Global Anthropogenic Heat as Source of Ices Disappearance; Consequences for the Future of Earth and Humanity

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Abstract

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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 water thermodynamic properties showed the predominance of evaporation-condensation in heat absorption and dispatching
- Fighting CO_2-producing fossil sources of energy may not be sufficient to avoid worsening of climate events in the future

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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 and anthropogenic heats and also any 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 are efficient physical factors to fight global warming. It is also shown that the pool of water present on Earth is progressively augmented by the water liberated parallel to CO_2 during the combustion of fossil hydrocarbons in which it was stored millions years ago. Water as source of hydrogen may be an alternative to the sources of energy produced and 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 predictions, the global temperature should not raise as much as predicted by IPCC. 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 those reported in successive Intergovernmental Panel on Climate Change (IPCC) reports (IPCC, 2014; IPCC, 2022) issued from an international consensual exploitation of the available literature to predict climate changes in distant future. The trends are 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, blogs 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 at the top of the troposphere (rAHR) (IPCC, 2014; NASA, 2009; Mackenzie & Lerman, 2006) without consideration to heat in the low atmosphere, notably anthropogenic heat release (eAHR), also known as waste heat energy, generated by the sources of energy produced and exploited by humanity for works. In the past, only rAHR related to greenhouse gas was taken into account and considered as absorbed predominantly by oceans (Hansen, et al., 2011; Trenberth et al., 2014; IPCC, 2014). rAHR is said resulting from electromagnetic radiative flux that amounted annually from 0.5 to 1 W/m^2 in the early 2000s (Trenberth et al., 2014; IPCC, 2014), i.e. between about 8 and 16 x 10^{21} Joules (8 and 16 Zeta Joules (ZJ)). The AR6 IPCC reports an observed annual average rate of heating of the climate system at 0.79 [0.52 to 1.06] W m^{-2} (12.7 ZJ) for the period 2006–2018 (IPCC, 2022). Regardless of its origin, heat energy released or generated in the atmosphere has to be evacuated to space otherwise it is absorbed and causes warming as it is proposed in the case of residual radiative forcing assigned to greenhouse gas. According to (IPCC, 2022), "*ocean warming accounted for 91% of the heating in the climate system, with land warming, ice loss and atmospheric warming accounting for about 5%, 3% and 1%, respectively (high confidence)* ".

In general, global ice was considered a negligible heat absorber relative to oceans (Hansen et al., 2011; IPCC 2022). 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) on top of temperature-dependent dilatation. Long considered negligible, eAHR is now more and more regarded as a contributing factor to climate changes. The context and the history are 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.

Earth, as living systems, is too complex to be represented experimentally so that exploitations using climate models is necessarily based on local measurements or on global averaged data like radiative forcing in term of flux in W/m^2. We recently attempted 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 provide work. On the basis of this estimate, it was deduced that eAHR released from all the energy sources in the low atmosphere between 1994 and 2017 provided enough thermal energy (7.2 ZJ) to melt 77% (Vert, 2021) of the 28 trillion tonnes of disappeared ice reported recently for the same long period (Slater et all, 2021). The corresponding 0.31 ZJ annual average eAHR estimate was effectively negligible when compared with the 12.7 ZJ estimate of annual average rAHR deduced from the 0.79 W/m^2 annual average rate of heating of the climate system applied to the surface of the planet (IPCC AR6, 2022). As ices imbalance is a partial signature of heat energy supply regardless of its origin, the large dominance of rAHr, a source of energy assigned to CO_2-based radiative forcing, raises a question: why rAHR that is said warming the environment does not cause much greater ices imbalance than presently observed since, in physics, any source of heat tend to transfer part of it to its environment up to equilibrium?

In attempt to answer 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 the origin of a 15°C excess of average temperature relative to an atmosphere-free Earth. 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 locally since no matter or molecule can escape in intersidereal space. Only the energy stored in molecules can escape to space through radiation phenomena.

A few thousand years ago, humans began to use biomass as sources of heat and light. The generated eAHR remained very small compared with solar inputs until about 150 years ago when humans began to exploit fossil sources and, more recently, nuclear energy and renewable resources for the production of electricity in order to satisfy work, heat and comfort needs. The side effect was the appearance of increasing eAHR in the low atmosphere in addition to rAHR in the high troposphere (Yang et al.; 2017). Therefore, 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 to keep its temperature constant. Cooling is provided by the evaporation of sweat. If water cycle has been recognized for years as an important factor in climate control (Allan & Liepert; 2010), water evaporation and condensation have not been considered as important to limit the storage of radiative forcing in oceans.

The present article aims to compare Earth's water with the refrigerant that controls the temperature inside a refrigerator, a simpler example than human body, 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.

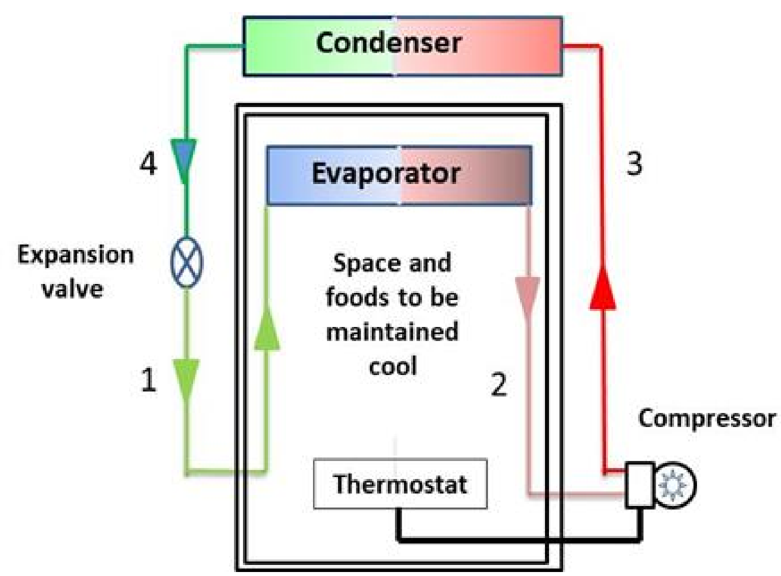

Figure 1: Schematic representation of a Vapor Compression-Refrigeration cycle.

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

The components of the environment (atmosphere, land, oceans, etc.) have been heated by the Sun for billions of years and kept without dramatic 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 the mechanical and mixing actions of chaotic turbulences in atmosphere (winds, streams, tornadoes, hurricanes, storms, etc.) and oceans (hot and cold streams) that 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 from which the heat stored at the evaporation stage is released to space. 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 return to the surface via rain and snow. The whole process is schematized in Figure 2. It is important to note that the concentration of water molecules above clouds is much lower than below. This low concentration is favorable to radiation transmission to space according to the Beer-Lambert law, in contrast to the case of CO_2,the concentration of which is not affected by condensation (Sirroco, 2018).

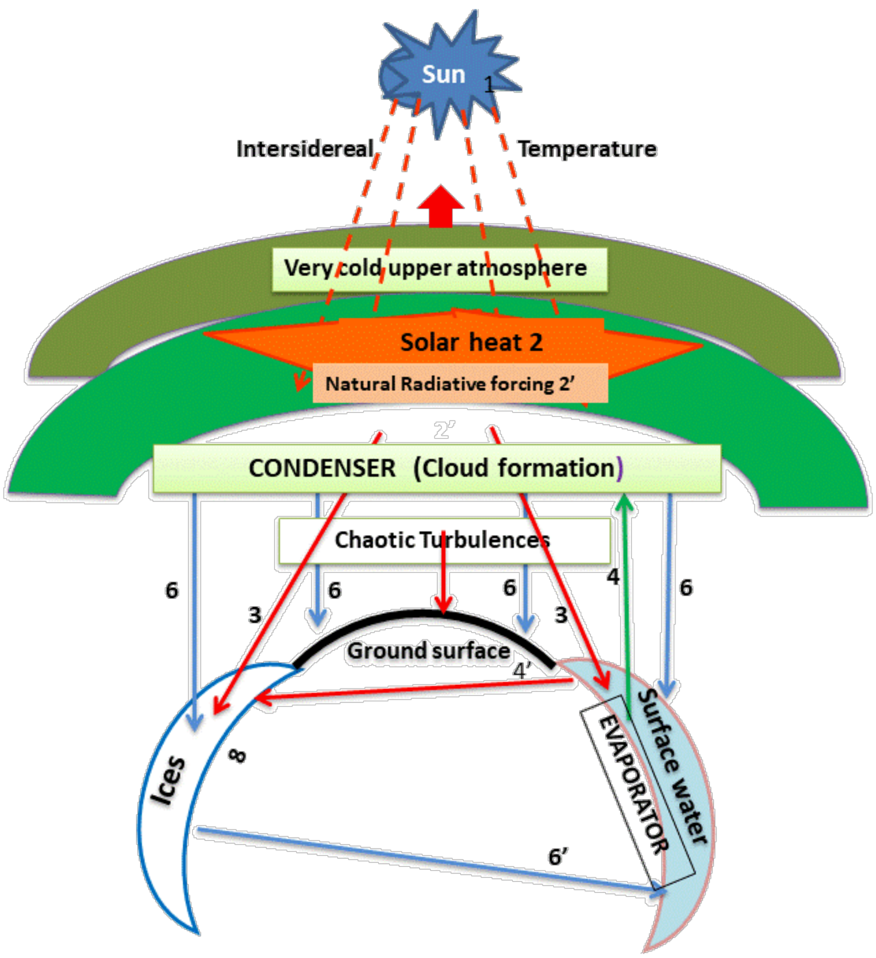

Figure 2: Schematic representation of the machinery that manages residual solar heat energy through water phase exchanges.

In this scheme, the Sun (1) heats the whole environment as everybody feels it under sunshine (2 and 3). Natural greenhouse effect is included in (2'). Humid air ascension and atmosphere turbulences dispatch and tend to average local imbalanced heat and raise it to 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. It is worth noting that in contrast to humid air, the dense CO_2 tends to go down. The supply of geothermal heat is generally considered negligible as many other heat sources on Earth are, including the combustion of fossil fuels ((Zhang & Caldeira, 2015) and electricity-related ones. The temperatures of land surface and of oceans tend to increase but rising is unavoidably limited by heat absorption by the melting of ices (4' and 6') over the whole globe and also 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). 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 from which the released heat is eliminated by radiation (7) and rains and snow (6) that close the cycle. 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. In hot summers, ices melt. In cold winter, ices are restored but the process is more and more imbalanced. If ice imbalance continues to grow, all ices will disappear sooner or later and warming will then be controlled by the sole right shift of evaporation - vapor - condensation interphases equilibria. This will occur progressively over the years with more and more clouds to form a thick cover that will tend to limit the solar input like durst particles and aerosols do. Less solar heat will lead to ices regeneration like in past glacial eras (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 are major obstacle to quantification. Anyhow, temperature rise or not, the more heat to be dispatched over the globe, the stronger and the more frequent chaotic environmental have to be, at least qualitatively (Fig. 2), a trend already observed today (Reed et al., 2021) although temperature rise is no more than a few hundredths of a Celsius degree annually. Water cycle has been already proposed as climate factor but generally without involving ices and not in terms of quantitative water interphase equilibria.

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 energy started bringing in extra heat in the middle of the 19th century and alerted people recently. In parallel, both natural gas and, more recently, electricity provided progressively more waste heat in the low atmosphere. 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 now with anthropogenic heat releases eAHR (2"). Both rAHR and eAHR anthropogenic heat issued from the consumed energy are dispatched in the atmosphere (4' and 4") for averaging over the whole planet. The corresponding surplus of heat is absorbed by oceans, ices melt (8) and water evaporation (4) to close the ring like in section 2.

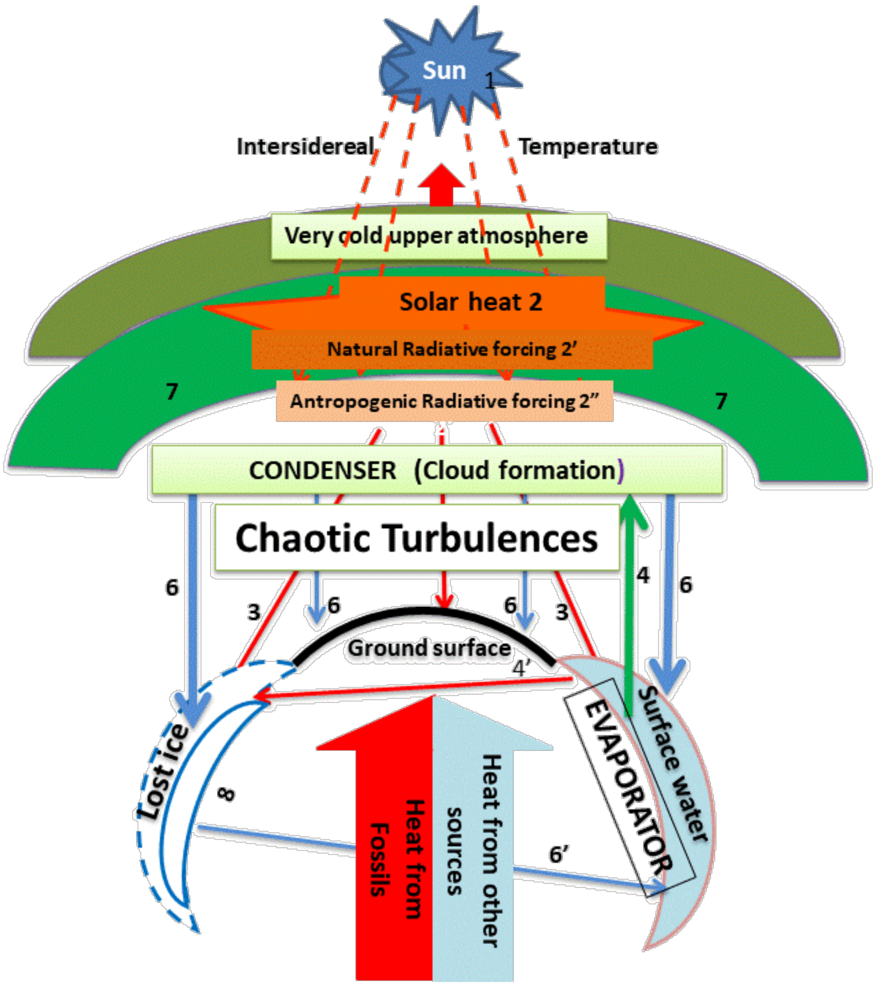

Figure 3: Schematic representation of the management of increasing amount of anthropogenic heat through evaporation-condensation-evaporation and ices melting.

Having to dispatch more thermal energy, local chaotic climate perturbations (hurricanes, tornados, storms, rains, streams, etc...) become more important and more frequent. In contrast to Sun, rAHR and volcanoes that caused discrete heating, eAHR warming related to human activities around the globe occurs over days and nights.

5. Attempts to quantify the action of water as refrigerant

In this section, we look at where the mechanisms schematized in Figures 2 and 3 can lead on the basis of thermodynamics characteristics typical of the water cycle, namely, the 333.55 KJ/Kg latent heat of ice melting, the 2,447 KJ/Kg latent heat of evaporation at 14°C, the 2.11 KJ/Kg/°C specific heat capacity of solid ice and the 4.184 KJ/Kg/°C specific heat of water, various factors with minor effects like salinity, CO2 dissolution in ocean and cloud liquid water, dusts, etc. being neglected (Engineering Tool Box, 2003).

To estimate and compare rAHR and eAHR in terms of Joules, the following data available for year 2018 were used:

- 14°C, the average temperature of Earth's surface determined from multiple land and ocean local measurements (NOAA; 2021), a value considered common to low atmosphere and ocean surface water;

- 0.79 W/m2 the average radiative forcing (IPCC, 2022);

- 0.03°C and 3.7 mm, the temperature and ocean level respective changes (IPCC, 2022);

- 1.5 trillion tonnes ice imbalance assumed similar to the estimate of 2017 deduced from Figure 4 in (Slater, 2021);

- 20°C, the average temperature of global ices, a temperature proposed in (Slater, 2021); and

- 13.864 GT of oil equivalent, the global energy consumption (BP, 2019), 60 % of which generated 0.35 ZJ eAHR according to 44 MJ/Kg, the average heat of combustion.

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. Then, the temperatures of ice and formed liquid water remained constant at 0°C during the melting of the whole mass of disappeared ices that required c.a. 0.50 ZJ of thermal energy according to ice latent heat of fusion. The heat energy necessary to melt 1.5 trillion tonnes of ice at -20°C and form 1.5 10^{15} Kg of liquid water at 0°C required about 0.56 ZJ. In addition, bringing 1.5 trillion tonnes of water from 0 °C up to 14°C, required about 0.09 ZJ according to the specific water heat capacity. In total, the heat energy necessary to turn the disappeared ices at -20°C to water at 14°C was thus about 0.65 ZJ (0.56 + 0.09). In other words, the disappeared 1.5 million tonnes of ices absorbed 0.65 ZJ of heat energy introduced in the low atmosphere, regardless of its origin.

The estimate of eAHR did not take into account the injection of Joules in the atmosphere by mammalians (humans, cattle and animals with hot blood), hydrogen-using rockets, criminal wildfires and volcanoes. Based on 80 W per capita, 7.5 billion humans generate about 0.02 ZJ annually to which a minimum of 0.01 ZJ can be added due to cattle. In 2018, 80 volcanoes were active, the Hawaii eruption being the largest with c.a. 0.76 10^9 cubic meters of 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 by the Hawaiian volcano after cooling was c.a. 0.002 ZJ. Assuming an average of 0.001 ZJ/volcano, heat released by volcanoes was in the range of 0.08 ZJ. Wildfires could hardly be estimated but like volcanoes, they are very likely negligible relative to the 0.35 ZJ of eARH that finally represent less than 3% of the 12.7 ZJ of radiative forcing deduced from the 0.79 W/m^2 annual average rate of heating of the climate system for the period 2006-2018 applied to the surface of the planet (IPCC, 2022). This large difference of magnitude between annual e and rAHRs has already been pointed out in the literature (Chaisson, 2008; Zhang & Caldeira, 2015) but for different systems and under different conditions.

In terms of thermodynamics, the estimate of total anthropogenic heat energy released in the atmosphere in 2018 stored in the climate system was about 13 ZJ (0.35 + 12.7). 0.65 ZJ were absorbed by the lost ices, leaving 11.7 ZJ absorbed by oceans (90% of 12.35 ZJ) and land and atmosphere for the rest based on IPCC's mechanisms. Basically, the storage of heat energy in liquid raises the temperature of this medium unavoidably. However, when ice is present, melting fights temperature rise like when an ice cube is in a glass of water under summer sun. Therefore, one may ask why the 2018 ice imbalance was not much greater than the 1.5 trillion tonnes estimate (Slater, 2021). There are several possible reasons. Firstly, radiative forcing was largely overestimated, a hypothesis going against the current universal CO_2-based claim but defended by some specialists of electromagnetic radiations who goes up to denying CO2-related anthropogenic warming (Sirroco, 2016; Humlum, 2022; Guesken, 2020). In this case, the share of eAHR would become predominant or the only source of anthropogenic heat to be eliminated. Secondly, atmospheric and oceanic streams were far from equilibrium and thus were not efficient enough to dispatch and homogenize the radiative forcing up to the surface. Last but not least, the heat absorbing capacity of evaporation was able to absorb the huge excess of eAHR and justify the absence of more important ice imbalance. Evaporation was mentioned about 200 times in IPCC's AR5 WG1 report (IPCC, 2014), but only relative to its effect on salinity, pan evaporation, balance of evaporation-precipitation, localization and not in terms of heat absorption and temperature regulation. Secondly, the AR6 2022 report mentions only "it is virtually certain that evaporation will increase over the oceans" with no consideration to associated heat exchanges.

In 2018, the average ocean level rise was about 3.7 mm in rather good agreement with the 4 mm generated by a surplus of 1.5 trillion tonnes of ice-derived liquid water in oceans. In parallel, the annual average global ocean and land temperature rises was estimated about 0.02-0.03 °C (NOAA, 2021). Temperature rising observed when a compound is heated depends on the thermal characteristics and the mass of this compound. Based on the 4.184 KJ/Kg/°C heat capacity of salt-free water, a 1 dm thick layer of ocean surface water (361 10^{14} dm3 or 361 10^{14} Kg) is able to absorb about 0.15 ZJ of heat energy for 1° C rise. This means that a minimal layer of more than 200 m would be necessary to absorb 11.7 ZJ with 0.03°C homogeneous temperature rise. In contrast, evaporation, that plays an essential role in a refrigerator, is able to absorb 2,247 KJ/Kg according to the latent heat of water evaporation at 14°C, the temperature of the warmly heated source being maintained constant, basically. The surface of Earth covered by water being about 390 10^6km^2 or 390 10^{14}dm^2, the evaporation of 1dm layer of ocean water can absorb 95.5 ZJ without temperature change. Therefore, evaporation is about 600 times more efficient than ocean surface water to absorb global anthropogenic heat energy and fight global temperature change due to warming conditions.

6. Water released from fossil hydrocarbons

In the previous section, the discussion was based on a constant mass of water on Earth dispatched as solid, liquid, vapor and clouds since matter cannot escape to space. However, the combustion of all hydrocarbons (oil, natural gas, and biomass) that generates hot CO_2 from the carbon content generates also water as hot vapor from the atoms of hydrogen included in molecules. Once the heat stored in these hot gases is transferred to the environment; the cooled and condensed hot water constitutes a surplus that joins the existing pool of liquid water. It is important to note that heat produced by biomass burning is not compensated at the stage of biomass formation because this renewal requires solar light at ambient and not heat.

Quantifying the amount of extra water from hydrocarbons is as difficult as quantifying heats of e and rAHR-types. Nevertheless, estimates of the overall consumptions (close but slightly less than productions when heat release is concerned) of fossil oil and natural gas are available in oil equivalents 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 - 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 in about 150 years. In 2018, 8 GT of oil equivalent of the hydrocarbon-type generated about 11.3 GT of hot water, an amount negligible compared with the heat absorption capacity of 1,500 GT of disappeared ices and of surface water evaporation.

According to section 5 and 6, the waste heat derived from the production and the consumption of energy on Earth seems negligible today relative to the radiative forcing estimate. However, this may change in the future if the production of energy continues to grow while the production of anthropogenic CO_2 and the corresponding radiative forcing are decreased as recommended to politicians by IPCC.

7. Can hydrogen from water be a solution?

Apart from limiting CO_2 production, climate scientists propose the development of new sources of energy among which hydrogen is more and more regarded as an attractive alternative (Johnston et al, 2005) provided it can be produced from water with regeneration of water after exploitation as source of electric energy according to the following catalyzed reactions: energy + H_2O - H_2 + 1/2 O_2 - H_2O + electricity. So far, hydrogen is primarily produced from fossil resources. Catalytic electrolysis is of interest only if the energy needed to dissociate water in hydrogen and oxygen is produced using environmentally-friendly sources of electricity (Gardner, 2009). What is presently missing to decide whether a source of energy is better than another 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, we did not find any quantitative information relative to heat-cycles of wind turbines and of other CO_2-free sources of electricity in comparison with fossil and radioactive 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, and physics together with climatologists and chemists to collect information's necessary to decide.

8. Conclusion

The mechanism by which the temperature in a refrigerator is controlled appeared a rather consistent model of how the average temperature of the global environment may be controlled if water is given the role of refrigerant with: - ice melting and water evaporation as heat absorbing phenomena, - chaotic climatic events like hurricanes, tornadoes, ocean streams and humid air ascension to move the warm vapor to condensation zones as the compressor does in a refrigerator; and - clouds as source of radiative elimination to space of the transferred heat they release because of water condensation. Accordingly, surface temperature and thus sea level rises should be smaller than IPCC's calculated values for the next decades. In contrast, climatic events (flooding, drought, local temperatures, etc.) should increase in strength or magnitude and frequency if human population and its standard of living continue to grow and generate more and more anthropogenic heat release, regardless of its origin. In terms of thermodynamics, the refrigerant role of Earth's water appears a credible means to avoid heat accumulation on Earth and promote radiative elimination to space. The predominance of radiative forcing relative to anthropogenic heat releases suggested that 2018 ice imbalance should have been much larger than observed except if evaporation is taken into account or if scientists who deny radiative forcing turn to be right. In parallel, the amount of liquid water stored for millions of years in fossil hydrocarbons and released by combustion was shown negligible relative to the amount generated by disappeared ices. In the future, the contribution of anthropogenic heat residue of energy sources could become no longer negligible if the deny of CO2 as source of radiative forcing defended by some specialists of electromagnetic radiations is recognized. Presently, relying on the reduction of carbon-containing sources of energy may appear insufficient to limit climate evolution and ice imbalance growth if the replacing sources of energy, including water as source of hydrogen, generate similar amounts of waste heat. Heat amounts and heat transfers estimated in the present essay will have to be assessed more precisely 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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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 water thermodynamic properties showed the predominance of evaporation-condensation in heat absorption and dispatching
- Fighting CO_2-producing fossil sources of energy may not be sufficient to avoid worsening of climate 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 and anthropogenic heats and also any 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 are efficient physical factors to fight global warming. It is also shown that the pool of water present on Earth is progressively augmented by the water liberated parallel to CO_2 during the combustion of fossil hydrocarbons in which it was stored millions years ago. Water as source of hydrogen may be an alternative to the sources of energy produced and 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 predictions, the global temperature should not raise as much as predicted by IPCC. 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 those reported in successive Intergovernmental Panel on Climate Change (IPCC) reports (IPCC, 2014; IPCC, 2022) issued from an international consensual exploitation of the available literature to predict climate changes in distant future. The trends are 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, blogs 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 at the top of the troposphere (rAHR) (IPCC, 2014; NASA, 2009; Mackenzie & Lerman, 2006) without consideration to heat in the low atmosphere, notably anthropogenic heat release (eAHR), also known as waste heat energy, generated by the sources of energy produced and exploited by humanity for works. In the past, only rAHR related to greenhouse gas was taken into account and considered as absorbed predominantly by oceans (Hansen, et al., 2011**;** Trenberth et al., 2014; IPCC, 2014). rAHR is said resulting from electromagnetic radiative flux that amounted annually from 0.5 to 1 W/m^2 in the early 2000s (Trenberth et al., 2014; IPCC, 2014), i.e. between about 8 and 16 x 10^{21} Joules (8 and 16 Zeta Joules (ZJ)). The AR6 IPCC reports an observed annual average rate of heating of the climate system at 0.79 [0.52 to 1.06] W m^{-2} (12.7 ZJ) for the period 2006–2018 (IPCC, 2022). Regardless of its origin, heat energy released or generated in the atmosphere has to be evacuated to space otherwise it is absorbed and causes warming as it is proposed in the case of residual radiative forcing assigned to greenhouse gas. According to (IPCC, 2022), "*ocean warming accounted for 91% of the heating in the climate system, with land warming, ice loss and atmospheric warming accounting for about 5%, 3% and 1%, respectively (high confidence)*".

In general, global ice was considered a negligible heat absorber relative to oceans (Hansen et al., 2011; IPCC 2022). 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) on top of temperature-dependent dilatation. Long considered negligible, eAHR is now more and more regarded as a contributing factor to climate changes. The context and the history are 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.

Earth, as living systems, is too complex to be represented experimentally so that exploitations using climate models is necessarily based on local measurements or on global averaged data like radiative forcing in term of flux in W/m^2. We recently attempted 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 provide work. On the basis of this estimate, it was deduced that eAHR released from all the energy sources in the low atmosphere between 1994 and 2017 provided enough thermal energy (7.2 ZJ) to melt 77% (Vert, 2021) of the 28 trillion tonnes of disappeared ice reported recently for the same long period (Slater et all, 2021). The corresponding 0.31 ZJ annual average eAHR estimate was effectively negligible when compared with the 12.7 ZJ estimate of annual average rAHR deduced from the 0.79 W/m^2 annual average rate of heating of the climate system applied to the surface of the planet (IPCC AR6, 2022). As ices imbalance is a partial signature of heat energy supply regardless of its origin, the large dominance of rAHr, a source of energy assigned to CO_2-based radiative forcing, raises a question: why rAHR that is said warming the environment does not cause much greater ices imbalance than presently observed since, in physics, any source of heat tend to transfer part of it to its environment up to equilibrium?

In attempt to answer 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 the origin of a 15°C excess of average temperature relative to an atmosphere-free Earth. 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 locally since no matter or molecule can escape in intersidereal space. Only the energy stored in molecules can escape to space through radiation phenomena.

A few thousand years ago, humans began to use biomass as sources of heat and light. The generated eAHR remained very small compared with solar inputs until about 150 years ago when humans began to exploit fossil sources and, more recently, nuclear energy and renewable resources for the production of electricity in order to satisfy work, heat and comfort needs. The side effect was the appearance of increasing eAHR in the low atmosphere in addition to rAHR in the high troposphere (Yang et al.; 2017). Therefore, 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 to keep its temperature constant. Cooling is provided by the evaporation of sweat. If water cycle has been recognized for years as an important factor in climate control (Allan & Liepert; 2010), water evaporation and condensation have not been considered as important to limit the storage of radiative forcing in oceans.

The present article aims to compare Earth's water with the refrigerant that controls the temperature inside a refrigerator, a simpler example than human body, 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.

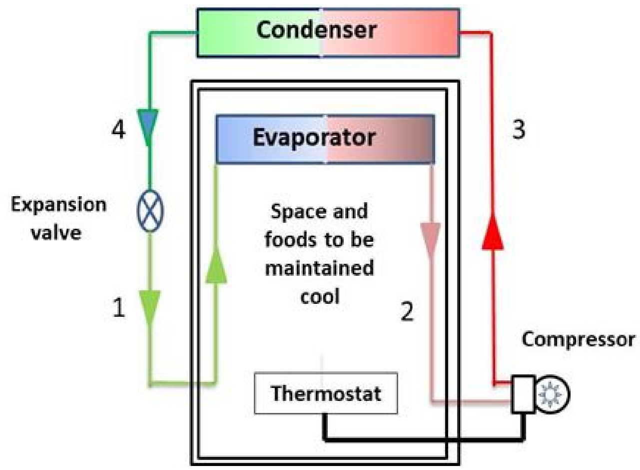

Figure 1: Schematic representation of a Vapor Compression-Refrigeration cycle.

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

The components of the environment (atmosphere, land, oceans, etc.) have been heated by the Sun for billions of years and kept without dramatic 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 the mechanical and mixing actions of chaotic turbulences in atmosphere (winds, streams, tornadoes, hurricanes, storms, etc.) and oceans (hot and cold streams) that 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 from which the heat stored at the evaporation stage is released to space. 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 return to the surface via rain and snow. The whole process is schematized in Figure 2. It is important to note that the concentration of water molecules above clouds is much lower than below. This low concentration is favorable to radiation transmission to space according to the Beer-Lambert law, in contrast to the case of $CO_{2,}$ the concentration of which is not affected by condensation (Sirroco, 2018).

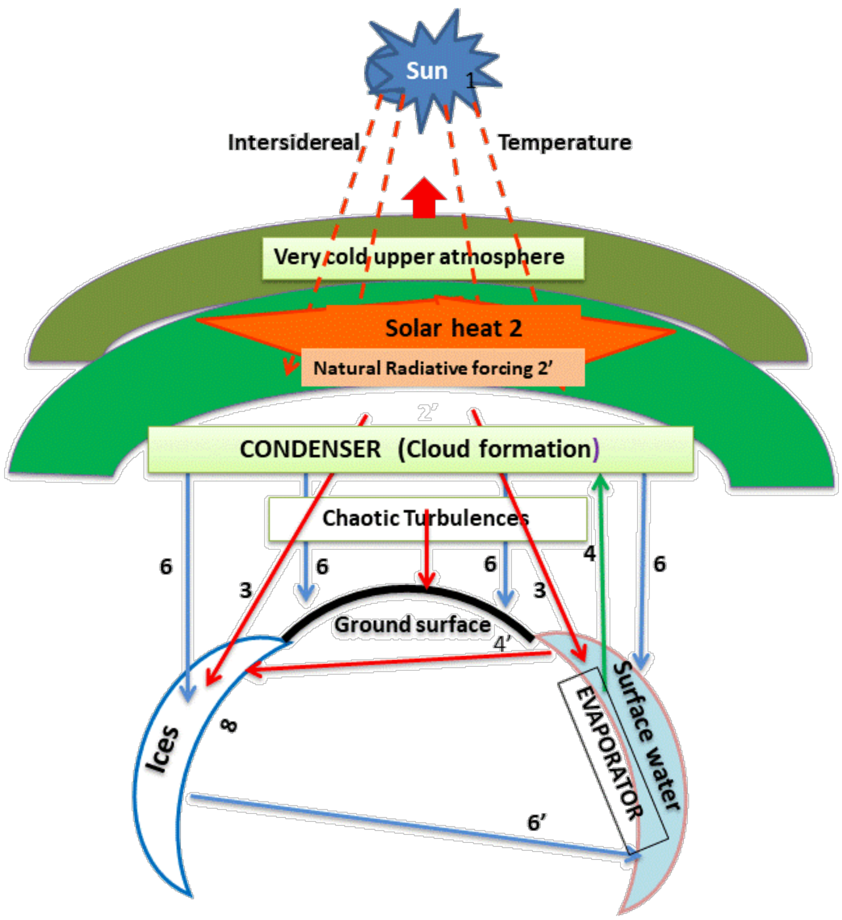

Figure 2: Schematic representation of the machinery that manages residual solar

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). Natural greenhouse effect is included in (2'). Humid air ascension and atmosphere turbulences dispatch and tend to average local imbalanced heat and raise it to 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. It is worth noting that in contrast to humid air, the dense CO_2 tends to go down. The supply of geothermal heat is generally considered negligible as many other heat sources on Earth are, including the combustion of fossil fuels ((Zhang & Caldeira, 2015) and electricity-related ones. The temperatures of land surface and of oceans tend to increase but rising is unavoidably limited by heat absorption by the melting of ices (4' and 6') over the whole globe and also 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). 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 from which the released heat is eliminated by radiation (7) and rains and snow (6) that close the cycle. 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. In hot summers, ices melt. In cold winter, ices are restored but the process is more and more imbalanced. If ice imbalance continues to grow, all ices will disappear sooner or later and warming will then be controlled by the sole right shift of evaporation vapor condensation interphases equilibria. This will occur progressively over the years with more and more clouds to form a thick cover that will tend to limit the solar input like durst particles and aerosols do. Less solar heat will lead to ices regeneration like in past glacial eras (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 are major obstacle to quantification. Anyhow, temperature rise or not, the more heat to be dispatched over the globe, the stronger and the more frequent chaotic environmental have to be, at least qualitatively (Fig. 2), a trend already observed today (Reed et al., 2021) although temperature rise is no more than a few hundredths of a Celsius degree annually. Water cycle has been already proposed as climate factor but generally without involving ices and not in terms of quantitative water interphase equilibria.

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 energy started bringing in extra heat in the middle of the 19th century and alerted people recently. In parallel, both natural gas and, more recently, electricity provided progressively more waste heat in the low atmosphere. 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 now with anthropogenic heat releases eAHR (2”). Both rAHR and eAHR anthropogenic heat issued from the consumed energy are dispatched in the atmosphere (4’ and 4”) for averaging over the whole planet. The corresponding surplus of heat is absorbed by oceans, ices melt (8) and water evaporation (4) to close the ring like in section 2.

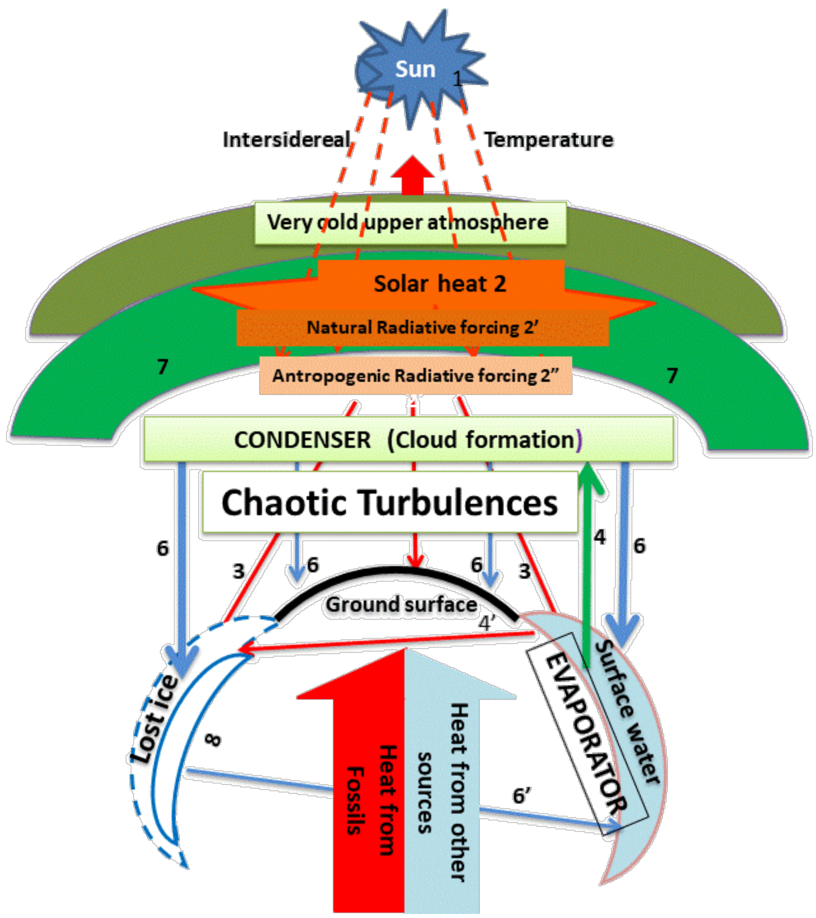

Figure 3: Schematic representation of the management of increasing amount of anthropogenic heat through evaporation-condensation-evaporation and ices melting.

Having to dispatch more thermal energy, local chaotic climate perturbations (hurricanes, tornados, storms, rains, streams, etc...) become more important and more frequent. In contrast to Sun, rAHR and volcanoes that caused discrete heating, eAHR warming related to human activities around the globe occurs over days and nights.

5. Attempts to quantify the action of water as refrigerant

In this section, we look at where the mechanisms schematized in Figures 2 and 3 can lead on the basis of thermodynamics characteristics typical of the water cycle, namely, the 333.55 KJ/Kg latent heat of ice melting, the 2,447 KJ/Kg latent heat of evaporation at 14°C, the 2.11 KJ/Kg/°C specific heat capacity of solid ice and the 4.184 KJ/Kg/°C specific heat of water, various factors with minor effects like salinity, CO2 dissolution in ocean and cloud liquid water, dusts, etc. being neglected (Engineering Tool Box, 2003).

To estimate and compare rAHR and eAHR in terms of Joules, the following data available for year 2018 were used:

- 14°C, the average temperature of Earth's surface determined from multiple land and ocean local measurements (NOAA; 2021), a value considered common to low atmosphere and ocean surface water;

- 0.79 W/m2 the average radiative forcing (IPCC, 2022);

- 0.03°C and 3.7 mm, the temperature and ocean level respective changes (IPCC, 2022);

- 1.5 trillion tonnes ice imbalance assumed similar to the estimate of 2017 deduced from Figure 4 in (Slater, 2021);

- 20°C, the average temperature of global ices, a temperature proposed in (Slater, 2021); and

- 13.864 GT of oil equivalent, the global energy consumption (BP, 2019), 60 % of which generated 0.35 ZJ eAHR according to 44 MJ/Kg, the average heat of combustion.

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. Then, the temperatures of ice and formed liquid water remained constant at 0°C during the melting of the whole mass of disappeared ices that required c.a. 0.50 ZJ of thermal energy according to ice latent heat of fusion. The heat energy necessary to melt 1.5 trillion tonnes of ice at -20°C and form 1.5 10^{15} Kg of liquid water at 0°C required about 0.56 ZJ. In addition, bringing 1.5 trillion tonnes of water from 0 °C up to 14°C, required about 0.09 ZJ according to the specific water heat capacity. In total, the heat energy necessary to turn the disappeared ices at -20°C to water at 14°C was thus about 0.65 ZJ (0.56 + 0.09). In other words, the disappeared 1.5 million tonnes of ices absorbed 0.65 ZJ of heat energy introduced in the low atmosphere, regardless of its origin.

The estimate of eAHR did not take into account the injection of Joules in the atmosphere by mammalians (humans, cattle and animals with hot blood), hydrogen-using rockets, criminal wildfires and volcanoes. Based on 80 W per capita, 7.5 billion humans generate about 0.02 ZJ annually to which a minimum of 0.01 ZJ can be added due to cattle. In 2018, 80 volcanoes were active, the Hawaii eruption being the largest with c.a. 0.76 10^9 cubic meters of 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 by the Hawaiian volcano after cooling was c.a. 0.002 ZJ. Assuming an average of 0.001 ZJ/volcano, heat released by volcanoes was in the range of 0.08 ZJ. Wildfires could hardly be estimated but like volcanoes, they are very likely negligible relative to the 0.35 ZJ of eARH that finally represent less than 3% of the 12.7 ZJ of radiative forcing deduced from the 0.79 W/m^2 annual average rate of heating of the climate system for the period 2006-2018 applied to the surface of the planet (IPCC, 2022). This large difference of magnitude between annual e and rAHRs has already been pointed out in the literature (Chaisson, 2008; Zhang & Caldeira, 2015) but for different systems and under different conditions.

In terms of thermodynamics, the estimate of total anthropogenic heat energy released in the atmosphere in 2018 stored in the climate system was about 13 ZJ (0.35 + 12.7). 0.65 ZJ were absorbed by the lost ices, leaving 11.7 ZJ absorbed by oceans (90% of 12.35 ZJ) and land and atmosphere for the rest based on IPCC's mechanisms. Basically, the storage of heat energy in liquid raises the temperature of this medium unavoidably. However, when ice is present, melting fights temperature rise like when an ice cube is in a glass of water under summer sun. Therefore, one may ask why the 2018 ice imbalance was not much greater than the 1.5 trillion tonnes estimate (Slater, 2021). There are several possible reasons. Firstly, radiative forcing was largely overestimated, a hypothesis going against the current universal CO_2-based claim but defended by some specialists of electromagnetic radiations who goes up to denying CO2-related anthropogenic warming (Sirroco, 2016; Humlum, 2022; Guesken, 2020). In this case, the share of eAHR would become predominant or the only source of anthropogenic heat to be eliminated. Secondly, atmospheric and oceanic streams were far from equilibrium and thus were not efficient enough to dispatch and homogenize the radiative forcing up to the surface. Last but not least, the heat absorbing capacity of evaporation was able to absorb the huge excess of eAHR and justify the absence of more important ice imbalance. Evaporation was mentioned about 200 times in IPCC's AR5 WG1 report (IPCC, 2014), but only relative to its effect on salinity, pan evaporation, balance of evaporation-precipitation, localization and not in terms of heat absorption and temperature regulation. Secondly, the AR6 2022 report mentions only "it is virtually certain that evaporation will increase over the oceans" with no consideration to associated heat exchanges.

In 2018, the average ocean level rise was about 3.7 mm in rather good agreement with the 4 mm generated by a surplus of 1.5 trillion tonnes of ice-derived liquid water in oceans. In parallel, the annual average global ocean and land temperature rises was estimated about 0.02-0.03 °C (NOAA, 2021). Temperature rising observed when a compound is heated depends on the thermal characteristics and the mass of this compound. Based on the 4.184 KJ/Kg/°C heat capacity of salt-free water, a 1 dm thick layer of ocean surface water (361 10^{14} dm3 or 361 10^{14} Kg) is able to absorb about 0.15 ZJ of heat energy for 1° C rise. This means that a minimal layer of more than 200 m would be necessary to absorb 11.7 ZJ with 0.03°C homogeneous temperature rise. In contrast, evaporation, that plays an essential role in a refrigerator, is able to absorb 2,247 KJ/Kg according to the latent heat of water evaporation at 14°C, the temperature of the warmly heated source being maintained constant, basically. The surface of Earth covered by water being about 390 10^6 km^2 or 390 10^{14} dm^2, the evaporation of 1dm layer of ocean water can absorb 95.5 ZJ without temperature change. Therefore, evaporation is about 600 times more efficient than ocean surface water to absorb global anthropogenic heat energy and fight global temperature change due to warming conditions.

6. Water released from fossil hydrocarbons

In the previous section, the discussion was based on a constant mass of water on Earth dispatched as solid, liquid, vapor and clouds since matter cannot escape to space. However, the combustion of all hydrocarbons (oil, natural gas, and biomass) that generates hot CO_2 from the carbon content generates also water as hot vapor from the atoms of hydrogen included in molecules. Once the heat stored in these hot gases is transferred to the environment; the cooled and condensed hot water constitutes a surplus that joins the existing pool of liquid water. It is important to note that heat produced by biomass burning is not compensated at the stage of biomass formation because this renewal requires solar light at ambient and not heat.

Quantifying the amount of extra water from hydrocarbons is as difficult as quantifying heats of e and rAHR-types. Nevertheless, estimates of the overall consumptions (close but slightly less than productions when heat release is concerned) of fossil oil and natural gas are available in oil equivalents 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 in about 150 years. In 2018, 8 GT of oil equivalent of the hydrocarbon-type generated about 11.3 GT of hot water, an amount negligible compared with the heat absorption capacity of 1,500 GT of disappeared ices and of surface water evaporation.

According to section 5 and 6, the waste heat derived from the production and the consumption of energy on Earth seems negligible today relative to the radiative forcing estimate. However, this may change in the future if the production of energy continues to grow while the production of anthropogenic CO_2 and the corresponding radiative forcing are decreased as recommended to politicians by IPCC.

7. Can hydrogen from water be a solution?

Apart from limiting CO_2 production, climate scientists propose the development of new sources of energy among which hydrogen is more and more regarded as an attractive alternative (Johnston et al, 2005) provided it can be produced from water with regeneration of water after exploitation as source of electric energy according to the following catalyzed reactions: energy + $H_2O \rightarrow H_2 + ½\ O_2 \rightarrow H_2O$ + electricity. So far, hydrogen is primarily produced from fossil resources. Catalytic electrolysis is of interest only if the energy needed to dissociate water in hydrogen and oxygen is produced using environmentally-friendly sources of electricity (Gardner, 2009). What is presently missing to decide whether a source of energy is better than another 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, we did not find any quantitative information relative to heat-cycles of wind turbines and of other CO_2-free sources of electricity in comparison with fossil and radioactive 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, and physics together with climatologists and chemists to collect information's necessary to decide.

8. Conclusion

The mechanism by which the temperature in a refrigerator is controlled appeared a rather consistent model of how the average temperature of the global environment may be controlled if water is given the role of refrigerant with: - ice melting and water evaporation as heat absorbing phenomena, - chaotic climatic events like hurricanes, tornadoes, ocean streams and humid air ascension to move the warm vapor to condensation zones as the compressor does in a refrigerator; and - clouds as source of radiative elimination to space of the transferred heat they release because of water condensation. Accordingly, surface temperature and thus sea level rises should be smaller than IPCC's calculated values for the next decades. In contrast, climatic events (flooding, drought, local temperatures, etc.) should increase in strength or magnitude and frequency if human population and its standard of living continue to grow and generate more and more anthropogenic heat release, regardless of its origin. In terms of thermodynamics, the refrigerant role of Earth's water appears a credible means to avoid heat accumulation on Earth and promote radiative elimination to space. The predominance of radiative forcing relative to anthropogenic heat releases suggested that 2018 ice imbalance should have been much larger than observed except if evaporation is taken into account or if scientists who deny radiative forcing turn to be right. In parallel, the amount of liquid water stored for millions of years in fossil hydrocarbons and released by combustion was shown negligible relative to the amount generated by disappeared ices. In the future, the contribution of anthropogenic heat residue of energy sources could become no longer negligible if the deny of CO2 as source of radiative forcing defended by some specialists of electromagnetic radiations is recognized. Presently, relying on the reduction of carbon-containing sources of energy may appear insufficient to limit climate evolution and ice imbalance growth if the replacing sources of energy, including water as source of hydrogen, generate similar amounts of waste heat. Heat amounts and heat transfers estimated in the present essay will have to be assessed more precisely 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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I am also indebted to the Editor-in-Chief of Earth's Future because he first accepted the submitted version after reviewing but faced complains later on and had to deny the acceptance on the basis of the reports of 5 extra reviewers. As I was not given the chance to reply to reviewer's reports although many comments and criticisms were disputable, the rejected submission was revised and the point-by-point reply at the origin is available as supplementary file or on e-mail request from readers who would like to appreciate the consistency of the reviewing and of the work.

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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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Extra reviewing of “Refrigerator as Model of How Earth’s Water Manages Solar and Anthropogenic Heats and Controls Global Warming” that led to reject after a deny of the initial acceptance. ***Italicized point-by-point reply by the author*****.**

REVIEWER 1

This manuscript makes several claims: (1) That Earth’s oceans and ice control climate and the rate of global warming under forcing via evaporation and phase changes, with an analogy made to how a refrigerator works. The stated implications are that climate change is cyclical and that global temperature will not change much in response to radiative forcing because the excess energy will simply go into increasing evaporation and melting ice. It is also stated that as ice melts, cloud cover will increase and limit global warming. *(This is not what is written. Briefly, it was stated that ices melt and ocean evaporation are phenomena that absorb excess of heat on Earth, that turbulences dispatch the heat toward averaging, and that eAHR appears large enough to cause a large part of ice loss. This is it)*. (2) Anthropogenic heat released as a byproduct of global energy production is comparable to the radiative forcing from the greenhouse gases, but because it is located near the surface it accounts for the majority of the observed ice loss.*(Again, this is not what was written. Both types of anthropogenic heats were not said comparable).* (3) That water stored in fossil hydrocarbons is released as vapor during combustion and returns to the global pool of water once condensed.

These claims are stated as fact rather than being supported by analyses *(True for some statements but in general the analysis and the discussion were based on quantitative data. For instance, the part of ice imbalance corresponding to eAHR was evaluated in this paper for year 2018 after quantitative evaluation for the period 1994-2017 proposed in another article rejected also by several journals, in most cases without reviewing. (Vert, 2021)*. As I describe below, claims (1) and (2) contain major errors, rest on fundamental misunderstandings of the climate system, and do not support the strong conclusions made in the manuscript. I do not evaluate claim (3) because it is not my area of expertise and it is not central to the results.*(This is simple chemistry, normally there is no need to evaluate it. I think the justification is clear, even for a person unskilled in chemistry)*. In addition, the manuscript is quite difficult to follow and needs substantial *rewriting (This is the first time such weakness is opposed but the remark was taken into account when judged necessary).* Based on this evaluation, I recommend that the manuscript be rejected from publication in Earth’s Future (*This conclusion should have been made after the detail of claims analysis*) .

Claim (1): The idea presented here is that Earth’s oceans and ice act to regulate global temperature through evaporation and phase change (L222-226) with an analogy made to the functioning of a refrigerator (Section 2). It is stated that these processes lead to climate cycles wherein excess energy goes into evaporation and melting ice, but then as ice melts a thick cloud cover will grow, in turn reducing solar heating and causing ice to grow again (L235-248). (Actually, the idea includes more, i.e. heat absorption via ice melting, ocean evaporation (condensation and cloud formation) with elimination of the heat released during cloud formation)

The argument is made that evaporation and ice melt act as heat absorbers such that radiative forcing (*any source of thermal heat energy on Earth i.e. eAHR and RAHR as was indicated in the text*) (e.g., due to increasing greenhouse gases) will simply increase evaporation and ice melt rather than increasing global temperature. An example is given that a radiative forcing leading to energy accumulation of 4.6 ZJ could be fully accounted for by an increase in global evaporation by only ~5 mm (per year), leading to the conclusion that global warming will be smaller than predicted (L329-338).

These claims rest on fundamental misunderstandings of the climate system. Even assuming that the energy accumulation by radiative forcing goes directly into increasing surface evaporation (which has not been demonstrated). (*No but the phenomenon occurs every day in a swimming pool, the owner of which knowing that water has to be added after a hot day because of evaporation; and also after a cold night during which the warm water evaporated to the cold atmosphere. This is basic physics the consequences of which are unavoidable*), a top-of-atmosphere radiation imbalance would still persist, requiring ongoing energy accumulation in the climate system. This ongoing energy accumulation cannot simply be balanced by increased evaporation forever as that ignores the fact that this would lead to increased condensation within the atmosphere, warming the atmosphere, resulting in increased thermal radiation to space (working to restore top-of-atmosphere balance) and changing surface turbulent and radiation fluxes, ultimately requiring the surface to warm. The amount of global warming is set by radiative processes rather than a surface energy flux condition. (*The reviewer seems to have missed that in the figures as in the text that condensation is indicated that leads to cloud formation and radiation to space from there. Also, the radiative evacuation to space is maintained. To avoid such misunderstandings, text and arguments were reconsidered to avoid such misunderstandings*).

The argument presented in the manuscript is thus based on only a partial view of the global energy budget, leading to incorrect conclusions (*the present work leads to the contrary: « radiative forcing has it is described is based on only a partial view of the global energy budget (evaporation is not included)leading to incorrect conclusion, the mechanism of radiative forcing being based on calculations and not on experiments*). The claim that thick clouds will form when ice melts is also not supported by any analysis in the manuscript or based on any result I know of. (*Again the described mechanism is misinterpreted. What is written is « evaporation will form clouds in contact with the upper cold zone, a process that will be amplified when the all ice being disappeared, evaporation will then be the sole means to compensate warming and absorb the supply of solar (and of any other sources of heat). The mechanism of glaciation periods seems logical as a paleogeophysicist mentioned to me*). There are major other issues with Section 5 as well, a few of which I will point out.

- The section attempts an accounting of various sources of global energy accumulation in the year 2018. But the method combines energy storage associated with ice loss and ocean warming (which belong in such a calculation) with the energy released from mammals breathing and from volcanic eruptions (which do not belong in such a calculation because they reflect energy fluxes rather than storage). (*The reviewer take again a shortcut. If heat energy is stored, it is become heat was produced somewhere before and the text indicates volcanoes, human and animals as other sources of thermal energy that join the other sources of heat forcing that included radiative forcing. Nothing was changed*).

- Ultimately, the argument is made that the global energy balance of 0.8 Wm^-2 (based on IPCC estimates for the 2000s) corresponding to a stated 9 ZJ (per year) should have caused more ice loss than observed, which the author estimates to equate to 0.67 ZJ. There is no physical argument being made here. Instead, this reflects a fundamental misunderstanding – the 0.8 Wm^-2 global energy balance is not a *cause* of ice loss, but instead represents a careful accounting of energy accumulation within the climate system, one term of which is ice melting (representing less than 4% in recent decades, see e.g., https://essd.copernicus.org/articles/12/2013/2020/). (*I did not claim that the yearly radiative flux caused ice loss, I claimed that rAHR being much larger than eAHR, ice loss should be larger than observed, ice melting occurring because of heat in transit in the atmosphere and in oceans. This to introduce the necessity to take into account evaporation and condensation phenomena*). The calculations in this section are generally flawed. For instance, 0.8 Wm^-2 integrated over a year corresponds to a global average energy accumulation of 12.8 ZJ, not 9 ZJ as stated *(I thank the reviewer for this remark. The calculation was referring to the ocean surface only which is a confusing shortcut. The reviewer was correct since the result was said global. This has been corrected by modifying the text to limit the discussion to estimates from physics and thermodynamics*). The units are also wrong on many of the constants used, such as the latent heat of vaporization. (*Correct again. There were typo errors dot should be comma and a zero is missing. Same for the latent heat of evaporation that should be 2,247 KJ/KG. These typo errors have been corrected and the text reporganized*).

- The calculation of ocean heat storage (L319-323) is incorrect. An accurate calculation gives approximately 13 ZJ per year (https://essd.copernicus.org/articles/12/2013/2020/), which is quite different from the value 4.4 ZJ stated here. It is difficult to say what has gone wrong because the manuscript does not show any details behind this calculation (*details have been supplied just before. Again, it is important to note that the correction will actually enlarge the estimate rAHR not absorbed by the melting of ices. It is now 11.7 ZJ*).

Claim (2): It's stated that the heat released from global energy production is 7.2 ZJ per year (L109) (*the reviewer did not read the sentence correctly. 7.2 ZJ accounts for 23 years from 1994 to 2017 calculated using Slater et al's estimation of ice imbalance over this long period of time. See the reference (Vert, 2021). The rest of the comment is then inappropriate*). This corresponds to a global average forcing of 0.45 Wm^-2. This is at least an order of magnitude too large. Global primary energy production is currently around 171200 TWhr, which gives 0.6 ZJ per year, or 0.04 Wm^-2, as an upper bound based on the assumption that all energy is released as heat rather than used for work. This is consistent with recent analyses, such as this one: https://www.nature.com/articles/s41597-019-0143-1
It's also stated that because the heat release from energy production occurs at the surface, it goes directly into melting ice. This is used to suggest that if radiative forcing really were as large as IPCC estimates, then more ice should have melted (L262-265). No analysis is provided in support these claims. It's plausible that forcings at different vertical levels of the atmosphere, or at different latitudes, can drive different degrees of climate change. But why anthropogenic heat release over land at mid- and low-latitudes will directly go into melting ice at the poles is not explained or justified. (This is not justified because it is not what was indicated as already emphasized before).(*Again there was no such direct relation. It is indicated that eAHR was large enough to have caused ice imbalance not only from poles*).

To summarize, the reject of the submitted work by reviewer 1 is mostly based on misinterpretation of the text and on irrelevant comparison with the today understanding of global warming. I think urgent that other disciplines be accepted to study the complexity of Earth which is, as I pointed out, a living system comparable to biological ones. After several attempts to have this work published in climate journals, it seems that this is not an acceptable strategy by specialists of climate changes.

REVIEWER 2

The paper ‘Refrigerator as Model of How Earth’s Water Manages Solar and Anthropogenic Heats and Controls Global Warming’ provides a qualitative discussion of climate forcing concepts, their impact on observed changes in Earth climate, and a discussion on proposed climate mitigation solutions. The paper has many major limitations, which reach from unprecise terminologies, missing theoretical concepts, missing in-depth analysis of either observed or modelled data for the quantification of the discussed concept over time scales relevant for the processes addressed, missing uncertainty frameworks, up to unprecise language use, incorrect description of published scientific results, and use of non-peer reviewed referencing (e.g. webpage level). The reader remains puzzled by the arguments developed (*this does not mean the work is wrong, the reviewer may lack knowledge in other sciences than the climate one*), and is unable to fully track the different aspects of the proposed concept (*again this does not mean the work is wrong. Thank you for recognizing the need to interdisciplinary investigations. Maybe a less systematic negative opinion and efforts to accept alternatives would lead to look at the work with more favorable eyes*). Several controversy statements are either not backboned by an in-depth analysis, nor linked to a peer-reviewed publication in which such an analysis had been performed (*analysis of what? The work is based on physics and thermodynamics*). None of the presented outcomes have been quantified by rigorous scientific analysis of data, or theoretical theorems (*how in the world using physical relationships to calculate energies needs analysis of data and theorems*), and a rigorous uncertainty framework is lacking. Particularly, two major mis-concepts appear on the concept of the ‘Earth system refrigerator’ as presented in this study: fully neglecting the thermodynamic role of the full-depth ocean, and neglecting climate sensitivity and the full picture of climate forcing. I recommend rejection of this manuscript. Further comments are provided below. (*There was no need to consider full-depth ocean, evaporation being a surface phenomenon. On the other hand, the work does mention the fact that about 90% of the radiative forcing is absorbed by oceans. This comment is not relevant. However new arguments were added to compare the ability of oceans and that of evaporation to absorb heat, the latter being much more efficient as clearly shown*)

L. 23-24: The relation between global warming and climate forcing is described as:

NTOA = FERF - |FP| TS

which represents the combined effect of the various climate feedbacks. Going through the entire paper challenges the reader to understand the pillars of this sentence, and would need overall clarification (*the object of the work is not global radiative forcing, it is a mechanism propose to explain ice imbalance and involve evaporation-condensation phenomena*)

L. 24-26: The opposition as expressed in this sentence is not further explained in the draft. As observed in various different observations, and reported in numerous scientific peer-reviewed literature, these changes have been observed (see IPCC AR6 (for an overview on assessed literature). (*What is wrong in the sentence? Maybe the term dramatic but temperature ocean rises are predicted source of water invasion of lands. On the other hand, ice are disappearing presently; a fact that can hardly be rejected*) Moreover, given the inertia of ocean water, and cryosphere components (particularly for ice sheets), long-term emerging change in the future is committed. This sentence needs revision accordingly. (I do not want to have it changed because there is nothing wrong in it) See also formula provided above.

L. 29-30: Variations in climate indicators such as for example ocean warming are triggered by numerous forcing factors, including natural and anthropogenic forcing components, and are acting on all time scales. For this reason, it is crucial to rely on long time series at climate relevant length if an analysis is aiming to infer results on the long-term signal and change such as the major topic of this paper – anthropogenic change (*A parent paper cited (Vert 2021), the reviewing of which turned to be delayed was finally retrieved because I never paid page charges to publish, contains an analysis on eAHR over 23 years correlating eAHR and ice imbalance. The reviewer should have had a look at the cited preprint available on ESSOAr free-access archives*). In addition, rigorous uncertainty evaluation is needed – which can for example range from technical limitations, validation, sampling etc.. A focus on one single year will not allow for the analysis of long-term aspects such as induced by climate change. The analysis of this paper would need to be performed hence on a long-term analysis reflecting and considering these different aspects, and to assure robust scientific conclusions on the long-term signal. Any conclusion drawn from one year-2 K-1. analysis cannot reflect aspects of long-term change, and a quantification of the different processes acting in one single year cannot be attributed to climate change. In addition, a rigorous uncertainty discussion is lacking to account for significance of the discussed results. (*I think the reviewers missed that 2018 was taken as model after the work referred to as (Vert, 2021) were a period of 23 years was considered as indicated in the text and missed by the reviewer*).

L. 60: According to the organization and structuration of IPCC (see for example https://www.ipcc.ch/about/), the statement is not correct, and IPCC does not 'hypothesize' – IPCC is based on rigorous assessment of peer-reviewed literature. This should be revised accordingly, or the author would need to provide a clear rationale based on references to found the use of the wording 'hypothesized'. (*Even if the IPCC report is a compilation of about 14,000 scientific contributions or more, these contributions made solid science but in absence of any possibility to make significant experimentation to compare with the results of calculations. A similar situation is found for mystery like the origin of life, for instance.)*

L. 64: The part of the sentence 'trends being still small' – what is the reference here? Small compared to what? Not significant after statistical uncertainty evaluation? Small compared to previous changes? This statement needs a clear rationale, and also a clarification on what this means, otherwise it would need to be removed.(*In the case of temperature and ocean rises, it is indisputable that rising is still small relative to the predictions found in the successive IPCC reports. I am not a climate-skeptic. I wanted only to see where the consideration of eAHR and that of water interphase equilibria end up on the basis of physics fundamentals*).

L. 65: The IPCC fully considers science controversy through the uncertainty language, which also includes the fact on how much evidence (e.g. peer-reviewed literature) is available for a specific assessed information, as well as also on how the peer-reviewed results agree (e.g. Mastrandrea et al., 2011). (*I am sorry but in physics and in thermodynamics demonstration is the rule not evidence even if evidence comes from peer-reviewed literature. In this work I was able to used solid thermodynamic relationships but unfortunately it was in many cases applied to climate related data that differ from one source to the other. On the other hand, I did not find similar works to be cited in the peer-review literature. This is the reason why there are many data that come from data sets found on the web. Maybe the reviewer has references to replace the selected data sets. Help would be very much appreciated*).

L. 66-67: This statement is a very strong one, and would need backboned by an analysis of such information. The reference provided does not contain such an analysis. If this statement remains, an in-depth analysis of all literature cited in all IPCC reports should be analyzed, and numbers would need to be shown to quantify such a statement. If this type of quantified information is not provided, the statement needs to be removed (*the reference supports the fact that controversial literature is seldom present in peer-review scientific journals. I let the readers decide whether there are controversies of this type in IPCC's reports*).

L. 70-71: There is a need to clarify what is behind the synonym 'radiative anthropogenic heat release' – it is not clear either from the references provided, nor is there no clarification provided in the manuscript (*The expression rAHR was introduced to complement and distinguish eAHR .Obviously; it means anthropogenic heat corresponding to radiation forcing. The precision was added*). For example, provide the formula to avoid any confusion. (*There is no possibility of formula, it is just a defined expression that is justified by the fact that radiative forcing given as global flux corresponds to heat in Joules*)? Second – and here the reader might be puzzled – a sentence before a strong statement is used for correctly working with scientific literature, particularly within the IPCC process, but then the author demonstrate weakness in scientific referencing, i.e. the doi for one of the cited papers does not exist, and a second reference is a webpage? This does not follow peer-review standards, and demonstrates inconsistency in the author's argumentation development. (*What can I do. Earth's Future requires data sets. In the data sets and in the list of references, hyperlinks are included when there is no doi. I think this is a good solution in a domain where data cannot be found in academic papers*.)

L. 71-74: As my comment above: please fundamentally precise 'anthropogenic heat release (eAHR) generated by the sources of energy produced and exploited by humanity'. (Also not a single reference is provided, and the reader remains fully in the dark with these definitions. (*I have a real problem understanding this remark. eAHR is defined l. 73 and rAHR l. 77 to 80. Usually, scientists use AHR only but, in the present work, distinction relative to radiative forcing was necessary.*). A best option would be for example to provide the formula (*the reviewer mentions the need of a formula again but it is not a matter of formula, definitions are definitions*), and clearly develop the theoretical background for this argumentation (these are abbreviations relative to thermal energies, nothing else). The concept established in l. 70-74 provides the underlying concept for the upcoming discussions, albeit a clear theoretical foundation is lacking (*what the reviewer is mentioning is quantified later on in the text (see l. 309-312). It is too easy to argue and reject after superficial reading).*

L. 74-76: The authors would need to go back into the cited literature, and the statement provided here is not correct, and does not reflect the results discussed in the cited papers. The papers cited discuss and analyze all aspects of climate forcing, including anthropogenic and natural climate forcing. Please revise accordingly. *(The reviewer did not take into account that according to the strategy followed in the present work, anthropogenic contribution to the thermal pool is the sum of eAHR and rAHR, eAHR being generally negligible as shown l. 309-312? As for the citations they support the part of anthropogenic thermal energy absorbed by oceans. This looks clear to me)*.

L.76-77: referencing of peer-reviewed documentation is needed to support this statement. Please add, otherwise would need to be removed. (*This point was addressed before in the introduction with a pertinent reference (Dunlap and Jaques, 2013*).

L.77-78: the wording is misleading, and the sentence is not correct as it stands. The values provided by the cited references refer to the Earth energy imbalance at the top of the atmosphere; and not as stated from electromagnetic radiative flux. However, confusion is also induced here according to missing clarifications on the terminologies used in this manuscript as mentioned above. (rAHR come from electromagnetic radiation interacting with greenhouse gas molecules. The expression can be replaced by radiative forcing. Another reviewer raised the problem of eAHR dispatching in the low atmosphere via turbulences and streams and emphasized slow exchange rates. What about dispatching of radiative forcing from high to low atmosphere? Any local source high or low or East or West in the atmosphere has to be dispatch over the Globe to cause global warming. This is the reason why I did not exploit flux data average to the whole Globe and prefer dispatched local heats (eAHR) by chaotic turbulences towards never reached averaging (phenomena far from equilibrium as observed on Earth. This limit was added).

L. 79-80: the values provided are not clear, and need further clarification. (*Do I need to indicate that the annual thermal energy in Joules (1W = 1J sec) is obtained from the flux in W/m^{-2}, the number of second in a year and the surface of the globe in m^{-2} although this is basic*)

L. 80: the wording 'c.a.' is not a standard scientific wording to account for in-depth analysis and consideration of related uncertainties frameworks (will be replaced by « about »). Also, uncertainties are not provided for any of the listed values. Those should be added, and the sentence need to be revised accordingly. (*This work aimed at showing trends. It will need deeper investigations to determine uncertainties, particularly when data like fluxes temperatures and ocean level are changing from one source to the other. Let me point out that the IPCC's mode of treating the problem use high, medium or low confidence in addition to uncertainties. I thought like the reviewer that uncertainties are uncertainties*)

L. 83-85: There is a need to rely on more recent literature. Most recent literature on this topic can be for example found in the last IPCC assessment report. (*Again, there is no need to exploit the latest data since the probability for new modifications in the future is highly probable as it was the case in successive IPCC reports. I believe at this time that estimates are informative enough without doubtful uncertainties.*).

L. 91-93: With the sentence just before – in which also sea ice is listed – this statement is incorrect, as only land ice is considered for sea level rise (e.g. WCRP, 2018; Munk, 2003). Also, it is the mass loss from land ice melt considered. A reference is also needed at the end of the sentence mentioning sea ice. . (*I think the reviewer missed a detail. The sentence relates to ice loss not to ocean level increase. The more general next sentence does not mention sea ice. The reviewer should not combine two independent sentences to generate his comment. I do not understand why a reference is necessary to justify an obvious statement*)

L. 93-94: This sentence is not clear, what does the author mean by 'an actor'? Further clarification is needed. (The term will be replaced, maybe by "contributor » or "factor").

L.111-113: First, there is clarification needed in l. 79: so the author is referring to an annual number for the value in J, but for the Earth energy imbalance values for a long period are discussed? Not clear, (*correct. The sentence is not necessary and it has been removed.*) and if yes – this is not comparable. This is a prominent example how critical it is to provide all

specific information to avoid confusion, and to allow the reader to follow the arguments. *(the value for the 23 years period was estimated in a previous parent preprint stage (see ref (Vert, 2021) as mentioned before*). Moreover, I would be keen to see the related uncertainty to this 'annual value' and the source of where this value is coming from – both critical information are not provided in the manuscript. This is not robust, and the upcoming argument is not quantified. (*read the cited preprint in ESSOAr for instance*)
Also, which is the theoretical foundation to quantify a dominant role of ice melt in the Earth heat inventory – storing more accumulated heat than the global ocean – a body on Earth which covers 71%, and is so deep? Containing huge amount of sea water, and thus provide means for thermal storage? This is not convincing, nor quantified at all. (*Again, the reviewer should have consulted the reference (Vert, 2021). Like in the present work, it is not indicated that ice melt has a dominant role. It was only large enough to have caused ice imbalance.).*

L. 119-122: Puzzled here: where is this information coming from? The author pulled forward an argument before that IPCC is biased by 'freely available literature' (a statement which had been not quantified by the author), and here the author is biased by its own opinions? Where is the referencing for example? Though, this proceeding is inconsistent allover. *(I thank the reviewer for this comment. The remark is effectively puzzling. Actually, 33°C resulted from the sum of 15°C due to the atmosphere + 17.2 °C, one of the present average global temperature. The sentence was rephrased on the basis of natural 15°C greenhouse effect only. Despite the correction, the predicted 2 to 4 °C increase due to doubling the anthropogenic CO_2 atmospheric concentration seems excessive and thus not logical as pointed out).*

L.124-126: A critical Earth system component is missing in this list: the ocean. That is not only surface water. This may be explains the whole miss-conception of the qualitative discussion: Did the author exclude the ocean in the concept? (*No but the discussion is about evaporation, a phenomenon that occurs at the surface. Basically, it can be quantified according to the heat of evaporation as clearly done. Unfortunately, evaporation depends on many factors (as indicated in the text) that exclude quantification and solid estimation as well*).

L. 128-131: It is difficult for the reader to follow, and further clarification is needed. *(The sentence was rephrased to be more precise*).

L 138-144: There is one element missing in this argumentation – or metabolism: the ocean, and its huge heat capacity, and thermal inertia. This is not convincing, and would need further clarification. Which are the arguments to rule out the immense storage capacity of Earth climate? This argumentation is incomplete, and does not reflect the functioning of Earth climate system. *(Again, heat storage is not the object. The discussed phenomenon is temperature control by evaporation, the human body being taken as example to introduce the refrigerator model*).

L.145-221: A simple question: what would happen if the refrigerator would be filled by 70% of warm water*? (I am surprised by this question. The case occurs every day when one introduces a hot soup in a refrigerator to cool it and keep it cool. Anyway, the machinery would start to bring the temperature of the water at the programmed temperature via the thermostat.).* Second question: What would happen if this volume of water is kept on the same temperature level? *(This can hardly happen. Even if the refrigerator is dead, the temperature of the water will move up to ambient).* And finally: what would happen if this volume of water would constantly warm up, for example at a rate of 1 W/m2? *(The refrigerator would fight as* *much as possible the heat newly introduced until the heat is ejected via the condenser. (comparison with the increase of turbulences involved in this article).* In my point of view, the whole concept raised here, and then applied to Earth climate is ignoring the ocean – the concept only considers 'surface water' but this does not represent reality. *(I already reply to this kind of comment. Evaporation is an unavoidable surface phenomenon and I am surprised not to see it involved generally. This is probably because quantification is not possible in terms of heat exchanges as mentioned before.)*

L.283-318: Another question: how does this calculation look like for another year? For example, 2019? or 2011? Or 1996, 1997? Or how would this calculation look like represented as an evolution over time? For example, from 1971-2018 onwards? And how would this calculation look like if the full-depth ocean would be considered? Simple examples: A time series for Global Mean Surface Temperature, or Sea Level, or Ocean Heat Content: Those vary significantly over time due to the interplay of response to all climate forcing, and the aspect of climate sensitivity (see for example formula provided at the beginning of this review) – how is this variability taken into consideration? How are the different response periods considered linked to physical characteristics and processes which differ for the different components discussed (or even not discussed, like the full-depth ocean)? Which are the time scales for example for the atmosphere, and then compared to the cryosphere, or the ocean? All these fundamental aspects have been neglected in this approach, which question the possibilities for reliable interpretation of the results. Moreover, what are the uncertainties of all those values, and how significant are these results? All these missing aspects in the approach question the conclusion drawn from this qualitative discussion, and are neither convincing, nor traceable. *(It is pity the reviewer did not consult the reference (Vert, 2021). In the citation, a period of 23 years was considered. Of course taking one year is not reasonable unless it is only an example, what it is actually with year 2018. It seems that the reviewer missed that point)*.

Remark: The reviewer seems to have missed that there is no discussion concerning sea level increase. We end up with the conclusion that temperature should not change much but we did not reject the idea of ocean level increase if ice melts. It is obvious. However, taking evaporation as temperature regulator, ocean level increase should be smaller that if evaporation is ignored). In conclusion, to me this report is affected by the lack of knowledge on non-climate sciences as the reviewer seems to recognize it at the beginning of this report and by the amazing question on the fate of hot water in a refrigerator.

References:

Mastrandrea, M.D., Mach, K.J., Plattner, GK. et al. The IPCC AR5 guidance note on consistent treatment of uncertainties: a common approach across the working groups. Climatic Change 108, 675 (2011). https://doi.org/10.1007/s10584-011-0178-6

Walter, M. (2003). Ocean Freshening, Sea Level Rising. Science, 300(5628), 2041–2043. https://doi.org/10.1126/science.1085534

WCRP (2018). Global sea-level budget 1993–present. Earth Syst. Sci. Data, 10(3), 1551–1590. https://doi.org/10.5194/essd-10-1551-2018

REVIEWER 3

This manuscript presents a very simplified model of the climate system based on an analogy with a refrigeration system and then uses it to revisit how the Earth responds to energy from the sun or from human activities. The topic is interesting and important, but this manuscript has many, many errors and does not meet any of the minimum requirements one would expect of a paper on climate physics. The assumptions of the simplified model are not or poorly justified, most are wrong. There is no justification for the refrigerator analogy. Considering the phase changes of water in the Earth's energy cycle is not original. The proposed model is not expressed in mathematical form but is used to support unjustified qualitative considerations. This article does not deserve to be published in any scientific journal, especially those of the AGU.

General comments:

This manuscript is full of errors and unjustified assertions and I present below only a few of them.

l. 195-199: "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." What justifies this statement? *(The chaotic turbulences contribute to dispatch heat in the world regardless of its origin, up to cold zones (ices, oceans and upper atmosphere where exchanges necessary to absorb the heat occur via ice melting and absorption in ocean water and water evaporation; and from cold zones to hot ones. In the absence of turbulences, dense CO_2, anthropogenic or natural would stay at the surface as it is the case in a room. (well known in chemistry). More heat to be absorbed leads to more important and more frequent turbulences (generating more energy as the compressor does in a refrigerator. This is it. The mentioned sentence should not be isolated from the rest of the text and the rest of the study. Doing this is too easy to kill a work)*. I don't see how one can make a parallel, without any demonstration, between a mechanical device (the compressor) and a physical phenomenon (turbulence). *(As explained, both are source of forcing energy (work). A sailing boat use winds, for instance. Is it really so difficult to deduce by a reader?)*

l. 205-209: "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 CO2 (Scirroco; 2018)." This claim is wrong. There is still a lot of water vapour above the boundary layer clouds that cover most of the Earth's surface, and radiative calculations show that the absorption by this water vapour is not negligible at all. The referenced article is published on a blog, has no scientific value and contains many errors. (*Fine, but are you meaning that the Beer-Lambert law is wrong? On the other hand, you are right. "Absence of water" was too much. Actually the statement should be « much lower than below clouds». The text was easily corrected. Please note that the interaction between ice particles that may be present in the troposphere do not interact with radiation as molecules do in vapor phase. By the way, water vapor is considered as much more efficient that CO2 as greenhouse gas but this was not the subject of the paper.)*

l. 226-228: "Water cycle has been proposed as climate factor but generally without involving ices and not in terms of quantitative water interphase equilibria." This is wrong. Most of simplified climate models and all ESMs include the water cycle and energy exchanges during water phase changes. Taking into the energy cycle associated with the water cycle is absolutely not new, it is even essential for many studies. (*With such an important criticism, the reviewer could have provides one or two references where the water cycle and especially evaporation is involved as we described quantitatively. Evaporation is mentioned many times in IPCC reports but not quantitatively in terms of joules. The text is now clearer with citation from AR6 relative to the point*)

l. 239-243; "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 massive increase in cloud mentioned is completely unjustified, and the reference to (Miller et al., 2012) is irrelevant for this matter. (*This is a point that interested very much a paleogeophysicist who reviewed the work for another climate journal that nevertheless rejected the submission. He was favorable to the work that other reviewers rejected similarly to the present ones. Warming seems to have preceded glaciation periods. Rests of reptiles have been found in Greenland. I can hardly go farther because I am not specialist but based on my domain of science, this is understandable*).

l. 314-318 : "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 318 trillion of tonnes (*I am sorry but it is 1.5 trillion 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." Why would the melting of the ice be due solely to energy from human activities? It is well known that this is not the case, most of this energy warms the ocean. (*Again I am sorry but the matter is not the melting of the ice; What is emphasized is the fact that eAHR was high enough to have caused the melting at the global lost. Again, I think the reviewer should not isolate a sentence from the rest of the text. According to the reported temperature increase for 2018, the ocean absorbed only part of the radiative forcing according to the heat capacity of water. Accordingly, this study discusses the fate of the unabsorbed radiative forcing heat energy and the possible reason(s) for that. This is it. For me if 0.67 ZJ was enough to have caused the observed ice lost, it is logical to think that the much greater heat from the rAHR radiative forcing should have heated the world much more than measured and thus melted more ice than observed. This looks very logical since it is the measured temperature which is at the start of the quantification leading to the statement*).

REVIEWER 4

Overall, I found the paper to be poorly written, the main point confusingly argued, and several important points simply asserted without evidence. In addition, there is virtually no analysis in the paper — it definitely does not meet the standards of an AGU publication.

Because of this, it is unsuitable for publication in anything close to its present form. Thus, I recommend rejection.

First, it is trivial to show that anthropogenic waste heat, eAHR, is about 1% of the total radiative forcing of 2.3 W/m2. Thus, it is not important in the problem of climate change. *(I am sorry but in fact, adding the detail was requested by a reviewer of the preceding reviewing turn. So I did after correct adaptation*). the authors acknowledge that in several places (e.g., line 401). Thus, I don't understand why the paper talks so much about it. (*Anyway, this is true and appear useful to justified that eAHR is generally neglected, something found also in this work. The previous reviewer was right. The text was modified to be clearrt and avoid misinterpretation*)

Second, the entire argument about the "water vapor refrigerator" *(refrigerant!, the difference is important)* makes no sense to me. Certainly, transport of water vapor transports enormous amounts of heat around the planet. But a refrigerator uses work to take heat out of a cold reservoir and eject it into a hot reservoir. In our atmosphere, water vapor is almost always carrying energy down gradient (from the tropics or the surface to mid latitudes or the upper atmosphere). Perhaps I'm misunderstanding the author, but the paper is so difficult to read and the explanations so impenetrable that I can't figure out if this is just nonsense or not, although it looks like nonsense. (*I am sorry to say that reviewers of the first turn of reviewing did not make any comment regarding difficulties to follow the development of the analysis. Maybe the problem here is the combination of climate, physics and thermodynamics sciences and not climate science only*). One of the important conclusions of this paper is that carbon dioxide will not significantly change the earth's climate. *(This is not correct. It is deduced that CO2 should not lead to important temperature changes in distant future whereas in parallel, due to heat imbalance, turbulences should be enhanced in intensity and frequency to dispatch and average heating as much as possible. It seems that the present flooding's and hurricanes and doughs observed in different countries in the world including in USA are already signatures of the trend. It will take time to see whether this is reality or just feeling, but not 50 or 100 years)* As far as I can tell, the argument arises around line 241, where the statement is made that "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." In other words, the author is postulating the existence of a strong negative cloud feedback that would cancel out warming from anthropogenic radiative forcing. However, no supporting evidence is provided anywhere in the paper. This is simply asserted. *(I can hardly accept that the whole text be ignored. The mechanism that is described is not that which is summarized in the comment. The argument says only that if a screen is placed on the way of a heat flux, less heat gets through than if there was no screen. The origin of the screen is detailed before)*. However, there's lots of evidence that this is not how the atmosphere operates – for example, no climate model simulates that. (*Are you saying that climate models consider that a screen made of clouds* *cannot be an obstacle to solar heating? Screening is a fact and it must operate also in the case of radiative forcing said occurring above the clouds. On the other hand, a cloud cover also retains heat from surface to atmosphere below this is type of heat is not dominant compared with the solar one).*

If the author wants to make this point, he needs to write a longer explanation of how his theory can be reconciled with, for example, estimates of the cloud feedback from observations (see Sherwood et al. 2020, Rev. Geophys.). (*I do not discuss any cloud feedback. I discuss conductive heat exchanges when vapor condensed at the dew point which is more or less high in the low atmosphere. Why not accepting or understanding that other sciences than the climate one exist that may be of interest to understand complex phenomena. This is currently done in biology, another science for a natural complex system*).

Section 5 is entitled "Quantification of the action of water as refrigerant ". This section makes absolutely no sense to me. The author first quantifies the energy required to melt ice, which looks reasonable. The author then points out that anthropogenic waste heat is large enough to melt a significant fraction of that. OK, but so what? Most of the energy stored in the climate system is going into the ocean and the oceans have stored hundreds of ZJ over the last few decades (from radiative forcing). The fact that anthropogenic waste heat is similar to the amount of energy required to melt ice does not mean you can conclude that waste heat is melting the ice. If you evenly distributed the waste heat over the entire planet, you would get little warming and little ice melt. *(Again this is not what was written. Anyhow, If evaporation was taken not account in IPCC's reports as opposed before, why the reviewer does not mention the cooling effect of evaporation? Everybody feels it when sweat evaporates. The text was made clearer to show that more heat means more ice melting.)*

If the author wishes to revise this paper (which I do not recommend), he needs to produce some kind of model to better explain the physics he is proposing and show it makes sense. *(The physics of water equilibria and thermal heat exchanges is very simple and basic since the quantifications are when well known relationships are used. No need of models*). The easiest thing to do would be to look at the output of global climate models. If you can show that the proposed physics is operating a climate model, then you would have a strong publishable case *(I know that in climate science, everything is based on models starting from assumptions and then using solid calculations. Why requiring a strategy based on models and relying on assumptions when facts and thermal physical relationships are available and exploited?)*

REVIEWER 5

This study presents a model of the Earth's hydrodynamic cycle by using refrigeration as an analogy. It is interesting to think of new simple ways to describe and explain the Earth and its climate system. This paper is certainly among the more interesting approaches. The technical accuracy is not very high, however and this paper should not be published. Not only are there clear and demonstrable errors in the work, but the author also makes unsubstantiated and unsupported claims about the climate that are inaccurate. I will provide some examples in the following.

First, the quality of the writing needs to be improved with special attention paid to the grammar. I
understand that English may not be the first language of the author, however, the writing leaves
ambiguous issues in this report. *(The reviewer is probably right but he is the first to argue against the language which, even if it is simpler than that of an English speaking native, has been considered comprehensive so far).*

Let me provide a few examples. In the first sentence of the abstract, the author writes that the relation between global warming and carbon dioxide is confusing. How is it confusing? THe author doesn't say. (*This reviewer, like some of the other previous reviewers, extracts sentences from the rest of the text to give a negative opinion. Here the questioned sentence is followed by « Experts predict that changes in ocean level and atmospheric temperature will increase considerably in distant future. On the other hand, loss of ices in the World is already dramatic and has increased over the recent years. » Aren't these facts amazing relative to time scales?)*
But, the central role that carbon dioxide has in influencing the climate has been understood for well
over 100 years. Hardly confusing. *(Again this is not the point, what is confusing are the predictions for the distant future relative to present observations. Maybe the reviewer should advise using "discordant" or "surprising" instead of "confusing". As a chemist and physical chemist, I am confused)*. In the very next sentence, the author says that "ocean level and atmospheric temperature rises are predicted to be dramatic in the distant future". What is meant by
"dramatic"? What is meant by "distant future". *(This is an interesting question. I did not want to argue on something which is appearing universally in medias when IPCC's reports are forwarded to the public with predictions for 2050 up to 2100)*. Without a magnitude of change and a time frame over which the changes are to occur, this statement has little to no meaning. *(See the previous reply).*
The author uses a representative year of 2018 in their analysis. But no climate study can be made based on what happens in a particular year. Climate change reflects long term changes to the Earth system. (*I think it is clearly indicated in the text that year 2018 is considered because data are available to tentatively quantify the factors described qualitatively before. How can this indication be missed? The text looks to me perfectly understandable)*.

Line 32, the author claims that equilibrium will be maintained and global average temperatures
relatively unchanged in the future. Really? What is the basis for this statement? (*I am sorry to say that the reviewer find short a result emphasized in the abstract. To me the basis of that statement is presented in the text and can be easily found on reading it)*. tmay have missed the demonstration presented in the rest of the text *(it seems to be the case)* What is meant by "relatively unchanged"? What is meant by "the future"? And why would anyone expect the climate to suddenly become more or less constant, after years of warming? (*Fortunately, warming of Earth is effective from Earth's formation, even when there was no atmosphere, and the Earth surface was cool because of the absence of atmosphere. Since the appearance of the atmosphere and of water, the temperature varied very much but remained stable enough over billions pf years to allow life to appear and persist).*

In the plain language summary we get a sense of what the focus of this paper is. *(Thank you very much for this comment. Understanding by non-specialists is exactly what is required by a plain language summary.)* Apparently the author is comparing heat from greenhouse gas effects to the thermal waste energy from energy sources. But the heat flowing in the environment is vastly greater than the waste heat from human activities. *(Yes, this fact is not new. This is now explicitly recognized and confirmed in the demonstration)*. In this same paragraph, the author implies that a compression refrigeration system can be an analogy to climate effects. But refrigeration cycles rely on a compression-evaporation process, driven by heat exchanges, pumps, evaporation coils, etc. The real climate doesn't have these components. *(In this work, water is shown behaving as a refrigerant, a compound the evaporation-condensation of which is the basis of the temperature control machinery of a refrigerator. I think the text clearly explain that turbulences bring mechanical energy to forced heat dispatching, something comparable to the energy brought by the compressor to move heat against negative gradient from cool to hot. As it seems to be difficult to understand, the text was complemented to state the point better).*

(but they rest on fundamentals of physics and thermodynamics. It turned out that the parent paper where the details are presented was not processed first as requested by the author although it was submitted first [Vert, M., 2021]. In this parent paper cited as preprint, it is emphasized that (1) an ice cube in a glass of water submitted to mild heating will melt to keep the temperature of the water constant and then when it is fully melted the water will get to the ambient temperature and evaporate keeping the temperature at this level if the heating rate is low. This is a simple experiment to do if not yet known. (2) A similar situation is found if a covered sauce pan containing ice and water is heated. First the ice melts at constant temperature, then the water heats up to generate vapor, this vapor goes to the cold cover where it condensates (cloud formation) and the condensed water droplets go back to the liquid water (raining). The cook often loads the cover with water to increase the cooling of the inner vapor by evaporation in the atmosphere, so that condensation is observed on cold wall or windows (cold upper tropopause). This is again a simple experiment to realize. My Granma know it when making a stew. Here there is no hypothesis or calculation)