of pure water and 3% dissolved solutes. These are the same proportions found in seawater. The blood in the body is circulated via vessels, arteries, capillaries and veins, while water on the earth is circulated around by streams and rivers in a cycle very similar to the blood circulatory system. The blood circulatory system is often referred to as the *flowing rivers of life!* A further analogy can be made between trees and (human) lungs given the function of both is to convert a gas into a useful form.

Another, lesser known analogy is between body fat and hydrocarbons (oil, coal and gas) stored in the earth (see [13]). The main functions of the fats and fatty tissues in the human body are to keep the core body temperature constant and to store energy. Fats are hydrocarbon and the fatty cells are mainly found in the body around the middle part, prominently in the abdominal region and the brain to reduce heat losses and store energy for future use. Fats in the body are normally under the skin and around the organs but not in a separate layer.

Equivalently, the fats of the earth are the fossil hydrocarbons too and mainly are made of coal, petroleum and natural gas which are called fossil fuels. Here we will call them fossil hydrocarbons. They were formed millions of years ago (in excess of 650 million years) by natural processes such as anaerobic decomposition of buried dead organisms, leading to oil, gas and coal. Their time scale of formation is different from the time of human existence and this makes them not necessarily part of the evolution process and certainly not for human use. They therefore must have different functions and one of them could be to sustain the earth's natural ecosystem. One of their prime functions arguably could be to prevent the underground heat of the core earth reaching the surface, i.e. they act as the natural insulators for the earth. Fat is mostly around the middle part of the body, because of the larger heat transfer surface area, to control the body core temperature. Interestingly, fossil hydrocarbons of oil and gas are mainly found in the warmer parts of the earth around the equator, where solar heating is high. Similar to the fat in the body, fossil fuels oil and gas are not found in a continuous one layer inside the earth but between the porous structure of the rocks.

Fossil hydrocarbons oil and gas as well coal are also found in some quantity in parts of the world that are north of the Equator, but in lesser amounts in places south of the Equator. It is interesting to note that according to the theory of Earth Evolution, about 300 million years ago, regions currently lying north of the equator such as India were located south of it as shown in Figure 1. This might explain why fossil hydrocarbons; mainly oil, gas-oil and gas are only found in larger quantities in some parts of the world, though they are found elsewhere but in small quantities and not economically feasible to extract. This may also explain why places like Australia, India, Latin America and South Africa have more coal than oil and gas (located in the southern hemisphere for a significant period), while places like Siberia and many parts of Russia as well as Norway have large quantities of oil because these regions were at the equator millions of years ago.

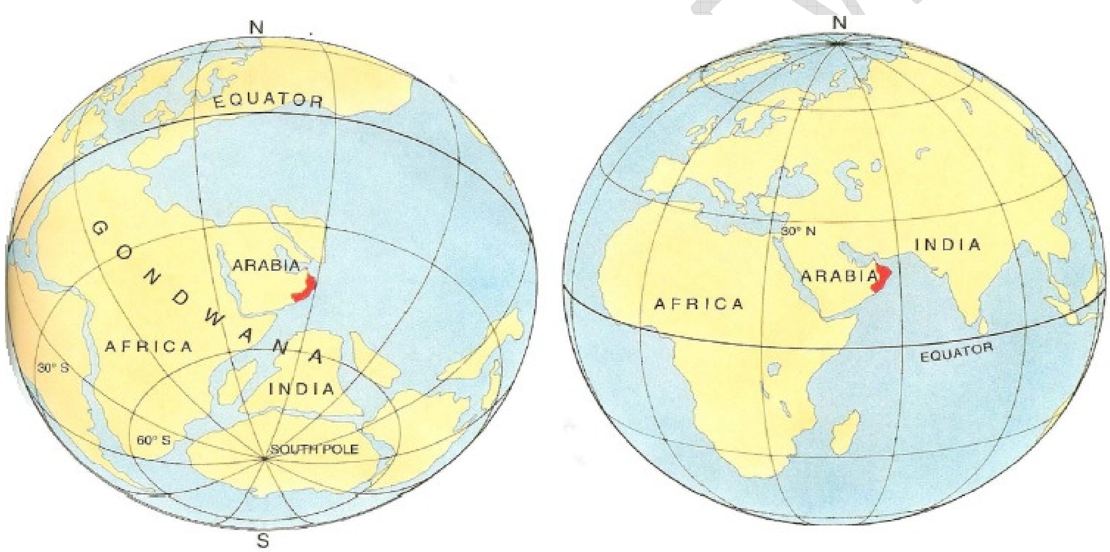

Figure 1. The earth 300 million years ago (left) and now (right) [Source: [23]].

When fossil hydrocarbons are extracted from the earth, they are naturally replaced by a layer of water. Water has high thermal conductivity as compared to coal, oil, and gas. This will further increase the heat transfer rate from the underground in all directions but most importantly towards the surface of the earth and the oceans and seas due to the greater temperature difference. Additionally, heat losses and thermal emissions from boreholes will be even higher and given that there are more than 4 million onshore hydrocarbon wells (producing and non-producing) around the world [24], the heat emissions could be significant. Added to this is the heat from thousands of coal mines across the world. The increased underground thermal activities horizontally and vertically will also increase the thermal expansion of the underground rocks with implications for sea-level rise. The importance of fully considering all potential drivers of sea-level rise including vertical land motion has been emphasised by [25].

[13] were the first to quantify the impact on global temperature of earth insulation loss. They concluded that a 0.84 °C global temperature rise had resulted as a direct result of fossil fuel extraction over the period spanning the start of the industrial revolution and 2010. They also projected a global temperature rise of 0.27 °C by 2020 on the basis of 2010 rates of fossil fuel extraction.

TEMPERATURE CHANGES IN AREAS SUBJECT TO HYDROCARBON EXTRACTION

In the UK, some evidence has been found for elevated subsurface temperatures in areas of coal mining activity. [18] have shown that in Gateshead and Newcastle upon Tyne in north east England, both towns subject to considerable coal mining activity, significant sub-surface heat islands are present. They also note that discharge of groundwater at a minewater pumping station has a significant heat flux attributed in part to heat flowing from the Earth's interior. They conclude that similar conductive heat flow and groundwater flow responses are expected in other urban former coalfields in Britain.

[16] also correlates hydrocarbon removal with air temperature increases. Investigating the mean annual air temperatures for Alaska in the last 30-50 years, He notes significantly more warming in and around Prudhoe bay compared with adjacent areas. This is attributed to the shipment of oil through the Trans-Alaska oil pipeline commencing in 1977. It is postulated that since more than 17 trillion barrels of oil have passed through the pipeline, it has caused heating of the surrounding air which has also resulted in melting of the adjacent sea-ice. The heating is caused because the oil temperature at the point of extraction exceeds 40 °C. This, the author argues, contrasts with the IPCC interpretation of warming in Alaska which assumes that the maximum climatic warming at Prudhoe Bay is typical of the entire region and as a result of greenhouse gases.

In the Middle East, which has been subjected to the most intense sub-surface hydrocarbon removal activity the world has seen, large temperature increases have been reported. For example, a recent study for Saudi Arabia [26] found that between 1985-2013 temperature had increased around 0.65 °C per decade which is four times higher than the global average. According to [27], summer temperatures in the Middle East and North Africa are set to rise over twice as fast as the global average. Extreme temperatures of 46 °C or more are likely to be about five times more likely by 2050 than they were at the beginning of the century according to the research.

Evidence is emerging of rapid warming of sea areas subject to hydrocarbon extraction activity. According to an online data portal [28], the three offshore regions with the largest number of oil/gas rigs are the North Sea, Gulf of Mexico and the Arabian Gulf. Temperatures of the Arabian Gulf are rising three times faster than the world average according to a study by [29]. The author discovered that since 1985, seawater temperature in Kuwait Bay, northern Arabian Gulf, has increased on average 0.6℃ per decade. Rapid warming of the Arabian Gulf waters has also been observed by [30, 31], the latter reporting Arabian Gulf sea-surface temperatures to have increased abruptly in the recent two decades.

Rapidly rising temperatures have been reported by [32] for the northern Gulf of Mexico who quantified trends in the 1985 to 2015 summer bottom-water temperature on the northern Gulf of Mexico continental shelf for data collected at 88 stations. The authors noted that this was the first analyses of decades-long temperature records for the continental shelf of the northern Gulf of Mexico. The observed bottom-water warming for the northern Gulf of Mexico was discovered to be over six times more than concurrent increase in annual global ocean sea surface temperatures.

Analysis of temperature records for the North Sea between 1982 and 2012 has revealed similar trends, with the average rise four times faster than the global average [33].

CLIMATE CHANGE IN THE POLAR REGIONS

Annual average atmospheric concentrations of carbon dioxide in both the Arctic and Antarctica are shown in Figure 2 and are now above 400 parts per million. Despite CO_2 concentrations in the Antarctic lagging behind those in the Arctic, it is clear that concentrations are increasing in both locations. It is interesting to consider the impact that the rising CO_2 is having on temperature and sea-ice extent in the Polar Regions.

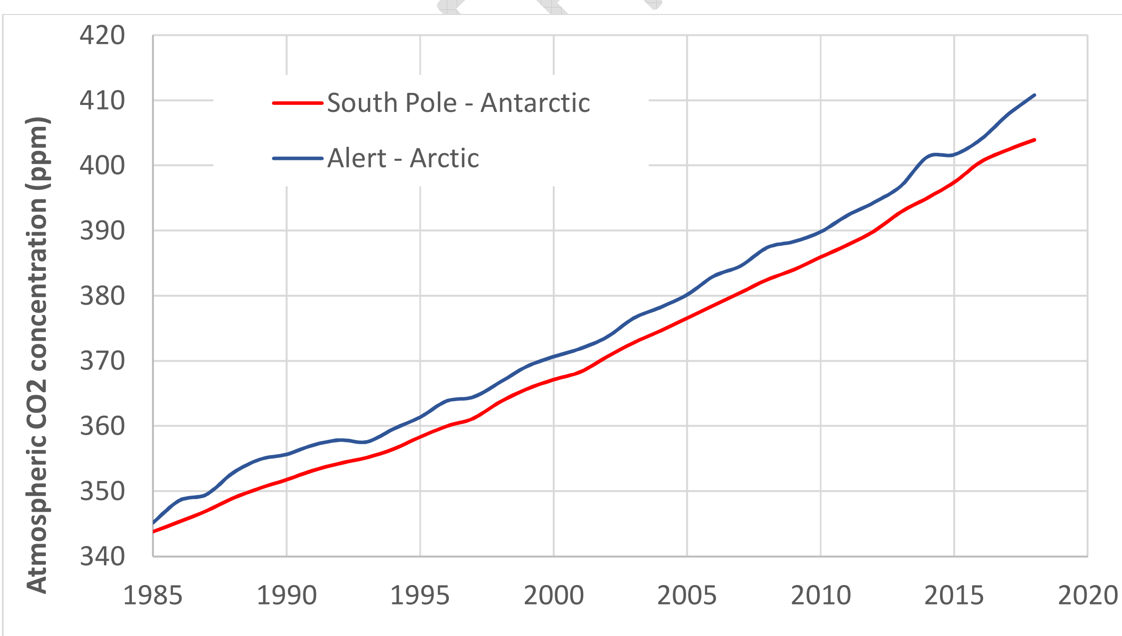

Figure 2. Atmospheric CO_2 concentrations between 1985 and 2018 for South Pole and Alert monitoring stations -data sourced from [34].

Despite rising atmospheric levels of CO_2, surface-temperature change in the Arctic and Antarctica differ substantially. A trend of 0.6°C decade^{-1} has been observed in the Arctic (considered one of the fastest warming regions) whilst a much lower change of 0.1^{0}C decade^{-1} has been observed in the Antarctica (compared with 0.2°C decade^{-1} globally, since 1981 [35]).

Sea-ice extent change between 1978 and 2017 is shown in Figure 3 for both the Arctic and Antarctica.

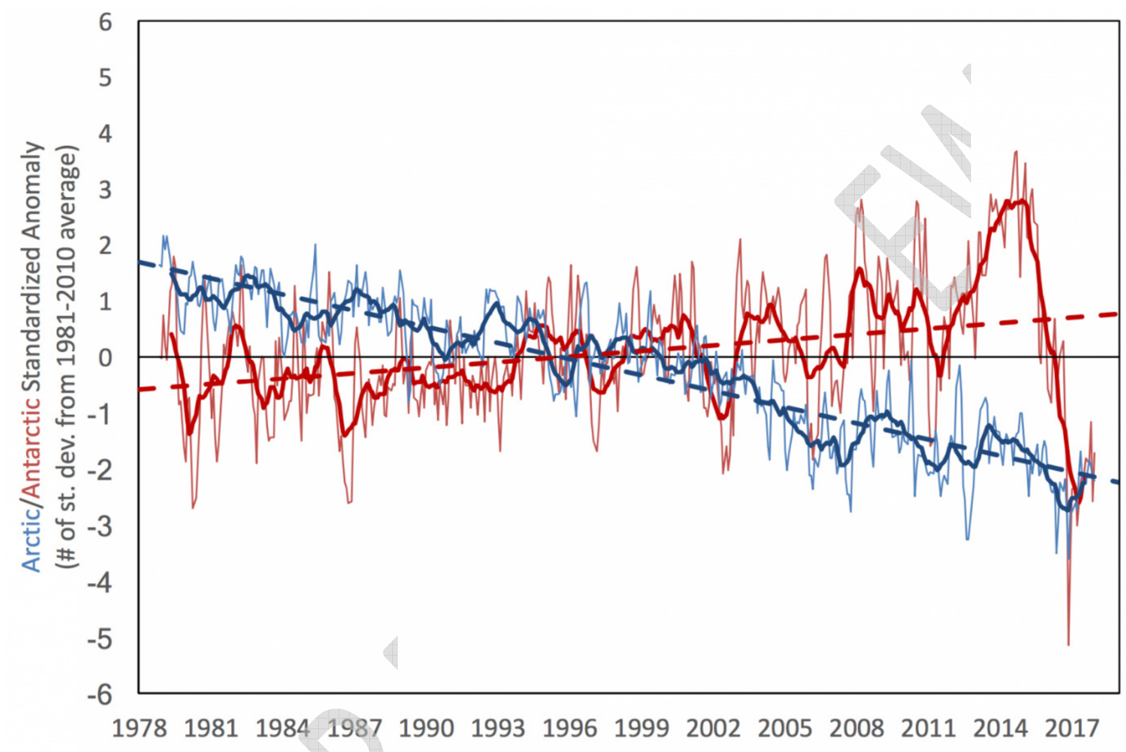

Figure 3. Arctic and Antarctic Sea Ice Extent Anomalies and Trend (blue = Arctic & red = Antarctic), 1979-2017. Thick lines indicate 12-month running means, and thin lines indicate monthly anomalies. [36].

According to Figure 3, Arctic sea ice extent underwent a strong decline from 1979 to 2012, but Antarctic sea ice underwent a slight increase. The positive trend in Antarctic sea-ice extent is intriguing because it appears to be physically counter-intuitive to global warming observations [35]. Various reasons have been put forward for this apparent discrepancy in the Antarctica including stratospheric ozone depletion that caused a deepening of the lows in the West Antarctic region [37], freshening of the Antarctic seawater [38] and changes in atmospheric circulation resulting from changes in the southern annular mode and ENSO and the greater frequency of La Nina events since the late 1990s [39].

We would like to argue that the difference could be explained by the loss of earth ‘insulation’ in the Arctic Circle. It has been estimated that by 2007, more than 400 oil and gas fields, containing 40 billion barrels of oil (BBO), 1136 trillion cubic feet (TCF) of natural gas, and 8 billion barrels of natural gas liquids had been extracted north of the Arctic Circle, mostly in the West Siberian Basin of Russia and on the North Slope of Alaska [40]. Much greater volumes of hydrocarbon extraction will have resulted considering the Arctic region as also extending southwards from the Arctic Circle and encompassing countries with a particularly cold climate, permafrost and frozen sea-ice. Under this definition, this is a vast region comprising West Siberia and Sakhalin, Russia, northern Canada and Alaska (USA). Major producing regions include Drake Point gas field on Melville Island and Brent Horn filed on Cameron Island (Canadian Arctic), Norwegian Continental Shelf (Barents Seas) and Kara and Pechora Seas (Russian Arctic).

In contrast to the Arctic, there has been no extraction of hydrocarbons in the Antarctica and all such activity is banned until 2048 under the Antarctic Treaty.

FUTURE OUTLOOK

Research is warranted to establish the extent to which heat flow from the earth's interior resulting from earth insulation loss caused by hydrocarbon removal may contribute to global warming. If a significant correlation is found, this would have major implications for climate mitigation policy. Gathering appropriate data will be key to understanding this. As usefully noted by [41], *"the only way to figure out what is happening to our planet is to measure it, and this means tracking changes decade after decade and poring over the records."*

Changes in sub-surface temperatures in areas subject to hydrocarbon extraction and in areas without such activity will need to be compared. This will require deep bore-hole repeat temperature measurements. The borehole temperature database established by [42] could be extended with repeat temperature measurements. The data may also be used to revise the estimate of the earth's surface heat flux reported by [43]. Geothermal heat emissions from operational and abandoned oil and oil-gas fields would also be useful allowing geothermal heat flux values to be estimated. Sea-bed temperatures for Shelf Seas (in regions subject to hydrocarbon extraction and those without) over time would also need to be investigated since much of the world's oil and gas production is offshore.

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