

2 **Earth Thermal Emissions and Global Warming**

3
4 **ABSTRACT**

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

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

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

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

39
40 **INTRODUCTION**

41 Although not widely known, Eunice Foote is believed to be the first person to suggest that an
42 atmosphere containing high levels of carbon dioxide would lead to a warmer world [1]. Her research
43 findings were presented in 1856 (see [2]) at the annual meeting of the American Association for the

44 Advancement of Science. Being a female, Foote was not permitted to present her own paper and
45 instead, Professor Joseph Henry of the Smithsonian Institution spoke on her behalf [1]. A few years
46 later, Foote's findings were reflected in the studies of English physicist John Tyndall.

47 From that period onwards, the idea of climate warming linked to increasing levels of atmospheric
48 carbon dioxide became the subject of intense debate. A few decades after the work of Eunice Foote and
49 John Tyndall, the Swedish scientist Svante Arrhenius, in 1896, quantified the effects of carbon dioxide
50 concentration on temperature. He estimated that a doubling of carbon dioxide would increase the global mean
51 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
52 Guy Stewart Callender during the 1930s and 1940s [3], and that of American scientists Roger Revelle
53 and Hans Suess [4], that the idea of increasing atmospheric carbon dioxide levels leading to increase
54 in global temperature was beginning to find greater acceptance.

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

64

65 **THERMAL EMISSIONS AND GLOBAL WARMING**

66 The role played by thermal emissions in elevating temperature has been the subject of research at
67 the global scale (e.g. [9, 10, 11, 12, 13]); regional scale (e.g. [14, 15, 16, 17]) and local scale (e.g.
68 [18]). As noted by [15], the idea that anthropogenic thermal emissions may contribute to global
69 warming was first brought forward almost half a century ago (see [9]) but has largely been forgotten.
70 In attempting to better understand the role of thermal emissions in global warming, [15] investigated
71 unexplained winter warming over northern Asia and North America. They concluded that thermal
72 emissions are likely to be a missing forcing for the additional winter warming trends in observations.

73

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

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81

82 [12] made a case for just over a quarter of the observed warming attributable to increasing levels of
83 atmospheric greenhouse gases, with the remainder resulting from heat emissions on Earth. They
84 argued that heat emissions arise from fossil fuel burning, nuclear power generation, nuclear bomb
85 tests and conventional bomb tests as well as natural processes including volcanic eruptions. [20]
86 argue that energy generation technologies such as nuclear (fission or fusion), fossil fuels and
87 geothermal power plants are human-made sources of heat energy which flows into Earth's climate
88 system. They also stress that such thermal emissions contribute directly to Earth's heat budget and
89 cause global warming.

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

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EARTH TEMPERATURE REGULATION AND THE HUMAN BODY ANALOGY

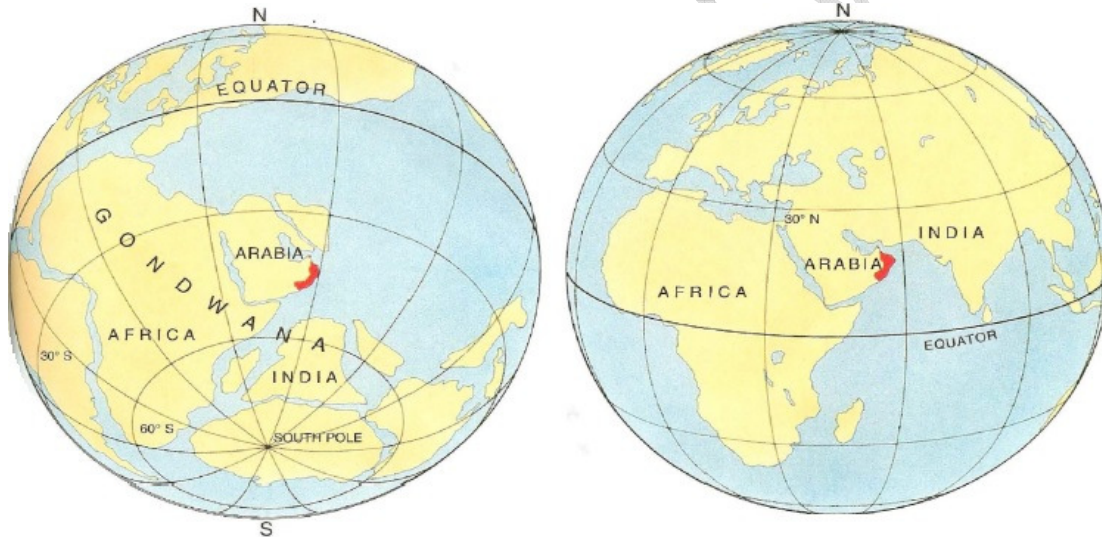
96 [21] were the first to apply the human body analogy to the earth climate change and global warming
97 phenomena. In their study, the authors highlighted the similarities between the human body and the
98 earth. For example, 70% of the earth is covered by water and a similar percentage accounts for the
99 amount of water that makes up the human body. 97% of human blood plasma is made up of pure
100 water and 3% dissolved solutes. These are the same proportions found in seawater. The blood in the
101 body is circulated via vessels, arteries, capillaries and veins, while water on the earth is circulated
102 around by streams and rivers in a cycle very similar to the blood circulatory system. The blood
103 circulatory system is often referred to as the *flowing rivers of life!* A further analogy can be made
104 between trees and (human) lungs given the function of both is to convert a gas into a useful form.

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

111 Equivalently, the fats of the earth are the fossil hydrocarbons too and mainly are made of coal,
112 petroleum and natural gas which are called fossil fuels. Here we will call them fossil hydrocarbons.
113 They were formed millions of years ago (in excess of 650 million years) by natural processes such as
114 anaerobic decomposition of buried dead organisms, leading to oil, gas and coal. Their time scale of
115 formation is different from the time of human existence and this makes them not necessarily part of
116 the evolution process and certainly not for human use. They therefore must have different functions
117 and one of them could be to sustain the earth's natural ecosystem. One of their prime functions
118 arguably could be to prevent the underground heat of the core earth reaching the surface, i.e. they act as
119 the natural insulators for the earth. Fat is mostly around the middle part of the body, because of the

120 larger heat transfer surface area, to control the body core temperature. Interestingly, fossil
121 hydrocarbons of oil and gas are mainly found in the warmer parts of the earth around the equator,
122 where solar heating is high. Similar to the fat in the body, fossil fuels oil and gas are not found in a
123 continuous one layer inside the earth but between the porous structure of the rocks.

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



134
135 **Figure 1.** The earth 300 million years ago (left) and now (right) [Source: [23]].

136
137 When fossil hydrocarbons are extracted from the earth, they are naturally replaced by a layer of
138 water. Water has high thermal conductivity as compared to coal, oil, and gas. This will further
139 increase the heat transfer rate from the underground in all directions but most importantly towards the
140 surface of the earth and the oceans and seas due to the greater temperature difference. Additionally,
141 heat losses and thermal emissions from boreholes will be even higher and given that there are more
142 than 4 million onshore hydrocarbon wells (producing and non-producing) around the world [24], the
143 heat emissions could be significant. Added to this is the heat from thousands of coal mines across
144 the world. The increased underground thermal activities horizontally and vertically will also increase
145 the thermal expansion of the underground rocks with implications for sea-level rise. The importance of

146 fully considering all potential drivers of sea-level rise including vertical land motion has been
147 emphasised by [25].

148 [13] were the first to quantify the impact on global temperature of earth insulation loss. They
149 concluded that a 0.84°C global temperature rise had resulted as a direct result of fossil fuel extraction
150 over the period spanning the start of the industrial revolution and 2010. They also projected a global
151 temperature rise of 0.27°C by 2020 on the basis of 2010 rates of fossil fuel extraction.

152

153 **TEMPERATURE CHANGES IN AREAS SUBJECT TO HYDROCARBON EXTRACTION**

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

161 [16] also correlates hydrocarbon removal with air temperature increases. Investigating the mean
162 annual air temperatures for Alaska in the last 30-50 years, He notes significantly more warming in and
163 around Prudhoe bay compared with adjacent areas. This is attributed to the shipment of oil through
164 the Trans-Alaska oil pipeline commencing in 1977. It is postulated that since more than 17 trillion
165 barrels of oil have passed through the pipeline, it has caused heating of the surrounding air which has
166 also resulted in melting of the adjacent sea-ice. The heating is caused because the oil temperature at
167 the point of extraction exceeds 40°C. This, the author argues, contrasts with the IPCC interpretation of
168 warming in Alaska which assumes that the maximum climatic warming at Prudhoe Bay is typical of
169 the entire region and as a result of greenhouse gases.

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

177 Evidence is emerging of rapid warming of sea areas subject to hydrocarbon extraction activity.
178 According to an online data portal [28], the three offshore regions with the largest number of oil/gas
179 rigs are the North Sea, Gulf of Mexico and the Arabian Gulf. Temperatures of the Arabian Gulf are
180 rising three times faster than the world average according to a study by [29]. The author discovered
181 that since 1985, seawater temperature in Kuwait Bay, northern Arabian Gulf, has increased on
182 average 0.6°C per decade. Rapid warming of the Arabian Gulf waters has also been observed by [30,

183 31], the latter reporting Arabian Gulf sea-surface temperatures to have increased abruptly in the
184 recent two decades.

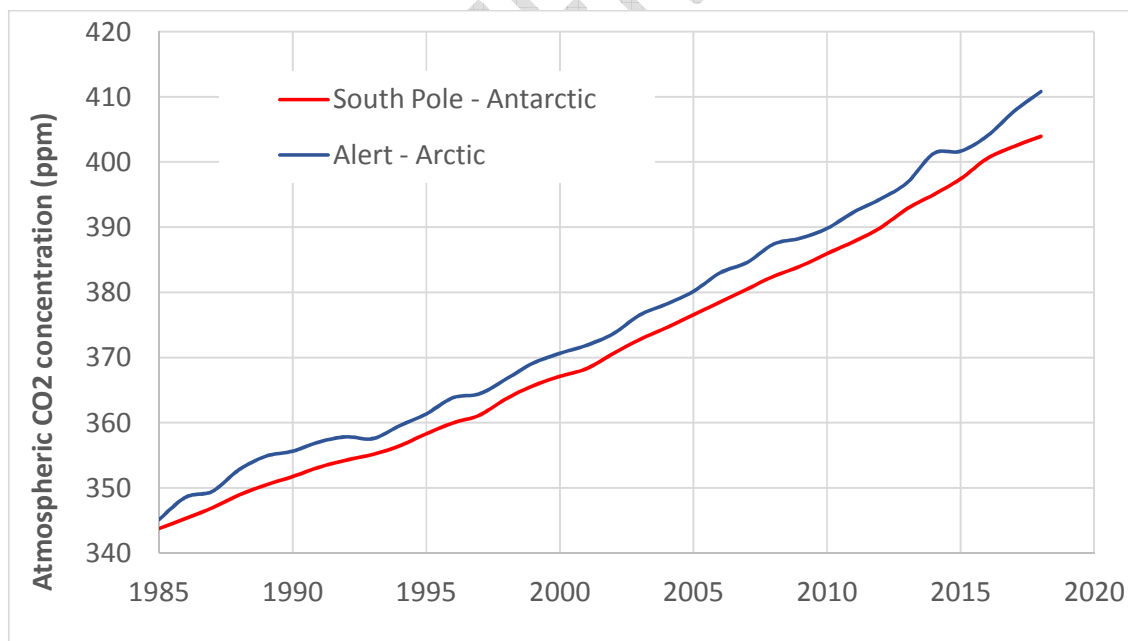
185 Rapidly rising temperatures have been reported by [32] for the northern Gulf of Mexico who quantified
186 trends in the 1985 to 2015 summer bottom-water temperature on the northern Gulf of Mexico
187 continental shelf for data collected at 88 stations. The authors noted that this was the first analyses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

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

193

194 CLIMATE CHANGE IN THE POLAR REGIONS

195 Annual average atmospheric concentrations of carbon dioxide in both the Arctic and Antarctica are
196 shown in Figure 2 and are now above 400 parts per million. Despite CO₂ concentrations in the
197 Antarctic lagging behind those in the Arctic, it is clear that concentrations are increasing in both
198 locations. It is interesting to consider the impact that the rising CO₂ is having on temperature and
199 sea-ice extent in the Polar Regions.



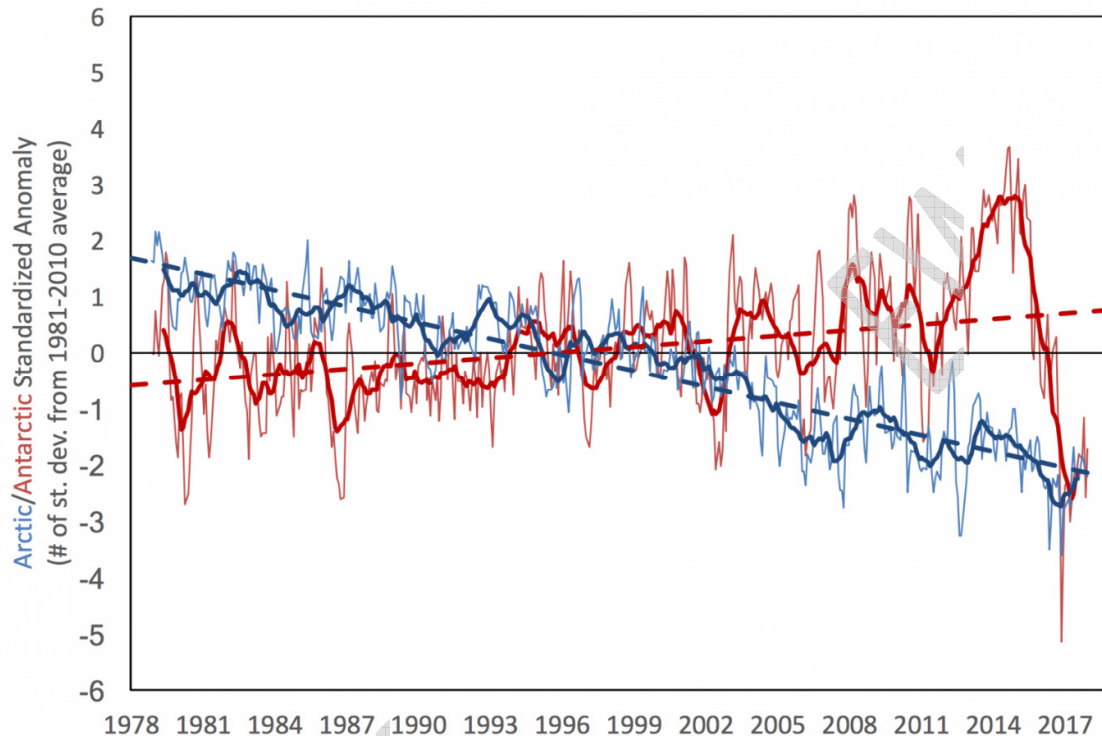
200
201 **Figure 2.** Atmospheric CO₂ concentrations between 1985 and 2018 for South Pole and Alert monitoring
202 stations -data sourced from [34].

203

204 Despite rising atmospheric levels of CO₂, surface-temperature change in the Arctic and Antarctica
205 differ substantially. A trend of 0.6°C decade⁻¹ has been observed in the Arctic (considered one of the

206 fastest warming regions) whilst a much lower change of $0.1^{\circ}\text{C decade}^{-1}$ has been observed in the
207 Antarctica (compared with $0.2^{\circ}\text{C decade}^{-1}$ globally, since 1981 [35]).

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



210

211 **Figure 3.** Arctic and Antarctic Sea Ice Extent Anomalies and Trend (blue = Arctic & red = Antarctic),
212 1979-2017. Thick lines indicate 12-month running means, and thin lines indicate monthly anomalies.
213 [36].

214

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

223 We would like to argue that the difference could be explained by the loss of earth 'insulation' in the
224 Arctic Circle. It has been estimated that by 2007, more than 400 oil and gas fields, containing 40
225 billion barrels of oil (BBO), 1136 trillion cubic feet (TCF) of natural gas, and 8 billion barrels of natural
226 gas liquids had been extracted north of the Arctic Circle, mostly in the West Siberian Basin of Russia

227 and on the North Slope of Alaska [40]. Much greater volumes of hydrocarbon extraction will have
228 resulted considering the Arctic region as also extending southwards from the Arctic Circle and
229 encompassing countries with a particularly cold climate, permafrost and frozen sea-ice. Under this
230 definition, this is a vast region comprising West Siberia and Sakhalin, Russia, northern Canada and
231 Alaska (USA). Major producing regions include Drake Point gas field on Melville Island and Brent
232 Horn field on Cameron Island (Canadian Arctic), Norwegian Continental Shelf (Barents Seas) and
233 Kara and Pechora Seas (Russian Arctic).

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

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238 **FUTURE OUTLOOK**

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

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

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