GLOBAL WARMING IS GLOBAL ENERGY STORAGE

Bo Nordell and Bruno Gervet
Dept. of Civil and Environmental Engineering, Luleå University of Technology
SE-97187 Luleå, Sweden,
bon@ltu.se; brunogervet@hotmail.fr

ABSTRACT
The global air temperature increase is an inadequate measure of global warming, which rather should be considered in terms of energy. The ongoing global warming means that heat has been accumulating since 1880, in air, ground, and water. Before explaining this warming by external heat sources the net heat emissions on Earth must be considered. Such emissions, from e.g. the global use of fossil fuel and nuclear power, must contribute to global warming.

The aim of this study was to compare globally accumulated and emitted heat. The heat accumulated in air corresponds to 6.6% of the global warming, while the remaining heat is stored in the ground (31.5%), melting of ice (33.4%), and sea water (28.5%).

It was found that the net heat emissions 1880-2000 correspond to 74% of accumulated heat, i.e. the global warming, during the same period. The missing heat (26%) must have other causes; e.g. the greenhouse effect, natural variation of the climate, and/or underestimation of net heat emissions. Most measures already taken to combat global warming are beneficial also for current explanation, though nuclear power is not a solution but part of the problem.

KEYWORDS: Global warming, heat accumulation, heat emission, thermal pollution
INTRODUCTION

Global mean temperatures have been compiled based on long-term air temperature measurements [NCDC-NOAA, 2007]. These temperatures (Fig 1) are separated into one monthly Sea Surface Temperature (SST) and one monthly Land Area Temperature (LAT). The global mean temperature is the area weighted mean of LAT and SST. In 1880, SST was 15.9°C and LAT was 8.6°C, with a global mean of 13.6°C. Until 2000, SST had increased by 0.5°C and the LAT 1.2°C. The corresponding global mean temperature increase 1880-2000 was 0.7°C.

The global air temperature increase is an inadequate measure of global warming, which rather should be considered in terms of energy [Pielke et.al., 2004; Pielke, 2005]. The ongoing global warming means that heat has been accumulating since 1880, in air, ground, and water. Before explaining this warming by external heat sources the net heat emissions on Earth must be considered. Such emissions, from e.g. the global use of fossil fuel and nuclear power, must contribute to global warming [Nordell, 2003]. In current study, accumulated and emitted heat was estimated and compared.

GLOBAL HEAT ACCUMULATION

The methods used to calculate the temperature increase and subsequent heat accumulation in the ground and air are described in Appendix A. Performed calculations include the period 1880-2000.

Heat Accumulation in Ground

As a result of the increased air temperature also the ground surface has warmed up and heat has been conducted into the ground. Performed calculations show that the ground heat accumulation rate was relatively linear until 1960 when it began accelerating. Since the late 1990s it has exceeded the geothermal heat flow, indicating a net heat inflow from the surface into the ground. The heat content of the ground increased by 23.4 kWh m\(^{-2}\) from 1880 to 2000. This ground heat accumulation neither occurs in permafrost areas, defined as perennial ground ice, nor on glacier ice or icings [NSIDC, 2007a]. Such areas, which are affected differently by the global warming, are included in the melting of ice and its contribution to the sea level rise. Glaciated areas (0.16 \(10^{14}\) m\(^2\)) [Singh and Singh, 2001] and permafrost areas of the world (0.30 \(10^{14}\) m\(^2\)) thus reduce the total land area (1.5 \(10^{14}\) m\(^2\)) affected by the heating to 1.02 \(10^{14}\) m\(^2\). The total ground heat accumulation since 1880 then becomes 23.9 \(10^{14}\) kWh.

Heat Accumulation in Air

The heat accumulation in air (moist static energy) was estimated separately for over the sea surface and land surface. Hence, different mean air temperatures over sea and land were considered. The total heat accumulation in air is 5.0 \(10^{14}\) kWh of which 44.6% is distributed over the land area.

Heat Accumulation in Water

The heat accumulation in ocean water was estimated from the global sea level rise (GSLR), compiled by the Permanent Service for Mean Sea Level [PSMSL, 2007]. The GSLR is a result of various factors, e.g. inflow of water from melting glaciers and thermal expansion of the warmer water, which are both a result of global warming, i.e. indirect anthropogenic effects. Examples of direct anthropogenic effects [Harvey, 2000] since 1880 are increasing water vapor content of the air, permanent removal of water from aquifers, deforestation and loss of soil moisture, reduction in the extent of wetlands, storage behind dams, deep infiltration behind dams, deep infiltration of irrigation water, and ocean sedimentation. An important factor might be the ocean sedimentation rate, which increases with increasing global mean temperature [Broecker et.al., 1958].
Measurements show that the GSLR has been relatively steady since 1880, rising 0.18 m until 2000 [PSMSL, 2007]. Its constant increase indicates that it is not directly a result of the global energy consumption, which is far from linear (Fig 3). Values based on the processes mostly responsible for GSLR-mass increase, from melting land ice and volume increase due to thermal expansion, give considerably lower sea level change [Miller and Douglas, 2006], suggesting that most of the rise is caused by direct anthropogenic effects. There are various data regarding the contribution of thermal expansion to the 20th century sea level rise. The most commonly suggested thermal volume expansion rate is presently 0.5 mm per year [Church et.al., 2001, Antonov et.al., 2002]. Recent studies show considerably lower values [Ishii et.al. 2003] and it is reported that the ocean water has been cooled for several years [Lyman et.al. 2006]. Satellite measurements show that large-scale El Nino like ocean temperature fluctuations occurred between 1955 and 1995 [Ishii et.al. 2003]. Such fluctuations and the recently reported ocean temperature decrease is a result of large-scale and long-cycled (~15 years) ocean circulation, leading to melting of sea ice and subsequent cooling of the water. Based on the temperature fluctuations between 1955 and 1995, with three maximum and two minimum values during the period, a thermal expansion rate of 0.02 mm year^{-1} was estimated [Ishii et.al. 2003]. Since this expansion, i.e. 1 mm over the last 50 years, is a result of global warming the corresponding previous expansion until 1955 should be insignificant. Assuming that this sea water heating occurred in the top 1,000 m of the ocean with a salinity of 36 ppm, this 1 mm thermal expansion corresponds to 21.6.10^{14} kWh of heat. Recent estimates of the total sea level rise due to the melting of small glaciers and Greenland about 60 mm. Here, this contribution was estimated to about 50 mm until 2000. The main uncertainty is whether the ice mass of Antarctica is decreasing or increasing, i.e. causes the sea level to rise or not [Harvey, 2000]. If the mass of ice on Antarctica increases, the total melt heat will be correspondingly less. The energy required to melt glaciers and permafrost, totaling 50 mm sea level rise, is 16.8.10^{14} kWh. The total area of sea ice is 19.9.10^{12} m^2 of which 14.8.10^{12} m^2 is floating on the northern hemisphere. The estimated annual melting 1980-2000 was 0.38%±0.02% on the northern hemisphere and 0.02%±0.48% [NSIDC, 2007b] on the southern. During the same period the total thinning of the 3 m thick ice was estimated to 4% [Johannesness et.al. 2003]. Here, values for the northern hemisphere are used, while the very uncertain values for the southern hemisphere are disregarded. The resulting annual melting of 258 km^3 sea ice requires 0.22.10^{14} kWh year^{-1}, during 1980-2000. The total sea ice melting during the last 120 years is considered proportional to the energy consumption during the same period, see Fig 3, resulting in the melting of 10^8 km^3 of sea ice and a corresponding heat absorption of 8.5.10^{14} kWh. The melted sea ice, which is often considered not to influence the sea level, will actually have a volume 2.6% greater than that of the ice and thus contribute slightly to the sea level rise [Noerdlinger and Brower, 2008]. The total heat accumulation in ocean water during 1880-2000, i.e. by heating of sea water and melting of land and sea ice, then adds up to 46.9.10^{14} kWh. The global heat accumulation in the air, ground and water during 1880-2000 is thus 75.8.10^{14} kWh (27.3.10^{21} J). This heat is distributed in air (6.6%), ground (31.5%), water (28.5%), and melting of land and sea ice (33.3%) according to Fig 2. It is noticeable that the heat content in air only corresponds to 6.6% of the global warming.

GLOBAL NET HEAT GENERATION

The major natural heat source is the geothermal heat flow but heat is also generated by, e.g. volcanic eruptions, earthquakes, and meteorites. Non-natural heat sources include the global use of fossil fuel, nuclear power, and deforestation. Heat emissions from nuclear bomb tests and conventional bombs also add to the net heat generation. Global heat flow data are collected by the International Heat Flow Commission, [IHFC, 2007]. The compiled mean geothermal heat flow [Pollak et.al., 1993] is 0.065 W m^{-2} for the continents and 0.101 W m^{-2} and for the oceans. Its variation is a result of the composition and thickness of the upper part of the crust. The total geothermal heat flow during the last 120 years is 486.10^{14} kWh (175.10^{21} J). This energy is considerably greater than the global energy consumption during the same period, and is given as a reference value to other net heat sources though it does not contribute to the global warming.
The world’s consumption of commercial non-renewable energy from 1880 to 2000 [CDIAC, 2007; EIA, 2007] is shown in Fig 3. It has been steadily increasing and was smaller than the preceding years, only in 1975 and 1981. The use of renewable energy has also increased though it represents less than 5% of the world energy consumption.

The total commercial energy consumption 1880-2000 is $3.85 \times 10^{14}$ kWh ($1.39 \times 10^{21}$ J). All this energy dissipates into heat when consumed and must contribute to the heating of our planet. A useful key value is that the global energy consumption in 2000 was approximately $10^{14}$ kWh ($0.36 \times 10^{21}$ J).

The energy released through volcanic eruptions comes from several sources though the most significant, and the one considered here, is the thermal energy of the eruption. Based on the number and magnitudes of eruptions [Simkin and Siebert, 1994] the thermal energy released from a few large volcanic eruptions during the last 120 years was estimated to $3.95 \times 10^{14}$ kWh.

An average of 1.4 million earthquakes occurs each year on Earth. Most are small and disregarded while larger earthquakes with a magnitude of 8-9 are included in this net heat calculation. The energy released in an earthquake is given by the Gutenberg-Richter [Gutenberg and Richter, 1956] magnitude-energy relation. The USGS Frequency of Occurrence of Earthquakes [USGS, 2007] was used to estimate the total energy dissipation to $2.7 \times 10^{14}$ kWh. A few earthquakes occurring once a century or so would result in greater heat emissions than all others combined. Such quakes are not included here, but must be considered in similar studies on geological timescales.

More than 2,000 nuclear tests, atmospheric and underground, were carried out, 1945-1998. Though nuclear explosions have a great power, released energy was small because of its short duration. Performed nuclear tests [Lawson, 1998] released totally $6.64 \times 10^{12}$ kWh of heat.

Energy released by conventional bombs was also investigated. Bombs and weapons used during the Second World War released a net heat of $6.7 \times 10^9$ kWh. The corresponding value for the 1990 Gulf War was $9.8 \times 10^7$ kWh. Therefore, wars do not directly mean any significant net heating, though their consequences do. During the 1990-1991 Gulf War, 700 oil wells were set on fire and 190 Mm$^3$ of oil burned for 8 months [GulfLINK, 2007]. This meant that $1.9 \times 10^{12}$ kWh of heat was added to the atmosphere. It is estimated that $10^{13}$ kWh of energy was released by bombs in all wars [SIPRI, 2007] during the last 120 years.

Fossil fuel consumed outside the energy market is not included in global energy statistics. Examples of such non-commercial energy are, for example flares at gas and oil fields, fires at coal fields and underground fires in coal mines, and petroleum products that are not used in energy production e.g. in the production of plastics. The amount of heat released from such sources and also the deforestation was evaluated by [Gervet, 2007].

Flaring of associated gas was a common industry practice in the early "decades" of oil production, when there were virtually no gas markets, or concerns regarding the environment or rational use of hydrocarbon resources. The gas flaring in Africa alone is presently equivalent to half of that continent’s power.
consumption. Fewer than 20 countries account for more than 85 percent of gas flaring and venting. The
magnitude of this problem is underlined by the World Bank’s The News Flare [GGFR, 2007; WB, 2007],
which is devoted to reducing the global gas flaring. The energy released by gas flaring during the last 120
years corresponds approximately to the annual global energy consumption in 1999, i.e. $0.9 \times 10^{14}$ kWh.
Hundreds of coal fields are burning out of control around the world. Some of the oldest and largest coal fires
occur in China, the United States, and India. In China alone such coal fires annually consume 20 Mt of coal
[Stracher and Taylor, 2004]. Those burning underground can be difficult to locate and are not included in this
net heat estimation. Fires in coal fields worldwide consumes 1307 Mt of coal that emits $8.8 \times 10^{12}$ kWh of heat.
Another net heat source is oil used for production of plastics. This oil which is not included in the energy
statistics will sooner or later be burnt or decomposed. The net heat generation from the use of crude oil in
plastic making is roughly $0.4 \times 10^{14}$ kWh from 1939 to 2000.
The annual deforestation rate is 200 km$^2$ since 2000, before which it was even greater. Most of the
deforestation occurs in tropical forests, mainly in Africa. Since 1850 11.1 Mkm$^2$ has been deforested totaling
282,800 Mtons of wood. Assuming that deforested wood was burnt or decomposed the net heat generation
since 1880 is $8.2 \times 10^{14}$ kWh.
Until the year 2000, the accumulated amount of electricity produced by nuclear power is approximately
$0.4 \times 10^{14}$ kWh. Since 78% of the world nuclear park has an efficiency of 33%, the resulting heat emission from
nuclear power plants is $0.8 \times 10^{14}$ kWh.
A summary of the net heat generation is given in Table 1. The main part (~70%) of the net heat emissions
($38.5 \times 10^{14}$ kWh) results from of the commercial consumption of oil, gas, coal and nuclear power, while other
non-renewable heat sources totals $10.4 \times 10^{14}$ kWh and miscellaneous heat sources (volcanoes, earth quakes etc.)
means $6.8 \times 10^{14}$ kWh. The global net heat generation between 1880 and 2000 was $55.7 \times 10^{14}$ kWh
($20.1 \times 10^{21}$ J).
As shown by Fig 4 the global net heat generation explains almost 74% of the global warming. The missing
heat could be a result natural variation in solar intensity, atmospheric forcing due to CO$_2$ emissions into the
atmosphere, and/or underestimation of the net heat emissions.

<table>
<thead>
<tr>
<th>Commercial Non-Renewable Energy Consumption</th>
<th>Heat Generation (10$^{14}$ kWh)</th>
<th>Heat Generation (10$^{18}$ kJ)</th>
<th>Ratio (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Crude oil</td>
<td>15.2</td>
<td>5.48</td>
<td>20.1</td>
</tr>
<tr>
<td>Gas</td>
<td>6.9</td>
<td>2.49</td>
<td>9.1</td>
</tr>
<tr>
<td>Coal</td>
<td>16.0</td>
<td>5.76</td>
<td>21.1</td>
</tr>
<tr>
<td>Nuclear</td>
<td>0.4</td>
<td>0.14</td>
<td>0.5</td>
</tr>
<tr>
<td>TOTAL</td>
<td>38.5</td>
<td>13.87</td>
<td>50.8</td>
</tr>
<tr>
<td>Other Non-Renewable Heat Sources</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Gas flaring</td>
<td>0.9</td>
<td>0.32</td>
<td>1.2</td>
</tr>
<tr>
<td>Coal fires</td>
<td>0.1</td>
<td>0.03</td>
<td>0.1</td>
</tr>
<tr>
<td>Deforestation</td>
<td>8.2</td>
<td>2.95</td>
<td>10.8</td>
</tr>
<tr>
<td>Production of plastics</td>
<td>0.4</td>
<td>0.14</td>
<td>0.5</td>
</tr>
<tr>
<td>Waste Heat from Nuclear Power</td>
<td>0.8</td>
<td>0.29</td>
<td>1.1</td>
</tr>
<tr>
<td>TOTAL</td>
<td>10.4</td>
<td>3.42</td>
<td>13.7</td>
</tr>
<tr>
<td>Miscellaneous Heat Sources</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Volcanoes</td>
<td>4.0</td>
<td>1.42</td>
<td>5.2</td>
</tr>
<tr>
<td>Earthquakes</td>
<td>2.7</td>
<td>0.97</td>
<td>3.6</td>
</tr>
<tr>
<td>Nuclear tests</td>
<td>0.1</td>
<td>0.03</td>
<td>0.1</td>
</tr>
<tr>
<td>Wars (bombs)</td>
<td>0.1</td>
<td>0.04</td>
<td>0.1</td>
</tr>
<tr>
<td>TOTAL</td>
<td>6.8</td>
<td>2.46</td>
<td>9.0</td>
</tr>
<tr>
<td>TOTAL: NET HEAT EMISSION</td>
<td>55.7</td>
<td>20.1</td>
<td>73.5</td>
</tr>
<tr>
<td>TOTAL: ACCUMULATED HEAT</td>
<td>75.8</td>
<td>27.3</td>
<td>100.0</td>
</tr>
<tr>
<td>MISSING HEAT</td>
<td>20.1</td>
<td>7.2</td>
<td>26.5</td>
</tr>
</tbody>
</table>
CONCLUDING REMARKS
Independent of what causes the global warming it should be considered in terms of accumulated energy. Performed estimations of global heat accumulation in air, ground, and global net heat emissions only include the years 1880 to 2000. Data used in estimating global heat accumulation in air, ground, and melting of land ice are fairly reliable while the melting of sea ice might be overestimated. The main uncertainty concerns the sea temperature increase, which means that sensible heat accumulation in sea water might be underestimated. The air only contains 6.6% of globally accumulated heat, of which 45% is distributed over the land area though it accounts for about 30% of Earth’s total area. The remaining heat is accumulated in the ground (31.5%), sea water (28.5%), sea ice melt (11.2%) and land ice melt (22.2%). So, the melting of ice has absorbed 33.4% of the total global warming. The heat stored by sea water, melting of sea ice, and in the air over the oceans accounts for almost 43% of the global heat accumulation while the corresponding value for the land area is about 35% if the land ice of ~22% mainly Greenland is treated separately.

It is concluded that net heat emissions contributes to 74% of the global warming. The missing heat (26%) must be a result of other causes, the greenhouse effect, natural variation of the climate, and/or underestimation of net heat emissions. Most measures already taken to combat global warming are beneficial also for current explanation. However, CO₂ sequestration and subsequent storage will have very little effect on the global warming. It is also concluded that nuclear power is not a solution but part of the problem.

Acknowledgement
Performed research has depended on students, who over several years made different sub-studies on this subject; Sergi Mas Miret (Global Heat Storage), Lara Nunes de Carvalho (Nuclear Tests), Ann-Marie Alakangas and Susanne Lamberg (Wars, Meteorites and Earthquakes), Nicolas Paget (Volcanos), Hubert Boulanger and Damien Orcel (Sea Level Rise), Dr. Jules Dim for his overview on the subject, and Dr. Göran Hellström for valuable comments on the manuscript. Many of performed sub-studies were repeated by even more students. I am most grateful to all of them. Correspondence and requests for materials should be addressed to: bon@ltu.se

Fig. 4. Global Warming and Heat Sources. The circle represents the global warming i.e. the global heat accumulation 1880-2000. It is seen that 74% of the warming is a result of heat emission while the remaining 26% (missing heat) must have other causes.
It was assumed that the temperature of the ground surface was equal to the global land area temperature (LAT) and that the mean thermal properties of the ground and geothermal heat flow are known.

The ground temperature change was determined by one dimensional heat conduction:

$$\frac{\partial^2 T}{\partial z^2} - \frac{1}{\alpha} \frac{\partial T}{\partial t} = 0$$

(1)

where \(T\) is the ground temperature, \(t\) time, \(\lambda\) the thermal conductivity of the ground, \(\alpha = \lambda/C_v\) the thermal diffusivity, \(C_v\) the volumetric heat capacity of the ground, and \(z\) the vertical direction. Eq. (1) was numerically solved for \(T(z=0) = \text{LAT}(t)\) and \(T(z=400) = C\), a time step of 0.5 h during 120 years, and a length step of 0.1 m. A ground thermal conductivity of 2.5 W m\(^{-1}\) K\(^{-1}\), volumetric heat capacity of 0.6 kWh m\(^{-3}\) K\(^{-1}\), and a geothermal heat flow of 0.065 W m\(^{-2}\) were assumed.

The resulting heat accumulation in the ground (\(Q\)) caused by the temperature change \(\Delta T(z)\) after 120 years of global warming was calculated by:

$$Q = \int_{D}^{0} C_v \cdot \Delta T(z) \, dz$$

(2)

\(D\) is any depth at which the ground temperature is undisturbed by the global warming. Eq. (2) was solved for the boundary conditions used above. In performed calculations, a sufficient \(D = 400\) m was used since the temperature disturbance did not reach below a depth of 270 m. The calculated heat accumulation in the ground is based on ground surface temperature (LAT) shown in Fig 1.

In calculating the heat accumulation in air, its temperature profile was assumed linear from the ground surface to a height of 5,500 m, where the Earth’s effective temperature occurs (-18.8°C) [Salby, 1996]. The estimation of the mean relative humidity was assumed unchanged from 1880 to 2000. It was found to be 62%, after area weighting of data for different latitudes [CDC, 2007]. The calculations were separated into two air volumes, i.e. air over the sea surface and land surface.
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