

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. Here we report on a source of heat that may be contributing directly to global warming and currently not accounted for in climate models. 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. We review the literature and report on temperature trends observed in areas subject to fossil fuel extraction. We find that land and sea areas subject to fossil fuel extraction are experiencing relatively high rates of temperature rise. We examine the case of the Arctic in some detail and compare sea-ice extent change in both the Arctic and Antarctica. We find that despite increasing levels of CO₂ observed in the polar regions, sea-ice extent is shrinking in the Arctic and expanding in the Antarctic. We believe that a possible cause of shrinking sea-ice in the Arctic could be geothermal heat rising to the surface as a direct result of fossil fuel extraction in regions such as Siberia and Alaska. We recommend further research is prioritised 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 fossil fuel extraction 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. 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

45 not until after the work of Guy Stewart Callender during the 1930s and 1940s [3], and that of
46 American scientists Roger Revelle and Hans Suess [4], that the idea of increasing atmospheric
47 carbon dioxide levels leading to increase in global temperature was beginning to find greater
48 acceptance.

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

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59 **THERMAL EMISSIONS AND GLOBAL WARMING**

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

68
69 The impact of thermal emissions from thermoelectric power plants on riverine temperature was
70 recently quantified for the first time by [18]. In the analysis comprising 565 power stations from across
71 the world, they found the Mississippi receives the highest total amount of heat emissions (sourced
72 from coal-fuelled and nuclear power plants) whilst the Rhine is the thermally most polluted river in the
73 world in relation to the total flow per watershed. One third of the total flow of the latter is found to
74 experience temperature increases of $\geq 5^{\circ}\text{C}$ on average over the year.

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77 Nordell and Gervet [12] made a case for just over a quarter of the observed warming attributable to
78 increasing levels of atmospheric greenhouse gases, with the remainder resulting from heat emissions
79 on Earth. They argued that heat emissions arise from fossil fuel burning, nuclear power generation,
80 nuclear bomb tests and conventional bomb tests as well as natural processes including volcanic
81 eruptions. [19] argue that energy generation technologies such as nuclear (fission or fusion), fossil
82 fuels and geothermal power plants are human-made sources of heat energy which flows into Earth's

83 climate system. They also stress that such thermal emissions contribute directly to Earth's heat
84 budget and cause global warming.

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

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EARTH TEMPERATURE REGULATION AND THE HUMAN BODY ANALOGY

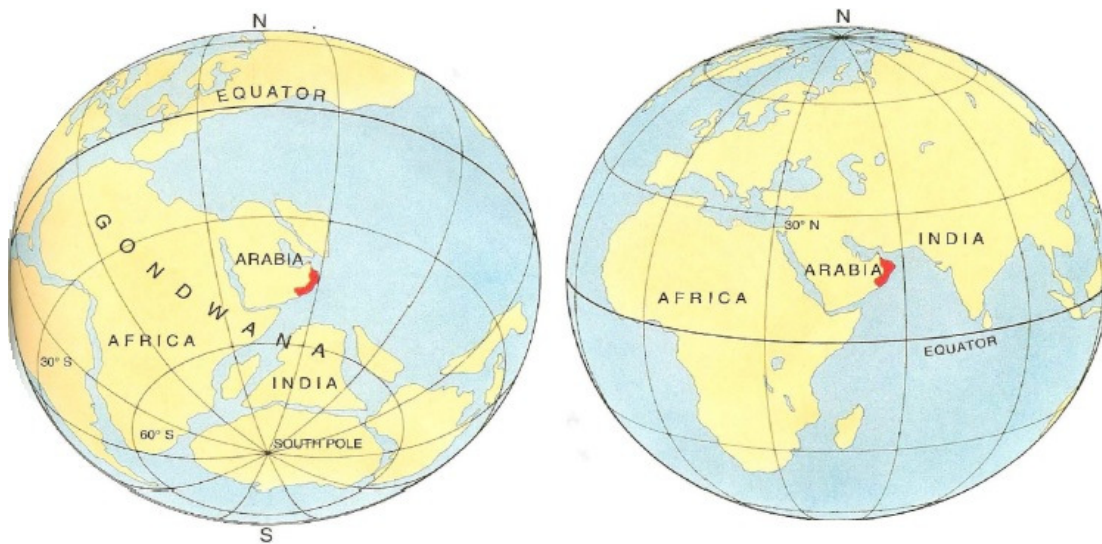
91 Sharif and Sharif [20] were the first to apply the human body analogy to the earth climate change and
92 global warming phenomena. In their study, the authors highlighted the similarities between the human
93 body and the earth. For example, 70% of the earth is covered by water and a similar percentage
94 accounts for the amount of water that makes up the human body. 97% of human blood plasma is
95 made up of pure water and 3% dissolved solutes. These are the same proportions found in seawater.
96 The blood in the body is circulated via vessels, arteries, capillaries and veins, while water on the earth
97 is circulated around by streams and rivers in a cycle very similar to the blood circulatory system. The
98 blood circulatory system is often referred to as the *flowing rivers of life!*

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

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

118 Fossil hydrocarbons oil and gas as well coal are also found in some quantity in parts of the world that
119 are north of the Equator, but in lesser amounts in places south of the Equator. It is interesting to note
120 that according to the theory of Earth Evolution, about 300 million years ago, regions currently lying

121 north of the equator such as India were located south of it as shown in Figure 1. This might explain
122 why fossil hydrocarbons; mainly oil, gas-oil and gas are only found in larger quantities in some parts
123 of the world, though they are found elsewhere but in small quantities and not economically feasible to
124 extract. This may also explain why places like Australia, India, Latin America and South Africa have
125 more coal than oil and gas (located in the southern hemisphere for a significant period), while places
126 like Siberia and many parts of Russia as well as Norway have large quantities of oil because these
127 regions were at the equator millions of years ago.



128
129 **Figure 1.** The earth 300 million years ago (left) and now (right) [Source: [21]].

130
131 When fossil hydrocarbons are extracted from the earth, they are naturally replaced by a layer of
132 water. Water has high thermal conductivity as compared to coal, oil, and gas. This will further
133 increase the heat transfer rate from the underground in all directions but most importantly towards the
134 surface of the earth and the oceans and seas due to the greater temperature difference. Additionally,
135 heat losses and thermal emissions from boreholes will be even higher and given that there are more
136 than 4 million onshore hydrocarbon wells (producing and non-producing) around the world [22], the
137 heat emissions could be significant. Added to this is the heat from thousands of coal mines across
138 the world. The increased underground thermal activities horizontally and vertically will also increase
139 the thermal expansion of the underground rocks with implications for sea-level rise. The importance of
140 fully considering all potential drivers of sea-level rise including vertical land motion has been
141 emphasised by Gehrels and Long [23].

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

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

149 In the UK, some evidence has been found for elevated subsurface temperatures in areas of coal
150 mining activity. Westaway and Younger [17] have shown that in Gateshead and Newcastle upon
151 Tyne in north east England, both towns subject to considerable coal mining activity, significant sub-
152 surface heat islands are present. They also note that discharge of groundwater at a minewater
153 pumping station has a significant heat flux attributed in part to heat flowing from the Earth's interior.
154 They conclude that similar conductive heat flow and groundwater flow responses are expected in
155 other urban former coalfields in Britain.

156 In the Middle East, which has been subjected to the most intense sub-surface hydrocarbon removal
157 activity the world has seen, large temperature increases have been reported. For example, a recent
158 study for Saudi Arabia [26] found that between 1985-2013 temperature had increased around 0.65°C
159 per decade which is four times higher than the global average. According to Leliveld et al [25],
160 summer temperatures in the Middle East and North Africa are set to rise over twice as fast as the
161 global average. Extreme temperatures of 46°C or more are likely to be about five times more likely
162 by 2050 than they were at the beginning of the century according to the research.

163 Evidence is emerging of rapid warming of sea areas subject to hydrocarbon extraction activity.
164 According to an online data portal [26], the three offshore regions with the largest number of oil/gas
165 rigs are the North Sea, Gulf of Mexico and the Arabian Gulf. Temperatures of the Arabian Gulf are
166 rising three times faster than the world average according to a study by Al-Rashidi [27]. The author
167 discovered that since 1985, seawater temperature in Kuwait Bay, northern Arabian Gulf, has
168 increased on average 0.6°C per decade. Rapid warming of the Arabian Gulf waters has also been
169 observed by Nandkeolyar et al [28] and Shirvani et al [29], the latter reporting Arabian Gulf sea-
170 surface temperatures to have increased abruptly in the recent two decades.

171 Rapidly rising temperatures have been reported by Turner et al [30] for the northern Gulf of Mexico
172 who quantified trends in the 1985 to 2015 summer bottom-water temperature on the northern Gulf of
173 Mexico continental shelf for data collected at 88 stations. The authors noted that this was the first
174 analyses of decades-long temperature records for the continental shelf of the northern Gulf of Mexico.
175 The observed bottom-water warming for the northern Gulf of Mexico was discovered to be over six
176 times more than concurrent increase in annual global ocean sea surface temperatures.

177 Analysis of temperature records for the North Sea between 1982 and 2012 has revealed similar
178 trends, with the average rise four times faster than the global average [31].

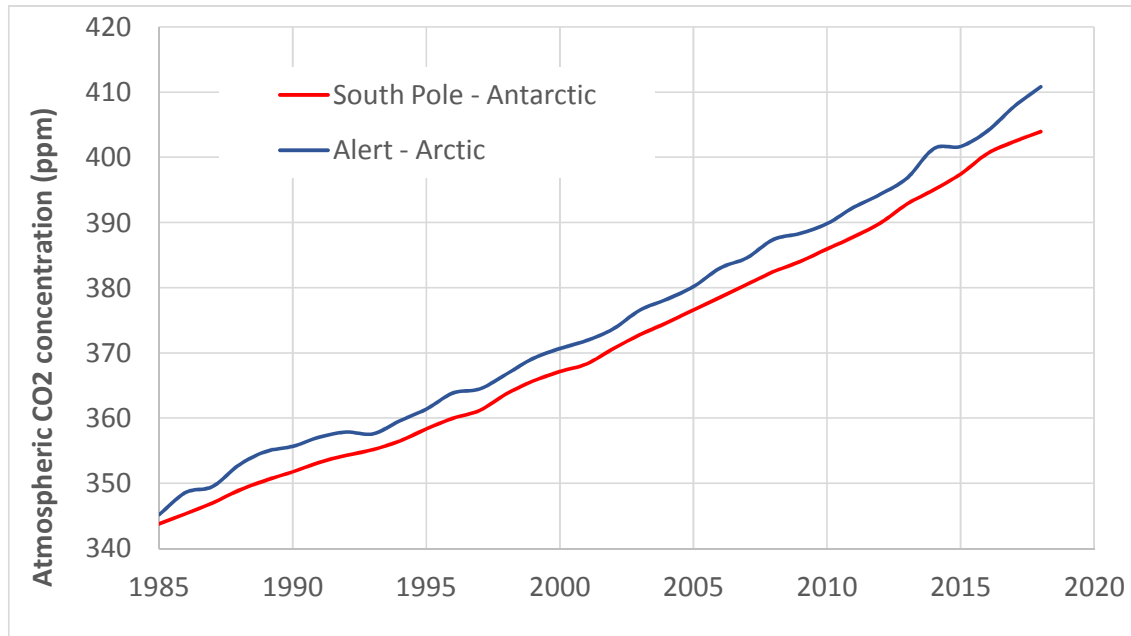
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182 **CLIMATE CHANGE IN AND AROUND THE POLAR REGIONS**

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

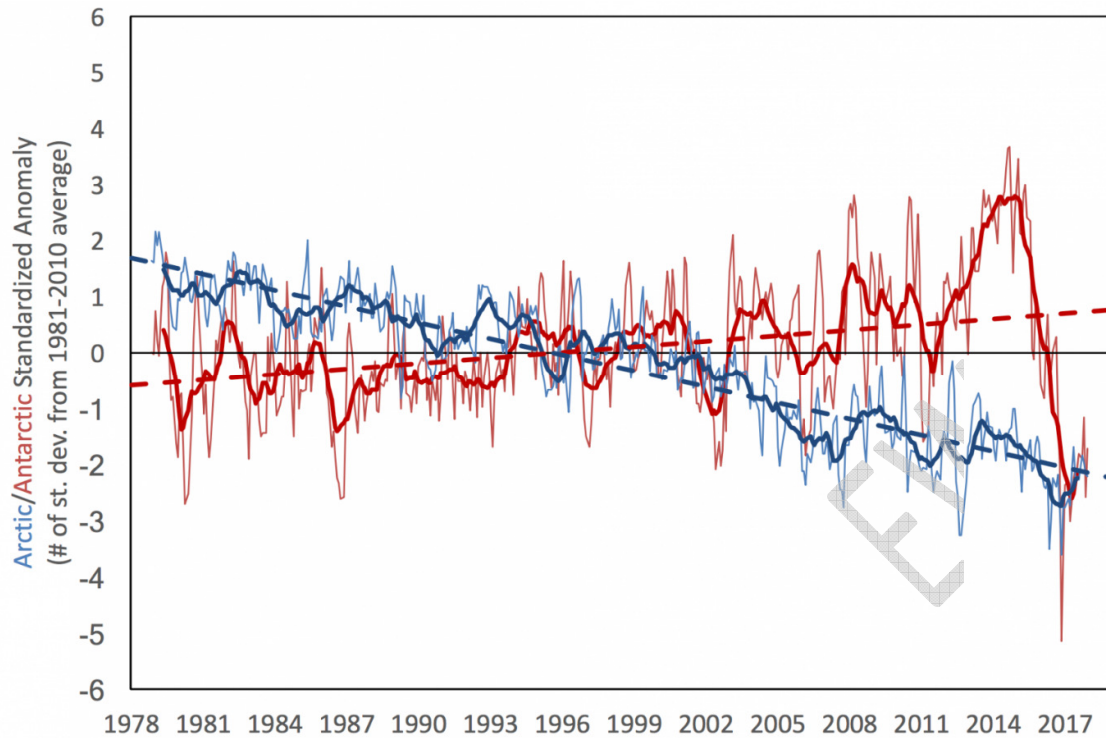


188 **Figure 2.** Atmospheric CO₂ concentrations between 1985 and 2018 for South Pole and Alert
189 monitoring stations -data sourced from [32].
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192 Despite rising atmospheric levels of CO₂, surface-temperature change in the Arctic and Antarctica
193 differ substantially. A trend of 0.6 °C decade⁻¹ has been observed in the Arctic (considered one of the
194 fastest warming regions) whilst a much lower change of 0.1 °C decade⁻¹ has been observed in the
195 Antarctica (compared with 0.2 °C decade⁻¹ globally, since 1981 [33]).

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



198

199 **Figure 3.** Arctic and Antarctic Sea Ice Extent Anomalies and Trend (blue = Arctic & red = Antarctic),
 200 1979-2017. Thick lines indicate 12-month running means, and thin lines indicate monthly anomalies.
 201 [34].

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203 According to Figure 3, Arctic sea ice extent underwent a strong decline from 1979 to 2012, but
 204 Antarctic sea ice underwent a slight increase. The positive trend in Antarctic sea-ice extent is
 205 intriguing because it appears to be physically counter-intuitive to global warming observations [33].
 206 Various reasons have been put forward for this apparent discrepancy in the Antarctica including
 207 stratospheric ozone depletion that caused a deepening of the lows in the West Antarctic region [35],
 208 freshening of the Antarctic seawater [38] and changes in atmospheric circulation resulting from
 209 changes in the southern annular mode and ENSO and the greater frequency of La Nina events since
 210 the late 1990s [37].

211 We would like to argue that the difference could be explained by the loss of earth 'insulation' in the
 212 Arctic Circle. It has been estimated that by 2007, more than 400 oil and gas fields, containing 40
 213 billion barrels of oil (BBO), 1136 trillion cubic feet (TCF) of natural gas, and 8 billion barrels of natural
 214 gas liquids had been extracted north of the Arctic Circle, mostly in the West Siberian Basin of Russia
 215 and on the North Slope of Alaska [38]. Much greater volumes of hydrocarbon extraction will have
 216 resulted considering the Arctic region as also extending southwards from the Arctic Circle and
 217 encompassing countries with a particularly cold climate, permafrost and frozen sea-ice. Under this
 218 definition, this is a vast region comprising West Siberia and Sakhalin, Russia, northern Canada and
 219 Alaska (USA). Major producing regions include Drake Point gas field on Melville Island and Brent

220 Horn filed on Cameron Island (Canadian Arctic), Norwegian Continental Shelf (Barents Seas), Kara
221 and Pechora Seas (Russian Arctic) and Prudhoe Bay (Alaska). In contrast to the Arctic, there has
222 been no extraction of hydrocarbons in the Antarctica and all such activity is banned until 2048 under
223 the Antarctic Treaty.

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226 Geothermal heat as a mechanism for climate change in the Alaskan Arctic was first identified by
227 Lachenbruch and Marshall over 30 years ago [39]. More recently, Harris [40] correlated hydrocarbon
228 removal with air temperature increases. Investigating the mean annual air temperatures for Alaska in
229 the last 30-50 years, He notes significantly more warming in and around Prudhoe bay compared with
230 adjacent areas. This is attributed to the shipment of oil through the Trans-Alaska oil pipeline
231 commencing in 1977. It is postulated that since more than 17 trillion barrels of oil have passed
232 through the pipeline, it has caused heating of the surrounding air which has also resulted in melting of
233 the adjacent sea-ice. The heating is caused because the oil temperature at the point of extraction
234 exceeds 40°C. This, the author argues, contrasts with the IPCC interpretation of warming in Alaska
235 which assumes that the maximum climatic warming at Prudhoe Bay is typical of the entire region and
236 as a result of greenhouse gases.

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238

239 **CONCLUSIONS**

240 To adequately address the most pressing environmental issues of our time, it is important to fully
241 identify the possible causes of global warming. We have shown, with reference to some relatively
242 recent research findings, that both onshore and offshore areas of fossil fuel extraction are
243 experiencing high rates of land and sea warming, respectively. Various causes might be attributed to
244 this including increased local CO₂ emissions in regions with cheap and plentiful fossil fuel resources
245 and/or greater particulate pollution impacting on the amount of solar radiation absorbed. We believe
246 that there is now some evidence to indicate that loss of earth insulation may be leading to heat from
247 the earth's interior rising to the surface and contributing to global warming. We also believe that
248 considerable further work is necessary to fully test the hypothesis that earth insulation loss is
249 contributing to global warming.

250 Data gathering needs to be at the heart of this effort, as usefully noted by Keeling [41], *"the only way*
251 *to figure out what is happening to our planet is to measure it, and this means tracking changes*
252 *decade after decade and poring over the records."*

253 Changes in sub-surface temperatures in areas subject to hydrocarbon extraction and in areas without
254 such activity will need to be compared. This will require deep bore-hole repeat temperature
255 measurements. The borehole temperature database established by Huang and Pollack [42] could be
256 extended with repeat temperature measurements. The data may also be used to revise the estimate
257 of the earth's surface heat flux reported by Davies and Davies [43]. Geothermal heat emissions from
258 operational and abandoned oil and oil-gas fields would also be useful allowing geothermal heat flux

259 values to be estimated. Sea-bed temperatures for Shelf Seas (in regions subject to fossil fuel
260 extraction and those without) over time would also need to be investigated since much of the world's
261 oil and gas production is offshore. Finally, calculations based on climate/physical models to quantify
262 the heating produced by loss of earth insulation need to be conducted.

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