Refrigerator as Model of How Earth's Water Manages Solar and Anthropogenic Heats and Controls Global Warming

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Key points

- Water controls Earth's global temperature via interphase equilibria as a refrigerant does in a refrigerator heated from inside and outside
- Applying thermodynamics to water interphase exchanges led to thermal data that question a reasonable 2018 estimate of radiative forcing
- Fighting CO_2-producing fossil sources of energy may not be sufficient to avoid dramatic climatic events in the future

Abstract:

The relation between global warming and the role of anthropogenic carbon dioxide (CO_2) is confusing. Ocean level and atmospheric temperature rises are predicted dramatic in distant future whereas global ices disappearance is already dramatic and increasing. In this article, we called on the heat control machinery exploited in a refrigerator to show that water behaves as a refrigerant to manage solar, anthropogenic heats and also non-solar heat generated from sources localized on Earth. Year 2018 was taken as example for quantitative evaluation of heat energy transfers involved in water phases and interphase exchanges. It was concluded that ice melting and evaporation-condensation equilibria should keep the global average temperature relatively unchanged in the future whereas local chaotic climate perturbations ensuring heat dispatching and temperature averaging should increase in strength and frequency. It is also shown that the water stored in fossil hydrocarbons is liberated as hot vapor during combustion and returns to the global pool of water once condensed. Hydrogen may be an alternative to the sources of energy consumed by humanity provided that heat-cycle assessment from cradle to grave complements the life cycle assessment favorably.

Plain language summary

Today, successive IPCC global warming-related reports predict dramatic atmosphere temperature and ocean rises in rather distant future. These evolutions are assigned to anthropogenic greenhouse gas, notably carbon dioxide, generated by fossil sources of energy exploited in the world. However, everybody

can observe that heat is also generated directly in the low atmosphere by the exploitation and consumption of all sources of energy and not only fossil ones. Production of electricity and its exploitation by cars, trains, planes, electric appliances, wildfires, etc.… heat the entire environment. The present work compares the management of solar and heat released in the environment to the mechanism that controls the temperature in the interior of a refrigerator. It is concluded that water plays a role of refrigerant via ice melting and evaporation-condensation phenomena and manages solar and anthropogenic heats similarly. According to the present study and in contrast to present prediction, the global temperature should not raise if ices continue to disappear over the next years. In contrast, cloud formation, rains, winds, storms, hurricanes, etc. should increase in frequency and damages. Hydrogen is proposed as alternative to fossil sources of energy. However its potential must be assessed positively relative to both thermal and environmental impacts.

1. Introduction

So far, the predictions of climate changes are based on hypotheses and calculations of evolutions for the distant future as reported in successive Intergovernmental Panel on Climate Change (IPCC) reports (IPCC, 2014; IPCC, 2019). These reports result from an international consensus predicting evolutions in distant future, trends being still small but nevertheless detectable today. The consensus is adopted almost universally although controversies exist, the dispatching of which is limited to articles in open access archives and magazine outlets [Dunlap & Jacques, 2013].

Until recently, global climate changes were assigned to imbalanced inputs and outputs of electromagnetic infrared radiations and to anthropogenic greenhouse gas, especially CO_2, considered as sources of radiative anthropogenic heat release (rAHR) (IPCC, 2014; NASA, 2009; Mackenzie & Lerman, 2006) without consideration to any other sources of internal heat considered as negligible, notably anthropogenic heat release (eAHR) generated by the sources of energy produced and exploited by humanity. In the past, only rAHR related to greenhouse gas was taken into account and considered as absorbed predominantly by oceans (Hansen, et all, 2011**;** Trenberth et al., 2014; IPCC, 2019) except by a minority of climate-skeptic people. rAHR is said resulting from electromagnetic radiative flux that amounted annually from 0.5 to 1W/m^2 in the early 2000s (Trenberth et al., 2014; IPCC, 2019), i.e. between 8.5 and 17 x 10^{21} Joules (8.5 and 17 ZettaJoules (ZJ)), the mean value being c.a. 0.79 W/m^2. Regardless of their origin, the heat energy that warms Earth has to be balanced by compensation or evacuated to space otherwise the Earth would grow warmer and warmer over the years. Water cycle has been recognized for years as an important factor in climate control through evaporation-condensation phenomena despite limitations due to uncertainties on available global data (Allan & Liepert; 2010). In general, global ice was considered negligible heat absorber relative to oceans (Hansen et al., 2011). Based on outstanding facilities including satellites, NASA is the reference body to quantify ice imbalance and its role on the polar environment (Scott & Hansen, 2016). The occurrence of dramatic global ice loss is now certain, especially over the recent years, and concerns different ices, namely ice caps, sea ice, glaciers and permafrost (Rignot et all, 2019; Slater et all, 2021). Ices melting is generally considered as a source of ocean rise (Allan & Liepert; 2010) in addition to temperature-dependent dilatation. The contribution of eAHR to global warming neglected in the past is more and more regarded as an actor. The context and the history were well introduced in a recent publication (Yang et al, 2017) in which the authors proposed an algorithm to evaluate global eAHR. This approach consisted in calculations based on heat energy estimates derived from urban zones. Although there were limitations, the algorithm provided multi-scale anthropogenic heat information said reliable and useable for further research on regional or global climate changes and on urban ecosystems despite difficulties to establish ratios for converting energy consumption to anthropogenic heat.

We recently proposed a different approach (Vert, 2021) based on ice loss, fundamentals of chemistry and physics and annual global energy consumptions derived from various sources (fossil ones, biomass, nuclear electricity, etc.) found converted in oil-equivalents (Martin-Amouroux, 2015; BP, 2019). According to (Manowska, & Nowrot (2019), eAHR corresponds to c.a. 60 % of the global energy consumption, the rest being consumed to generate work. Accordingly, it was shown that anthropogenic heat released from all the energy sources in the low atmosphere between 1994 and 2017 provided enough thermal energy (7.2 ZJ) to melt 77% of the 28 trillion tonnes of disappeared ice reported recently for the same long period (Slater et all, 2021). Therefore, eAHR estimated over 23 years was effectively negligible when compared with the 8.5 to 17 ZJ estimates of annual rAHR. As ices imbalance reflects a thermal energy supply regardless of its origin, why rAHR increases assigned to CO2 greenhouse gas do not cause much greater ices imbalance than presently observed?

In attempt to bring in an answer to this question, let us consider that solar radiations have been heating the global environment over billions of years without dramatic heat accumulation despite occurrence of short and long and more or less important local ups (high temperature) and downs (glaciation) periods. The relative stability included natural greenhouse effect assumed at the origin of a 33°C excess of average Earth temperature. Nowadays, eAHR, rAHR and any other sources of heat on Earth have to be managed similarly and simultaneously to solar heat to keep Earth's environment and climate under relative control and compatible with Life. Indeed, the Earth can be schematically considered as a huge globe with land, solid matters, surface water and atmosphere heated internally since no matter or molecule can escape in intersidereal space. Rejection of a large part of infrared electromagnetic waves to space is the consensual mechanism largely adopted in the world (IPCC, 2014 and 2019). However, if natural greenhouse effects cause a 33 °C excess of temperature on Earth, the 2-4 °C rise expected from the sole doubling of anthropogenic CO_2 concentration in part per millions of atmosphere seems logically disproportionate.

A few thousand years ago, humans began to use biomass as sources of heat and light. eAHR remained very small compared with solar inputs until about 150 years ago when humans began to exploit fossil sources and, more recently, nuclear plants and renewable resources for the production of electricity in order to satisfy work, heat and comfort needs. The side effect was the appearance of eAHR in the low atmosphere in addition to rAHR in the high troposphere (Yang et al.; 2017). Earth can be compared to a mammalian body which has its metabolism generating heat in a closed space, the body. This body which burns foods has to be cooled down to keep its temperature constant. Based on this analogy, the present article aims to compare Earth's water with the refrigerant that controls the temperature inside a refrigerator; a simpler case where inner heat has to be eliminated. Results are discussed relative to global warming and climate changes.

2. The refrigerator

From a thermodynamic viewpoint, a refrigerator is based on a simple rule: "when two substances are in contact, the hot one supplies heat to the cold one up to equilibrium". In a refrigerator, the transfer of heat proceeds by evaporation-condensation of a volatile fluid: the refrigerant. Heat is absorbed locally by the evaporation of the fluid, transported by the gas phase, and released from this gas by condensation outside as human and mammalian bodies do. The expulsed sweat cools the surface and the interior of the body by evaporation in the atmosphere until perspiration is no longer necessary.

The transfer of heat from a hot medium to a cold one is spontaneous and rather slow. In contrast, heat exchanges from a cold medium to a hot one cannot be spontaneous. Some energy must be supplied. It is the role of the compressor present in air-conditioning machines and refrigerators. For humans, there is no compressor and the pressure in tissues is the sole driving force to push water outside. A schematic representation of a refrigerator is shown in Figure 1. There are four main stages to control the inner temperature:

2.1 Evaporation

From 1 to 2 in Figure 1, the volatile refrigerant enters the inner evaporator as a liquid. Going through this multi-tube device, the liquid absorbs part of the heat present in the closed space, including that of foods in it. As a result, the liquid is turned to gas at the outlet of the evaporator while the temperature inside the closed space decreases slightly.

2.2 Compression

From point 2 to point 3, the gas is pressurized in the compressor where it is super-heated by compression and then transferred to the multi-tube condenser located outside, generally in the back.

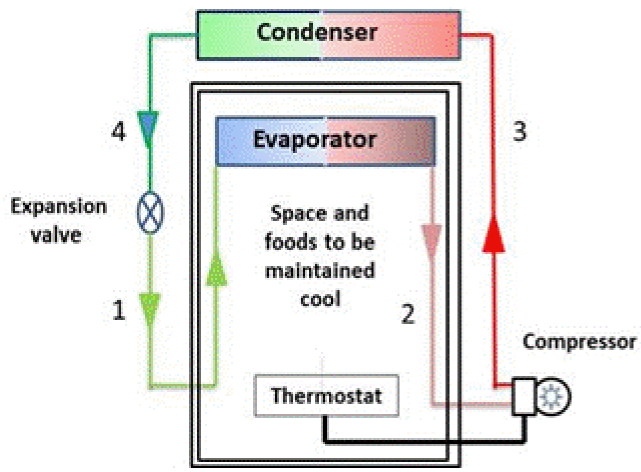

Figure 1: Schematic representation of a Vapor Compression-Refrigeration cycle.

2.3 Condensation

From point 3 to point 4, the hot pressurized gas enters the condenser. The initial part of the cooling process in the condenser is contact with the outer cold surface that decreases the temperature of the gas and finally turns it back to liquid. This step is where the inside thermal energy absorbed by the refrigerant at the evaporation stage is vented out to atmosphere. The condenser in the back of the refrigerator is hot as it can be easily observed.

2.4 Expansion of the subcooled and highly pressurized refrigerant

From point 4 to point 1, the high-pressure subcooled liquid passes through the expansion device which reduces its pressure and controls the flow of liquid into the evaporator (stage 1). The cycle is repeated until the temperature in the refrigerator reaches the temperature set at the thermostat otherwise the inner temperature would continue to decrease with ice formation on the walls of the internal compartment, something everybody can observe in a freezer.

3. Application to Solar energy management on Earth

Components of the environment have been heated by the Sun and kept more or less warm without heat accumulation. These environmental elements can be compared to the foods placed inside a refrigerator where the temperature is controlled. However, there are differences. The compressor present in Figure 1 that allows and speeds up thermal exchanges from cold inside to hot outside is replaced by chaotic turbulences in atmosphere (winds, streams, tornadoes, hurricanes) and oceans (hot and cold streams) to dispatch heat within the whole environment. The condenser is replaced by the cold zone of the atmosphere where vapor condenses at dew temperature to form clouds which release the heat stored at the evaporation stage. The refrigerant present in the cooling circuit of the refrigerator is replaced by water, and the heat energy released during cloud formation is eliminated from the high atmosphere partly by radiation to space partly by returning to the surface via rain and snow. The whole process is schematized in Figure 2. It is important to note that the part of heat eliminated to space by radiation from water located at the top of clouds will not be absorbed by water molecules located in the upper atmosphere since water is not present there, a favorable fact to avoid electromagnetic waves absorption according to the Beer-Lambert law, in contrast to the case of CO_2 (Scirroco; 2018).

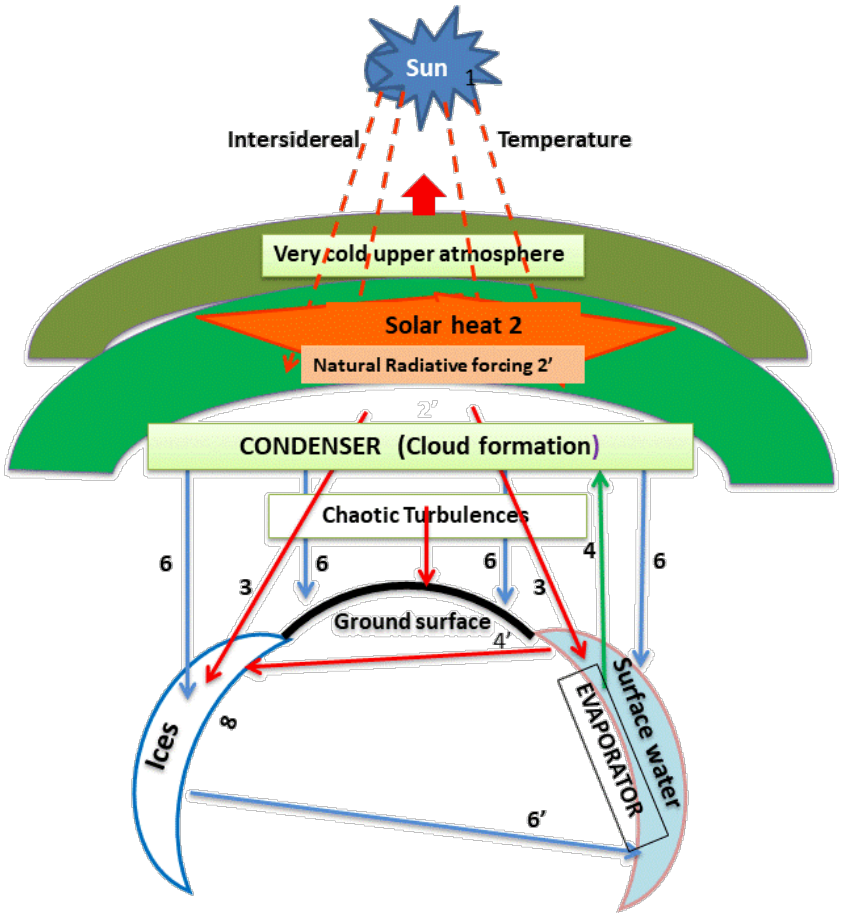

Figure 2: Schematic representation of the machinery that manages residual solar heat energy through water phase exchanges.

In this scheme, the Sun (1) heats the whole environment as everybody feels it under sunshine (2 and 3). Greenhouse effect-dependent radiative energy is represented in (2'). Atmospheric turbulences dispatch local imbalanced heat within the multilayered atmosphere in contact with the very cold intersidereal medium on one side, and with ground, ice and surface water on the other side. The supply of geothermal heat is generally considered as negligible like many other heat sources on Earth including the combustion of fossil fuels ((Zhang & Caldeira, 2015) and electricity-related ones). The temperatures of the ground surface and of oceans tend to increase but rising is unavoidably limited by heat absorption related to the melting of ices (4' and 6') over the whole globe. It is also balanced by the process of evaporation (evaporator) that cools ocean and surface liquid water (the refrigerant) and transfers the corresponding heat to the atmosphere as warm vapor (4). Water cycle has been proposed as climate factor but generally without involving ices and not in terms of quantitative water interphase equilibria. The air enriched in warm vapor being less dense than dry air, it rises up to a zone cold enough to condense the vapor as dispersed droplets and ice particles forming clouds while the heat stored in the vapor is released to molecules present in the upper cold atmosphere which radiate it away (7). Rains and snow (6) close the cycle. Such cycle is not uniform. In reality, the Sun does not heat continuously. Earth inclination and rotation lead to cyclic heating like day and night, summer and winter, North and South hemispheres, and the Sun long cycles. The process of ices melting and reformation is thus cyclic with ups and downs as in a refrigerator. If all the ice disappears inside the refrigerator, the inner temperature starts rising up to the outside one unless the thermostat restarts the cycle to reform ice. On Earth, the thermostat consists in water interphase equilibria. When all ices will have melted, the control of heat, regardless of its origin, will be handled by the dominance of right shift of evaporation vapor condensation interphases equilibria. At this stage, a thick cover of clouds will be formed that will block the input of heat from the Sun like durst particles and aerosols do. Less solar heat will lead to regeneration of ice on Earth (Miller et al., 2012). The temperature control by evaporation-condensation depends on the latent heat of evaporation but it depends also on many dynamic factors that precluded estimations. Anyhow temperature rising or not, the more heat is to be dispatched over the globe, the stronger and the more frequent chaotic environmental will be, at least qualitatively (Fig. 2).

4. The evolution after the appearance of Anthropogenic Heat

The controlling process described in the previous section worked for billions of years to manage Sun, volcanoes and biomass-burning heats by cyclic ice melt and reformation and by radiation to space. The exploitation of fossil oil-derived energy started bringing in extra heat in the middle of the 19th century and alerted people recently. Both natural gas and more recently electricity provided more heat to be balanced. The new situation is schematically represented in Figure 3.

The comparison between Figures 2 and 3 does not reveal important differences relative to the heat managing thermal machinery. Solar energy still heats the Earth dominantly (2) but with other terrestrial sources of heat including rAHR (2") and anthropogenic heat released from the sources of energy use by humans for their comfort and exploitation to provide work. In contrast to radiative forcing, the anthropogenic heat issued from the consumed energy is released in the low atmosphere where it is slowly dispatched (4' and 4") for average over the whole planet. The corresponding surplus of heat must be absorbed by oceans and by heat transfer to ices melt (8) and water evaporation (4) to close the ring like in section 2.

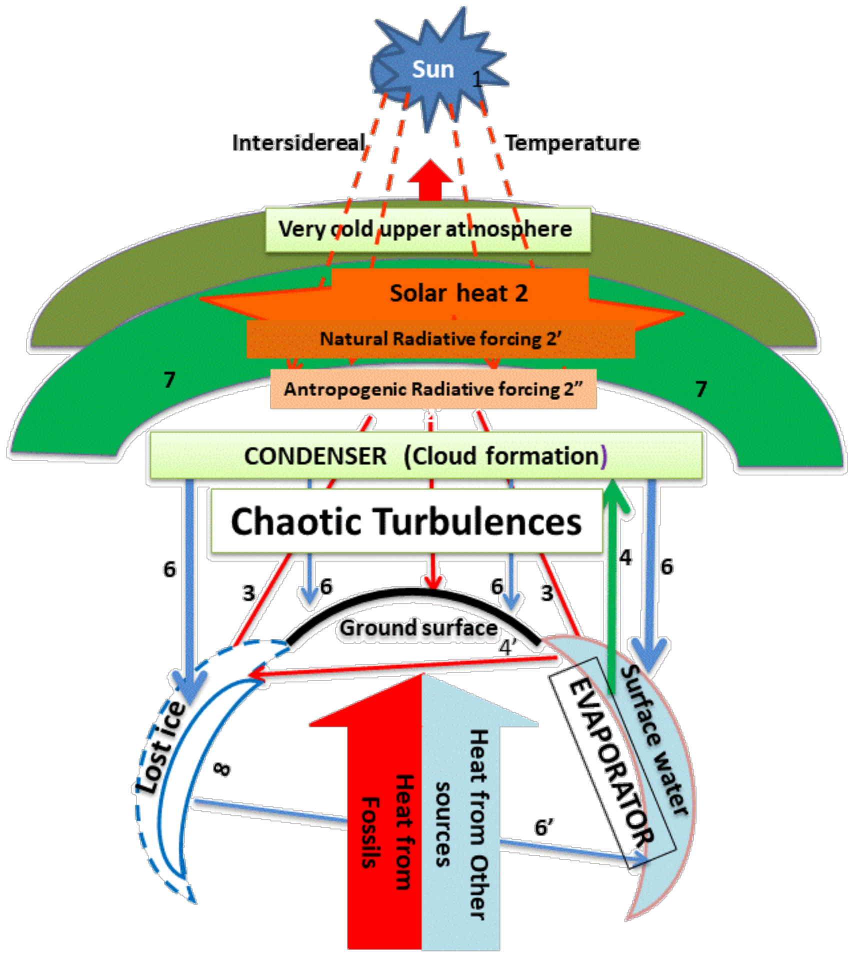

Figure 3: Schematic representation of the management of increasing amount of anthropogenic heat through evaporation-condensation-evaporation and ices melting.

Having to dispatch more thermal energy, local chaotic climate perturbations (hurricanes, tornados, rains, flooding's, etc...) are to be more important and more frequent. In contrast to heating by Sun, rAHR and volcanoes that caused discrete heating, eAHR warming is almost continuous over days and nights, this in acceleration over the years.

5. Quantification of the action of water as refrigerant

According to physics and thermodynamics, the thermal fate of heated ices described schematically in Figure 3 can be estimated quantitatively in terms of conductive heat exchanges using the specific heat of ice melting (333.55 KJ/Kg), and the specific heat capacities of solid ice (2.110 KJ/Kg/°C) and of water (4.184 KJ/Kg/°C), the presence of salts in sea water being neglected (Engineering Tool Box, 2003).

Let us take year 2018 as example, 17.2°C being the generally accepted global average temperature common to low atmosphere and ocean surface water. The 2018 global ice imbalance was 1.5 trillion tonnes assumed similar to the estimate of 2017 deduced from Figure 4 in (Slater, 2021). Let us take -20°C as average temperature of global ices according to the value retained to evaluate ice imbalance (Slater, 2021). According to the specific heat capacity of ice, 1.5 trillion tonnes of ice at -20°C required about 0,063 ZJ to reach 0°C, the melting temperature of ice. The temperature of ice and that of the formed liquid water remained constant at 0°C during the melting of the whole mass of ices that required c.a. 0.50 ZJ of thermal energy according to ice latent specific heat of fusion. The melting of 1.5 trillion tonnes of ice yielded 1.5 10^{15} Kg of liquid water at 0°C that required c.a. 0.108 ZJ to reach 17.2°C according to the specific water heat capacity. The heat energy necessary to turn the disappeared ices at -20°C to water at 17.2°C was thus c.a. 0.67 ZJ. Therefore, 0.346 ZJ eAHR (60% of the 0.576 ZJ heat energy consumed in 2018) was enough to cause 52 % of the 2018 imbalanced ice. This estimation does not take into account the injection of Joules in the atmosphere by mammalians (humans, cattle and animals with hot blood, hydrogen-using rockets, and criminal wildfires. Based on lung volume and on breathing frequency, the contribution of 7.5 billion humans and 1 billion cattle heads to eAHR was less than 0.02 ZJ and thus rather negligible. In addition to eAHR, volcanoes contribute to heat Earth from inside. In 2018, 80 volcanoes were active, the Hawaii eruption being the largest with c.a. 0.76 10^9 cubic meters of flowing lava. Assuming density, specific heat capacity and difference of temperature of lava being 2.6, 840 J/Kg/°C and 1000°C, respectively, the heat released after cooling was c.a. 0.002 ZJ. Assuming an average of 0.001 ZJ/volcano, heat released by volcanoes was c.a. 0.040 ZJ raising non-radiative heat energy introduced in the atmosphere to c.a. 0.4 ZJ, an amount about 4% smaller than the c.a. 9 ZJ rAHR corresponding to 0.8 W/m^2 taken as minimal estimate of the annual mean radiative forcing in the 2000's applied to the whole surface of the planet. This large difference of magnitude has already been pointed out in the literature (Chaisson, 2008; Zhang & Caldeira, 2015) but for different systems and under different conditions. Anyhow, based on physics and thermodynamics, the dominant 9 ZJ rAHR [(27 ZJ if radiative forcing was 2.3W/m^2 (IPCC, 2014)] should have caused much greater ice loss than the 1.5 trillion of tonnes estimated for 2018 that required only 0.67 ZJ of heat energy to turn lost ice at -20°C to water at 17.2°C.

Since in 2018, temperature and oceans rises were reported 0.79 °C and 3.7 mm respectively, and according to the 4.184 KJ/Kg/°C water heat capacity, oceans stored about 4.4 ZJ leaving 4.6 ZJ unabsorbed (c.a. 22.6 ZJ in case of 2.3 W/m^2 forcing) and thus available to heat the rest of the planet and double the global temperature, something against observations and logic.

Amounts of heat exchanges that involved water and water interphase equilibria were obtained using thermodynamics and physics and can hardly be challenged. In contrast, the radiative forcing may be questioned in terms of overestimation or even inconsistency as pointed out by some scientists (Scirocco, 2018). As an alternative, the refrigerator model suggests evaporation as heat absorber, in addition to ice melting. Evaporation may well explain the absorption of 4.6 ZJ by evaporation. Indeed, the capacity of ocean to absorb heat by a thin layer of evaporated water is approximately 81.2 ZJ/dm/°C using 2.25 KJ/Kg/°C as specific heat of evaporation of water. Therefore, 5 mm of evaporated ocean water are basically able to absorb and compensate the warming effect due to a 4.6 ZJ radiative forcing but this goes against global warming since glace melting and evaporation are physical phenomena that normally should compensate warming globally with locally temperature ups and down and enhanced climatic events in strength and frequency as discussed in the previous sections. In other words, global warming in distant future should be less important than presently predicted.

Evaporation is not the only factor that may affect climate-related predictions in distant future.

6. Water released from fossil hydrocarbons

In the previous section, the discussion assumed constant volume of water dispatched between ice caps, floating ice and land ice since matter cannot escape to space. However the combustion of all the hydrocarbons (oil, natural gas, and biomass) generates hot CO_2 from the carbon content and hot water vapor from hydrogen. Once the heat stored in these hot gases is transferred to the environment; the generated cool water becomes surplus of water on Earth.

Quantifying the amount of such extra water is as difficult as quantifying e and rAHRs. Nevertheless, data on the overall production of fossil oil and natural gas are available and provide means to estimate the surplus of water. Between 1870 and 2018, about 180 Gt of oil and 30 GToe of natural gas have been extracted (Martin-Amouroux, 2015; BP, 2019) i.e. about 210 Gt of hydrocarbons. To compensate the complex composition of oil and natural gas, one can assume these fossil hydrocarbons, including methane (CH_4), composed of alkanes only, the general chemical formula of which is C_nH_{2n+2} reasonably simplified to nCH_2. Accordingly, 210 Gt of oil equivalent contain c.a. 180 Gt of carbon and 30 Gt of hydrogen. From the general equation $CH_2 + 3\ O_2 \rightarrow CO_2 + H_2O$ + heat, 14 g of hydrocarbon (12 + 2) generates 44 g of CO_2 (12 + 32) and 18 g of water (16 + 2), both compounds being hot. One can deduced that 210 Gt of hydrocarbons produced about 270 Gt of hot water. Based on the amount of water released from 28,000 Gt of ice lost between 1994 and 2017, the estimated 270 Gt of extra water cumulated since 1870 corresponds to c.a. 1 year of recent ice loss and, thus, it is rather small and negligible in terms of ocean level rise. However this hot water inserted 2.3 KJ/Kg/°C of heat in the environment, this heat being dispatched between biomass, atmosphere, and liquid water. Whether this liberated water played a role in the context of greenhouse gas is difficult to guess. Anyhow, the release of hot water from the combustion of oil and natural gas could become problematic if the production and the consumption of energy, fossil or not, continue to grow in parallel to the growth of the mammalian population (Zou et al., 2016).

7. Can hydrogen be the solution?

Apart from limiting the growth of population, hydrogen is more and more regarded today as an attractive alternative to replace fossil fuels in the future (Johnston et al, 2005). Basically it can be produced from water and it regenerates water after exploitation as source of energy according to the following scheme: electric energy + $H_2O \rightarrow H_2 + ½\ O_2 \rightarrow H_2O$ + energy. So far, hydrogen is primarily produced from fossil resources and catalysts. Catalytic electrolysis will be of particular interest only if the energy needed to dissociate water in hydrogen and oxygen is produced by low heat-producing renewable sources of electricity (Gardner, 2009). What is presently missing to decide whether a source of energy is better than another relative to AHR is a heat-cycle assessment from cradle to grave, as it is currently done with life-cycle assessment to compare processes and materials that impact the environment (Muralikrishna & Manickam, 2017). So far, it seems that no quantitative information is available relative to heat-cycle of wind turbines and of other CO_2-free sources of electricity in comparison with the other sources of energy in terms of thermal impact on the climate. Hydro-electricity may be of particular interest in this regard. However, one can wonder whether large enough amounts of hydrogen will be producible from CO_2-free sources of energy. It will be the task of specialists in thermodynamics working together with climatologists and chemists to make the necessary assessments.

8. Conclusion

To complete our previous analysis that led to reasonably correlate an estimate of ice imbalance observed between 1994 and 2017 to an estimate of anthropogenic heat released during the same period of time, it was shown that heat management on Earth can be compared to the system which controls the temperature inside a refrigerator. The comparison showed that water acts as a refrigerant to manage solar and anthropogenic heats and control the global average environmental temperature and terrestrial heat accumulation. Thermodynamic characteristics of water and water interphases applied to data of year 2018 taken as example confirmed that eAHR was negligible relative to the reported rAHR. Nevertheless, eAHR was found again sufficient to have caused the melting of a large part of the lost ices. This finding led to the conclusion that much more ices should have been lost under the action of the dominant radiative forcing for 2018. The quantitative comparison between eAHR and rAHR in terms of thermodynamic exchanges and the finding of discrepancies relative to the reported temperature and ocean level data led to questioning the consistency of rAHR estimate. Quantification of thermal exchanges confirmed the qualitative analysis that led to conclusion that surface temperature should not change much even in distant future whereas chaotic events like hurricanes, tornadoes and flooding should increase already from now in strength and frequency with the increase of AHR regardless of its origin. In addition, it was emphasized that the combustion of hydrocarbon-based sources of energy generates new hot vapor in addition to CO_2. Once cooled, this water stored in oil and gas for millions of year increases the amount of free water on Earth. However, its estimated amount is still minor compared to the water generated by ice loss. Whether it can play a role in climate evolution remains to be studied. Finally, heat-cycle assessment is proposed to compare the different sources of energy and determine which ones may replace those currently exploited. Hydrogen seems to be an interesting candidate if it can be produced by electrolysis with competitive and acceptable heat-cycle and life-cycle assessments; an essential condition to respect both the climate and the environment. Such evaluations will have to be done by suitable interdisciplinary consortia attempting to understand and to take into account the complexity of Earth like biologists are doing for the human body.

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Data availability statement

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Conflict of Interest

The author does not have any conflict of interest to report

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