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Article

Resolution of the Faint Young Sun Paradox *via* the Expanding Earth and Radiation Balance Equilibrium Hypothesis

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Abstract: We present a plausible solution to the now forty seven year old paleoclimatology riddle of the so-called *Faint Young Sun Paradox via* the combined hypothesis of the conservation of the state of radiation balance between the Earth and Sun and that of an expanding Earth, where, in the face of a changing (increasing) Solar luminosity, the Earth would maintain steady temperatures by re-adjusting the height of its atmosphere. That is to say, depending on whether or not the radius of the solid Earth is changing, this re-adjustment of the height of the Earth's atmosphere would mean two things — *i.e.*: (1) either the height increases — in which event the Earth accretes matter from its immediate surroundings (*i.e.*, the obvious pool formed by the Solar wind) thereby increasing the mass of the Earth's atmosphere, or: (2) the height decreases — in which event the Earth naturally expels matter from its atmosphere, thereby decreasing the effective mass of the Earth. We demonstrate that if — as the current state of the art ITRF observations seem to indicate, namely that — the Earth's landmass is steadily expanding globally at a paltry rate of $\sim +0.45 \pm 0.05\,\mathrm{mm \cdot yr^{-1}}$, and, that the Earth's atmosphere is to have a present radial vertical height of about one third of the Earth's radius ($\sim 2860\,\mathrm{km}$) from the Earth's surface, then, one can (might) with relative ease, explain not only the presence of liquid water on the Earth's surface some $\sim 3.20 \pm 0.70\,\mathrm{Gyr}$ ago during the *Archaean eon* when the Sun was about 75% of its current luminosity, but also the present radial expansion rate of the Earth. When all is said and done, the Earth system is herein cast as an *auto-self-regulating* incubator where the *auto-self-regulating mechanism* is as a result of the Earth's atmosphere responding by automatically re-adjusting its height.

Keywords: Expanding Earth; Exolife; Faint Young Sun Paradox; Radiation Balance Equation.

1. Introduction

Writing in 1972 in the journal *Science*, renowned American astronomer, cosmologist, astrophysicist, astrobiologist, author, and one of the greatest inspirational science communicators in the history of humankind — Carl Edward Sagan (1934-1996), and his fellow astronomer — George Mullen; brought (for the first time) to the international limelight[1], an apparent paradox [3] concerning the evolution of the Sun and the supposed presence of liquid water on the Earth's surface [see *e.g.* Refs., 3–8]. As initially pointed out by Donn *et al.* [2] and Sagan & Mullen [3] noted that according to the then just established evolutionary stellar models that describe stars like our own Sun — models that still hold to this day [see *e.g.* Refs., 9,10]; the Sun's energy output (which should

[1] According to Feulner [1], it was Donn *et al.* [2] who was were the first — in recorded literature — to point out the apparent discrepancy between the low solar luminosity predicted for the young Sun and the evidence for liquid water on early Earth. Sagan & Mullen [3] where the first to bring this problem to the popular attention of the wider scientific community.

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have been $\sim 0.75\mathcal{L}_{\odot}$) during the *Archaean eon*[2] [*i.e.*: $t_A \sim (3.80$ to $2.50)$ Gyr ago], should — *according to prevalent wisdom of stellar evolution* — have been insufficient to sustain liquid water on the Earth's surface, the meaning of which is that, contrary, to geological evidence [*e.g.*, 4,5], liquid water should not have been present — hence, the '*paradox*' of how did a *Faint Young Sun* manage to warm-up the Earth to the extent of sustaining liquid water on its surface despite the '*insufficient*' energy budget to do so? Accordingly, the Earth should have had only frozen water, thus, making the prospects of the diversity of life witnessed today, very much remote, if not unlikely. This paleoclimatology paradox is today commonly referred to as the *Faint Young Sun Paradox* (herefater *FYS-Paradox*) [*e.g.*, 11–23].

For a solution to this apparent riddle, Sagan & Mullen [3] proposed that the Earth's atmosphere at the time (*Archaean eon*), must have been rich in carbon dioxide (CO_2) and that the consequent *greenhouse effect* [*e.g.*, 24,25], should have been responsible for warming our nascent planet. However, geological evidence seem to indicate that atmospheric CO_2 concentrations during the *Archaean* and *Proterozoic eons* were far too low to keep the surface from freezing [see *e.g.*, 5,22,26]. The *FYS-Paradox* is even more compelling for the planet Mars which we now know to have been covered with oceans for periods of hundreds of millions of years in its nascent life [*e.g.*, 27–29], with only half of the incoming energy flux of Sunlight of the Earth [*e.g.*, 13]. We here make an attempt at this riddle by invoking the hypothesis of an expanding Earth whose albedo is regulated by the radiation balance equilibrium of the Earth system. This supposed radiation balance, we have called it the — *Radiation Balance Equilibrium Hypothesis* (RBE-Hypothesis).

In closing this introductory section, we shall give a synopsis of the reminder of this reading — it is organised as follows: in the subsequent §(2), we discuss some of this proposed solutions to the *FYS-Paradox*. In §(3), we discuss the expanding Earth hypothesis. In §(4), we present a standard exposition of the derivation of the Solar radiation balance equation. In §(5), we give a critic of this very derivation of the standard Solar radiation balance equation and as a result, we bring in a new concept of the effective radius of the Earth. In §(6), we provide an improved Solar radiation balance equation and we also discuss the concept of a changing albedo for a radially expanding Earth. In §(7), from an effective average global temperature of the Earth standpoint, we discuss the model of the Earth with a constant effective average global temperature and further, we present our proposed solution to the *FYS-Paradox*. Lastly, in §(8), we give a general discussion and the conclusion drawn thereof.

2. Proposed Solutions

Proposed solutions to the *FYS-Paradox* include, but, are not limited to:

1. ***Greenhouse Effects*** [see *e.g.*, 20,21,23,30,31]. In this scenario, we have enhanced greenhouse effect by carbon dioxide or methane, geothermal heath from an initially much warmer terrestrial core, a much smaller Earth albedo, life developing in a cold environment under a 200 m thick ice sheet, a secular variation in the gravitational constant, *etc*. According to Kasting [22], most of these greenhouse effect models have serious shortcomings: for example, the greenhouse effect from methane appears to be self-limiting, and not enough carbon dioxide is indicated by the geological record to justify a greatly enhanced greenhouse effect in the past. Further, according to Rossing *et al.* [5], examination of Archaean sediments appears inconsistent with the hypothesis of high greenhouse concentrations. Rossing *et al.* [5] argues that instead, the obtaining moderate temperature range of the Earth's

[2] *Archaean eon*, also spelled *Archaean eon*, is a period in the Earth's history which began about 4.00 billion years ago with the formation of Earth's crust and extended to the start of the *Proterozoic eon*[3] 2.50 billion years ago. During this time, unicellular organisms are the earliest forms of life that emerged.

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system through the *eons* may be explained by a lower surface albedo brought about by less continental area and the '*lack of biologically induced cloud condensation nuclei*'. This, Rossing *et al.* [5] say, would have led to increased absorption of solar energy, thereby compensating for the lower solar output.

2. ***Astrophysical Influences*** [*e.g.*, 5,18,32,33]. For example, Rossing *et al.* [5,18] hypothesizes a lower Earth albedo and this owing to considerably less continental area (this may include an Earth with a smaller radius) and to the lack of biologically induced cloud condensation nuclei. This would make an important contribution to moderating surface temperature in the *Archaean eon*. Further, Rossing *et al.* [18] suggests that the lower albedo of the early Earth provided environmental conditions above the freezing point of water, thus alleviating the need for extreme greenhouse-gas concentrations to satisfy the *FYS-Paradox*. In the same vein of an Earth with a smaller radius — *albeit*, on a different point of departure, our proposed model makes use of a lower albedo of the early Earth and this lower albedo results from a smaller Earth which gradually expands.

3. ***Active Young Sun Hypothesis*** [34]. Using κ^1-*Ceti* as a comparison for the young Sun, Karoff [34] have argued that not only was the young Sun much more effective in protecting the Earth environment from galactic cosmic rays than the present day Sun; it also had flare and corona mass ejection rates up to three orders of magnitude larger than the present day Sun. By means of the *Forbush Effect*[4], Karoff [34] contend that, these colossal coronal mass ejection rates of the young Sun could have had a critical life-changing effect on the young Earth's climate because, a young faint but active Sun producing far more coronal mass ejections would have had far fewer cosmic rays arriving on Earth, hence less cloud cover, thus, more Sunlight penetration hence a warmer young Earth (with a diversity of nascent life beaming on it).

4. ***Massive Young Sun Hypothesis*** [see *e.g.*, 13,19,35]. In this scenario, a somewhat more massive young Sun with a large mass loss rate ($\gtrsim 10^{-11}\mathcal{M}_{\odot}\text{yr}^{-1}$) sustained for two to three billion years is assumed. Such a massive young Sun bright enough to keep both the terrestrial and Martian oceans from freezing it thought to resolve the paradox. For example, Martens [13] finds that a large and sustained mass loss is consistent with the well observed spin-down rate of Sun-like stars, and indeed may be required for it. However, according (*e.g.*) to Refs. [36–38], such large mass loss rates contradict both solar evolutionary models calibrated using helioseismology [38] and measurements of stellar winds around solar-type stars [36,37].

5. ***Closer Earth Hypothesis*** Now, from an astrometric standpoint, a viable solution would be that: the Earth may have been much closer to the Sun at $\sim$ 95.6% [14] its present day heliocentric distance. This would allow the Earth to receive the required radiation intensity to sustain liquid water on the Earth's surface and with the progression of time as the Solar luminosity increases, the Earth-Moon system would have to recede from the Sun at just the right rate to maintain steady temperatures. For such a scenario, Iorio [14] calculates that, the change in the mean Earth-Moon distance $\delta r_{\oplus}(t)/r_{\oplus}(t)$ will have to be related to the change in the Solar luminosity $\delta\mathcal{L}_{\odot}(t)/\mathcal{L}_{\odot}(t)$, as follows:

$$\frac{\delta r_{\oplus}(t)}{r_{\oplus}(t)} = \frac{\delta\mathcal{L}_{\odot}(t)}{\mathcal{L}_{\odot}(t)}. \tag{1}$$

[4] Named after American astronomer, physicist and geophysicist — Scott Ellsworth Forbush (1904 − 1984), who studied galactic comsic rays in the 1930s and 1940s. The *Forbush Effect* is the observation that the number of galactic cosmic rays hitting Earth rapidly drops by up to 30% within a day or so of the Sun producing a coronal mass ejection.

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However [according to Refs., 39–42], the currently measured recessional rate of the Earth-Moon system from the Sun of $(7.00\,\mathrm{to}\,15.00)\,\mathrm{cm}\cdot\mathrm{yr}^{-1}$, is inadequate [14,15] to account for this idea of a *Closer-Earth-to-the-Sun* that would explain the presence of liquid water during the *Archaean eon*, as this would require a rate as high as $\sim 180\,\mathrm{cm}\cdot\mathrm{yr}^{-1}$, *i.e.*, $30-70$ times the currently measured recessional rate. Given the recessional rate of $(7.00\,\mathrm{to}\,15.00)\,\mathrm{cm}\cdot\mathrm{yr}^{-1}$ and assuming it to be steady, then — it follows that since the *Archaean eon*, $\delta r_{\oplus}(t)/r_{\oplus}(t)$ must be such that:

$$\frac{\delta r_{\oplus}(t)}{r_{\oplus}(t)} = (3.00-1.00)\times 10^{-5}. \tag{2}$$

Compared to $\delta\mathcal{L}_{\odot}(t)/\mathcal{L}_{\odot}(t)$, the term $\delta r_{\oplus}(t)/r_{\oplus}(t)$ is four orders of magnitude too small, the meaning of which is that the secular Earth-Moon system drift of $(7.00\,\mathrm{to}\,15.00)\,\mathrm{cm}\cdot\mathrm{yr}^{-1}$, this can not be responsible for the sustenance of the liquid water during the *Archaean eon* to the present day. If indeed a closer Earth is the solution to the *FYS-Paradox*, then, an extra mechanism presently pushing the Earth-Moon system away from the Sun is needed [14,15].

In-conclusion

Extensive reviews on this subject have been carried out with the most recent being those by Iorio [14,15] and Feulner [1]. The *FYS-Paradox* not only remains an *Open Question*, but an active field of research where a solution is much sought for [*e.g.*, 11–23]. In the present endeavour, we shall add a completely new solution to this long-standing and very interesting riddle. Our solution lies in the domain of '*Astrophysical Influences*' where the Earth-system is cast as an auto-self-regulating incubator which auto-adjusts its albedo as the Solar luminosity changes.

As said, the *Archaean eon* occurred during the period: $t_A \sim (3.80\,\mathrm{to}\,2.50)\,\mathrm{Gyr}$ ago. In-order for us to have convenient calculations, we need a single value of t_A rather than a lower and upper limit. To that end, we shall take the *Archaean eon* period: $t_A \sim (3.80\,\mathrm{to}\,2.50)\,\mathrm{Gyr}$, to be the average of: $(3.80\,\mathrm{to}\,2.50)\,\mathrm{Gyr}]$, that is: $(3.80+2.50)\,\mathrm{Gyr}/2 = 3.15\,\mathrm{Gyr}$, and the upper & lower limits (range or 'error') of this will be the average of the difference: $(3.80-2.50)\,\mathrm{Gyr}$, *i.e.* $(3.80-2.50)\,\mathrm{Gyr}/2 = 0.65\,\mathrm{Gyr}$, hence: $t_{\mathrm{A}} = (3.20\pm 0.70)\,\mathrm{Gyr}$. We shall adopt this value: $t_{\mathrm{A}} = (3.20\pm 0.70)\,\mathrm{Gyr}$, as representative of the *Archaean eon*, with the upper and lower limits represented by the '*error*' bars.

Now, here at the *ante-penultimate*, we need to state that in the present work, we shall demonstrate (and hence propose) a solution under the currently observed (and yet to be confirmed) radial expansion rate of the solid Earth of $\sim (0.45\pm 0.05)\,\mathrm{mm}\cdot\mathrm{yr}^{-1}$ [43] assuming that this rate has — *through the eons* — been steady. With this radial rate of expansion of the Earth, one can explain the steady temperatures for the Earth system by assuming that — since the *Archaean eon*, the Earth as a system:

> *...has been in a state were it preserves the state of radiation balance between the radiation it receives and that which it emits. This key assumption that the state of radiation balance between the radiation received and that emitted by the Earth system is conserved, we shall call the Solar* ***Radiation Balance Equilibrium Hypothesis*** *(RBE-Hypothesis).*

With steady temperatures having been achieved through the *eons via* the RBE-Hypothesis, the presence of the diversity of life seen today on Earth and stretching back to as far as the *Archaean eon* can be explained.

3. Expanding Earth Hypothesis

The great and renowned German polar researcher, geophysicist and meteorologist — Alfred Lothar Wegener (1880–1930), was the first to setforth the *polemical* idea of an *Expanding Earth Hypothesis* (EEH). This *all-daring hypothesis*, he arrived at upon noticing that the different continental landmasses of the Earth (*i.e.*, continental plates) almost fit '*hand-in-glove*' together like a '*perfect*' jigsaw puzzle, thus, Wegener [44,45] seized the

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golden moment and proposed that these continents are slowly drifting around the Earth, and, as to the cause of this movement, he further proposed that it was as a result of the solid Earth expanding radially outward on a globally scale.

Handicapped by his inability to find a viable source of energy to power this supposed expansion of the Earth, Wegener's ideas faced a stiff resistance [*e.g.*, 46–49] and thus were largely rejected by the main stream science community. Despite this setback, Wegener [44,45]'s ideas were very attractive to the insatiably curious and inquisitive minds [*e.g.*, 50–54]. It was not until the 1950's when numerous discoveries such as palaeomagnetism provided strong support for continental drift, and thereby a substantial basis for today's model of plate tectonics [*e.g.*, 47], that Wegener [44,45]'s ideas began to receive widespread acceptance. While the idea of continental drift was finally accepted and stands today as the *Chief-Corner-Stone* of *Modern Geophysics*, the idea of an expanding Earth was ferociously rejected and is still rejected to this day [see *e.g.*, 55–57].

Be that as it may — while the idea of an expanding Earth stands *vehemently rejected* today by the majority of scientists, we shall demonstrate herein that this idea does offer an interesting solution to this *FYS-Paradox*. In the light of the aforesaid — interestingly — against the prevalent mainstream position on the state of the EEH, evidence of an expanding Earth appears to be emerging in the '*not so distant horizons*' of observational science [43,58–65]. At least, effort to answer the question of whether or not the Earth is expanding is being made and there are a number of efforts to bring this idea to the international fore of science *e.g.* by [66–69].

For example, Wu *et al.* [61] have made the first such direct measurements using data from the *International Terrestrial Reference Frame* (ITRF). The ITRF is a fundamental datum for precision orbit tracking, navigation, and global change monitoring which combines data from Satellite Laser Ranging (SLR), Very Long Baseline Interferometry (VLBI), Global Positioning System (GPS), and Doppler Orbitography and Radiopositioning Integrated by Satellite (DORIS), its origin is currently realized by the single technique of SLR. Much to the chagrin of the advocates of an EEH, Wu *et al.* [61]'s findings are anything but *negative*! They (Wu *et al.* [61]) find that, the mean radius of the Earth is not changing to within 1σ-level measurement uncertainty of $0.20\,\mathrm{mm/yr}$. On the 'good' side, Shen *et al.* [58,59] also claim to have found evidence of an expanding Earth.

That is to say, on the positive side of things — just like Wu *et al.* [61], the researchers Shen *et al.* [59] used the ITRF-2008 space-geodetic data recorded at stations distributed globally (which includes GPS, VLBI, SLR, and DORIS), covering a period of more than ~ 10 years. From this, Shen *et al.* [59]'s calculations show that the Earth is expanding at a rate of: $\sim\; + 0.24 \pm 0.04\,\mathrm{mm\cdot yr^{-1}}$. From the *Archaean eon* to the resent day, this gives a change in the Earth radius of:

$$\frac{\delta\mathcal{R}_{\oplus}(t_0)}{\mathcal{R}_{\oplus}(t_0)} = +0.10 \pm 0.02, \tag{3}$$

that is to say, if the work of Shen *et al.* [59] is to be believed, then, one can safely say that the Earth has undergone a 10% radial growth since the *Archaean eon*. We must say here that 'δ' as applied in Eq. (3), *here-and-after*, shall be understood to mean a change since the *Archaean eon*.

Furthermore on Shen *et al.* [59]'s results, based on the *Earth Gravitational Model 2008*, they [59] find that the secular variation rates of the second-degree coefficients estimated by SLR and Earth mean-pole data, the principal inertia moments of the Earth, and, in particular their temporal variations, which they determined, they find a simple mean value of the three principal inertia moments of the solid Earth are gradually increasing thus clearly demonstrating that the Earth is indeed expanding, at least over the recent decades, and using this data, Shen *et al.* [59] says it [data] shows that the Earth is expanding at a rate ranging from: $\sim +0.17 \pm 0.02\,\mathrm{mm\cdot yr^{-1}}$, to: $\sim +0.21 \pm 0.02\,\mathrm{mm\cdot yr^{-1}}$, which coincides with the space geodetic evidence. Hence, based

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on both space geodetic observations and gravimetric data, Shen *et al.* [59] concludes that the Earth has been expanding at a rate of: $\sim +0.20\,\mathrm{mm}\cdot\mathrm{yr}^{-1}$ over the recent decade.

In a subsequent and latest study, Shen *et al.* [58] finds an even more favourable result for the expanding Earth. According to Shen *et al.* [58], this time using the ITRF-2008 data spanning 20 years, *i.e.*, space-geodetic data recorded at globally distributed stations over solid land, they (Shen *et al.* [58]) revised their previous estimate of: $\sim +0.24 \pm 0.05\,\mathrm{mm}\cdot\mathrm{yr}^{-1}$. They (Shen *et al.* [58]) find that from their new two decades of satellite altimetry observations that the sea level is raising at a rate of: $\sim + 3.20 \pm 0.40\,\mathrm{mm}\cdot\mathrm{yr}^{-1}$, of which: $\sim +1.80 \pm 0.50\,\mathrm{mm}\cdot\mathrm{yr}^{-1}$, is attributed to ice melting over land. Further, Shen *et al.* [58] finds that oceanic thermal expansion due to the temperature increase in recent half century is: $\sim +1.00 \pm 0.10\,\mathrm{mm}\cdot\mathrm{yr}^{-1}$.

To this sea level rise observation by altimetry, Shen *et al.* [58] points out that this is not balanced by the ice melting and thermal expansion phenomenon, and as such, they take this as an open problem in their study. However, Shen *et al.* [58] infer from their studies that the oceanic part of the Earth is expanding at a rate about $+0.40\,\mathrm{mm}\cdot\mathrm{yr}^{-1}$ and, in conclusion, when combining the expansion rates of land part and oceanic part, they (Shen *et al.* [58]) find that — at least, over the last two decades or so — the Earth has been expanding at a rate of: $\sim +0.35 \pm 0.47\,\mathrm{mm}\cdot\mathrm{yr}^{-1}$. Additionally, Shen *et al.* [58] say that if the Earth expands at this rate, then the altimetry-observed sea level rise can be well explained. The Earth expansion rate of: $\sim +0.35 \pm 0.47\,\mathrm{mm}\cdot\mathrm{yr}^{-1}$ [58], is 145% (nearly one and a half times) larger than: $\sim +0.24 \pm 0.05\,\mathrm{mm}\cdot\mathrm{yr}^{-1}$ [58], thus a welcome improvement for they that advocate for an expanding Earth.

From Shen *et al.* [43,58,59]'s recent work, it appears that those that had long and fervently written an obituary of the EEH, they may have to — not only retract them; but proceed to halt all the efforts that where currently under-way to complete the process by writing the epitaph of the EEH. In a (2018) private communication *via* email, Professor Wen-Bin Shen, has said that they have improved their results where they now find an Earth expansion rate of: $\sim +0.36 \pm 0.06\,\mathrm{mm}\cdot\mathrm{yr}^{-1}$, which is a weighted result of the landmass expansion rate: $\sim +0.45 \pm 0.05\,\mathrm{mm}\cdot\mathrm{yr}^{-1}$, and sea level raise: $\sim +0.32 \pm 0.09\,\mathrm{mm}\cdot\mathrm{yr}^{-1}$. Of these latest and very interesting findings, Professor Wenbin Shen (2018), says that they are expected to be published in the very near future.

The result: $\sim +0.36 \pm 0.06\,\mathrm{mm}\cdot\mathrm{yr}^{-1}$, takes into account the sea level rise, which apart from the global Earth expansion maybe affected by global warming due to the melting of ice in the North and South poles of the Earth. In our view, it is safe here for our purposes to consider only the landmass expansion. Thus, hereafter, we shall quote the result: $\sim +0.45 \pm 0.05\,\mathrm{mm}\cdot\mathrm{yr}^{-1}$, as representative of the present day Earth global expansion rate. This result: $\sim +0.45 \pm 0.05\,\mathrm{mm}\cdot\mathrm{yr}^{-1}$, corresponds to:

$$\frac{\delta\mathcal{R}_{\oplus}(t_0)}{\mathcal{R}_{\oplus}(t_0)} = +0.23 \pm 0.07. \tag{4}$$

At this point, we are of the view that we have not only motivated, but justified the veracity of the EEH.

In-closing this section, allow us to say that, what this reading shall do is to demonstrate that — according to the herein propounded *Expanding Earth and Solar Radiation Balance Equilibrium* model, the measured solid Earth expansion rate by Shen *at al.* (2018, private communication) given in Eq. (4), is in perfect agreement with a young faint Sun that was 75% its current luminosity during the *Archaean eon*, with an Earth endowed with (the life giving and sustaining) liquid water and steady global mean Earth surface temperatures of 288.15 K which have persistent up-until the start of the *Anthropocene epoch*[5].

[5] The *Anthropocene epoch*, is a proposed epoch of the present time, occurring since mid-20th century, when human activity began to effect significant environmental consequences, specifically on ecosystems and climate.

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4. Radiation Balance Equation

As is well known and as has already been stated — the mean global temperature of the Earth's surface has been remarkably constant over *geological epochs* and this comes mainly from isotopic considerations of Mg/Ca ratio of *foram* tests, *alkenones*[6] and especially δ^{18}O [*e.g.*, 71]. Even the dramatic cooling during the *Ice Age*[7] represented a change of only $\lesssim 1\%$, that is a $\sim 3.00\,^{\circ}$K change in the global average surface temperature, occurring over thousands of years. Seasonal changes in temperature, although large in a particular place, correspond to very tiny changes in the overall mean global temperature. To maintain this long-term temperature stability, the Earth must radiate into space a flux of energy sufficient to just balance the input from the Sun — the meaning of which is that, to a good degree of approximation, the Earth has been, and most probably is, in radiative equilibrium with the Sun's radiation that it freely receives. This situation is quite easy to fathom.

By absorbing the incoming Solar radiation, the Earth will warm up and as a consequence thereof, its temperature will rise accordingly. If say the Earth did not have an atmosphere or oceans, as is the case for example on the Moon, it would get very warm on the sunlit face of the planet, and, much colder than we experience presently, on the dark side. The modicum of warmth on the dark side would come from the paltry amount of heat stored in the ground from the sunlight of the previous daytime — this, to some extent, is, what we experience here on Earth in a cloud-free, land locked desert climate.

Further, we know that — according to Stefan [72] and Boltzmann [73]'s radiation law (hereafter Stefan-Boltzmann law); all heated objects must emit electromagnetic radiation, particularly so if they are surrounded by empty space. This radiation is referred to as the outgoing radiation. As long as the incoming radiative flux is larger than the outgoing, the radiation receiving object will continue to warm, and its temperature will continue to increase according. This in turn will result in an increase in the outgoing radiation (according to the Stefan-Boltzmann law the outgoing radiation increases faster than the temperature). At some point, the object will emit as much radiation as the amount of the incoming radiation, and, a radiative equilibrium (or balance) will be reached. The fact that the Earth has maintain and continues to maintain quasi-steady temperatures, means that the Earth is, one way or the other, in a state of equilibrium with the life giving and life sustaining Solar radiation it receives.

Now, in-order to compute this state of radiation balance between the radiant Sun and the Earth system, let: $\mathcal{L}_{\odot}(t) = 4\pi\sigma_0\mathcal{R}^2_{\odot}(t)\mathcal{T}^4_{\odot}(t)$, be the Solar luminosity at time t, with σ_0 being the usual Stephan-Boltzmann constant, $\mathcal{R}_{\odot}(t)$ the Solar radius at time t, $\mathcal{T}_{\odot}(t)$ the Solar temperature at time t; and let $r_{\oplus}(t)$ be the mean distance of planet Earth (or any given planet) from the Sun at time t. The total Solar flux: $\mathcal{F}_{\odot}(r,t)$, arriving at the spherical shell of radius r centred about the Solar center is such that:

$$\mathcal{F}_{\odot}(r,t) = \frac{\mathcal{L}_{\odot}(t)}{4\pi r^2(t)} = \sigma_0\left(\frac{\mathcal{R}_{\odot}(t)}{r_{\oplus}(t)}\right)^2\mathcal{T}^4_{\odot}(t). \tag{5}$$

The total Solar energy arriving at Earth per second [Power: $\mathcal{P}_{\oplus}(t)$] can be calculated by multiplying $\mathcal{F}_{\odot}(r,t)$ by the cross-sectional area (not the total surface area!) of the solid Earth $[\pi\mathcal{R}^2_{\oplus}(t)]$, *i.e.* the area of Solar beam intersected by the solid Earth. That is to say, $\mathcal{P}_{\oplus}(t) = \pi\mathcal{F}_{\odot}(r,t)\mathcal{R}^2_{\oplus}(t)$.

Not all Solar radiation intercepted by the Earth is absorbed by the Earth system — a good fraction of it is reflected back into space. The fraction of incident Solar radiation reflected is defined as the *albedo* and denoted by the symbol $\mathcal{A}$, and the fraction absorbed

[6] *Alkenones* are long-chain unsaturated *methyl* and *ethyl n-ketones* produced by a few *phytoplankton* species of the class *Prymnesiophyceae* [*e.g.*, 70]

[7] The *Ice Age* is believed to be a period of long-term reduction in the temperature of Earth's climate, resulting in an expansion of the continental ice sheets, polar ice sheets and mountain glaciers. There are three main types of evidence for ice ages: *geological*, *chemical*, and *paleontological*.

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by the Earth at time t is therefore $[1 - \mathcal{A}_{\oplus}(t)]$. The effective power $\mathcal{P}_{\oplus}^{\rm abs}(t)$ absorbed by the Earth system is therefore given by:

$$\mathcal{P}_{\oplus}^{\rm abs}(t) = \pi[1 - \mathcal{A}_{\oplus}(t)]\mathcal{F}_{\odot}(r,t)\mathcal{R}_{\oplus}^{2}(t). \tag{6}$$

According to the Stefan-Boltzmann law, the total energy emitted by the solid Earth per unit area is given by $\epsilon_{\oplus}\sigma_0 T_{\oplus}^{4}(t)$, where, $\epsilon_{\oplus}$ is the emissivity[8] of the solid Earth. The emitting total area is the surface area of the solid Earth, $4\pi\mathcal{R}_{\oplus}^{2}(t)$, therefore, the total energy emitted by the solid Earth per second is:

$$\mathcal{P}_{\oplus}^{\rm emit}(t) = 4\pi\epsilon_{\oplus}\sigma_0\mathcal{T}_{\oplus}^{4}(t)\mathcal{R}_{\oplus}^{2}(t). \tag{7}$$

This energy balance requires that (Incoming Radiation $=$ Outgoing Radiation) so that when averaged over eons, we will have:

$$\mathcal{P}_{\oplus}^{\rm abs}(t) = \mathcal{P}_{\oplus}^{\rm emit}(t), \tag{8}$$

thus:

$$4\pi\sigma_0 T_{\oplus}^{4}(t)\mathcal{R}_{\oplus}^{2}(r,t) = \pi[1 - \mathcal{A}_{\oplus}(t)]\mathcal{F}_{\odot}(r,t)\mathcal{R}_{\oplus}^{2}(t). \tag{9}$$

This deceptively simple looking Eq. (9) is the trivial *Solar Radiation Balance Equation*. It can be solved for the average temperature, $\mathcal{T}_{\oplus}(t)$, at which the Earth must emit radiation to bring the energy budget into balance. This temperature is called the effective temperature of the planet. *i.e.*:

$$\mathcal{T}_{\oplus}(t) = \left(\frac{[1 - \mathcal{A}_{\oplus}(t)]\mathcal{F}_{\odot}(r,t)}{4\sigma_0}\right)^{1/4}. \tag{10}$$

This Eq. (10) can further be re-written so that it reads:

$$\begin{aligned}\mathcal{T}_{\oplus}(t) &= \left(\frac{1 - \mathcal{A}_{\oplus}(t)}{4\varepsilon_{\oplus}\sigma_0}\frac{\mathcal{L}_{\odot}(t)}{4\pi r_{\oplus}^{2}(t)}\right)^{1/4} \\ &= \left(\frac{[1 - \mathcal{A}_{\oplus}(t)]\mathcal{S}_{\odot}(t)}{4\varepsilon_{\oplus}\sigma_0}\right)^{1/4}\end{aligned}, \tag{11}$$

where: $\mathcal{S}_{\odot}(t) = \mathcal{L}_{\odot}(t)/4\pi r_{\oplus}^{2}(t)$, is the *Solar constant* or *Solar irradiance* at time t, and this important quantity is measured by satellites orbiting above the Earth's atmosphere at 1.00 AU, and its current accepted value is: $1360.80 \pm 0.50\,\mathrm{W \cdot m^{-2}}$ [76].

As can be read off from column (3) of Table (1), an application of Eq. (11) to the Earth system, the effective temperature of the Earth is found to be: $\sim 255.52\,^{\circ}$K, and this temperature is: $\sim 32.53\,^{\circ}$K, below that which is actually measured for the mean global temperature, which is: $\sim 288.15\,^{\circ}$K. The: $\sim 32.53\,^{\circ}$K, discrepancy between theory and observation is usually attributed to the fact that effects such as the greenhouse effect are not included in the derivation of Eq. (11). From this same Table (1), it is seen that even for the other planets — Mercury, Venus and Mars, there exists a discrepancy between theory and observations. As is the case with the Earth system, the reason given for this discrepancy is that the derivation of Eq. (11) does not include all the processes at play. All in an effort to improve on Eq. (11), we shall in the subsequent section, give a critic of the derivation of the Solar radiation balance Eq. (11).

[8] The emissivity of the Earth shall here be assume to be unity [cf., 74,75]. Taken to the letter, this is obviously not correct because emissivity is defined as the ratio of the energy radiated from a material's surface to that radiated from a blackbody (a perfect emitter) at the same temperature, wavelength and under the same viewing conditions. This ratio varies from 0 to 1, with ($\epsilon = 1$) for a perfect blackbody and ($\epsilon = 0$) for a perfect absorber. The emissivity is dependent on the type of surface and many climate models set the value of the Earth's emissivity to 1. However, a more realistic value is ~ 0.96 [*e.g.*, 74,75].

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Table 1. Effective and Actual Temperatures of Mercury, Venus, Earth & Mars: Column (1) – (6) gives the name of the planet, its radius, orbital semi-major axis, its albedo, the actual global average temperature $\mathcal{T}_a(t_0)$, the expected global average temperature $\mathcal{T}_{pl}(t_0)$ in-accordance with Eq. (11), and the last column (7) gives the difference $[\mathcal{T}_a(t_0) - \mathcal{T}_{pl}(t_0)]$ in actual and expected global average temperatures of the listed planets.

Planet	Radius $(\mathcal{R}_\oplus)^a$	Semi-major axis $(1\text{AU})^a$	Albedo^b	$\mathcal{T}_a(t_0)$ $(°\text{K})^c$	$\mathcal{T}_{pl}(t_0)$ $(°\text{K})$	$\mathcal{T}_a(t_0) - \mathcal{T}_{pl}(t_0)$ $(°\text{K})$
Mercury	0.38	0.39	0.12	440.15	433.53	6.62
Venus	0.95	0.72	0.75	737.15	231.53	505.62
Earth	1.00	1.00	0.29	288.15	255.62	32.53
Mars	3.40	1.52	0.16	208.15	215.99	−7.84

Notes. — Adapted from: [a]https://nssdc.gsfc.nasa.gov/planetary/factsheet/index.html.
[b]http://astronomy.swin.edu.au/cosmos/A/Albedo.

5. Critic to the Radiation Balance Equation

In the derivation of the RB-Equation (10), we have one major issue, namely that — *the fact that, the Earth has an atmosphere, is not taken into account*. Our discussion on this perdurable fact will make reference to Fig. (2). It is *without any doubt whatsoever* that, we have to say: "the fact that, the Earth has an atmosphere — is not taken into account in the derivation of the RB-Equation (10)", because, only the Light rays travelling along the region $HCDG$ are considered, while those in the region $ABCH$ and $FGDE$ are not. Surely, we know that the Earth's atmosphere is a medium of higher refractive index compared to the Solar interplanetary medium, and, from our centuries collected wisdom derived from the study of the optical phenomenon through the ages, it — *obviously* — is expected that Light rays striking the boundary of the Earth's atmosphere, will be refracted into the Earth's atmosphere and once inside, these rays are trapped with only those being scattered by the Earth in a perpendicular manner along the region $HCDG$ being the ones that make it out of the Earth system into the interstellar space.

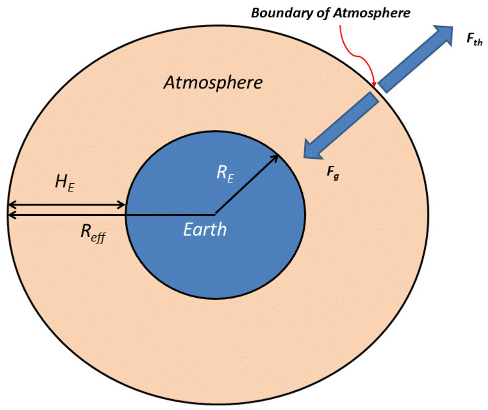

Figure 1. Effective Radius of the Earth: The boundary of the Earth's atmosphere is here defined as the surface where the Earth's gravitational force, $\boldsymbol{F}_{\text{g}}$, acting on an atmospheric molecule exactly balances the thermal force, $\boldsymbol{F}_{\text{th}}$, due to the atmospheric pressure on the molecule, *i.e.*: $\boldsymbol{F}_{\text{g}} = \boldsymbol{F}_{\text{th}}$.

5.1. New Definition of the Earth's Albedo

In this way — *i.e.*, in the new model of the Earth's atmosphere described above, the albedo of the Earth seizes to be the typical surface albedo that we are used to know — *i.e.*, the albedo which depends on the optical properties of the material forming the solid

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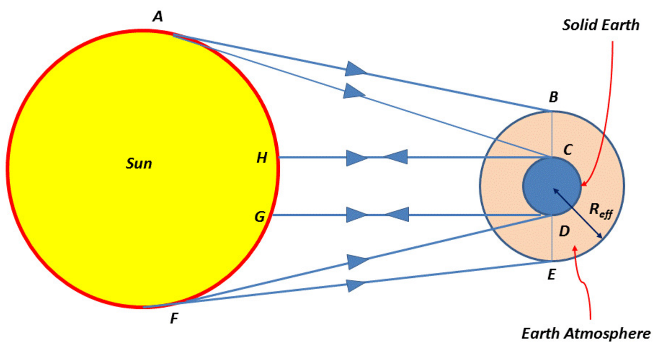

Figure 2. Diagram of Proposed Sunlight Capture of the Earth System: Sunlight striking the Earth's atmosphere will undergo a partial reflection and refraction. The refracted rays are absorbed, while the reflected ray disappears into the interstices of space. Of the Light absorbed by the Earth's atmosphere, the only Light reflected back into space by the Earth are the Photons reflected perpendicular to the surface of the Earth in the region *HCDG*.

Earth. The new albedo now simple becomes the ratio of the solid Earth's cross-sectional area to that of its atmosphere, *i.e.*:

$$\mathcal{A}_{\oplus}(t) = \frac{\mathcal{R}^2_{\oplus}(t)}{\mathcal{R}^2_{\text{eff}}(t)}. \tag{12}$$

In this way, a new model of the Earth's atmosphere is born where the Earth's atmosphere plays a central, critical and pivotal role in the much needed *sustenance* of steady mean global surface temperatures.

5.2. Effective Radius of the Earth System

If the Earth's atmosphere is not ignored but taken into account, then, the effective radiation capture radius $[\mathcal{R}_{\text{eff}}(t)]$ of the Earth system in Eq. (9) will not be equal to the radius of the solid Earth, but, will be equal to the radius of the solid Earth plus the size $\mathcal{H}^{\oplus}_{\text{atm}}(t)$ of the Earth's atmosphere — *i.e.*:

$$\mathcal{R}_{\text{eff}}(t) = \mathcal{R}_{\oplus}(t) + \mathcal{H}^{\oplus}_{\text{atm}}(t). \tag{13}$$

Figure (2) depicts this idea of an effective Earth radius that takes into account the Earth's atmosphere. Therefore, we need to make a correction for this because the atmosphere will certainly capture some radiation. In the next section, we construct a new model based on the criticism here given.

5.3. Boundary of Earth's Atmosphere

Once we talk of an atmospheric height, $\mathcal{H}^{\oplus}_{\text{atm}}(t)$, the most immediate question becomes: *What is the value of* $\mathcal{H}^{\oplus}_{\text{atm}}(t)$*?* The honest truth is that, the height of the Earth's atmosphere is not well known and most often the *Kármán line*, at $\sim 100\,\text{km}$, [*i.e.*, $0.0157\mathcal{R}_{\oplus}(t_0)$] is often used as the border between the atmosphere and outer space. This is so because atmospheric effects become noticeable during re-entry of spacecraft at an altitude of

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around $\sim 120\,\mathrm{km}$. This definition is accepted by the *Fédération Aéronautique Internationale*[9] (FAI). Be that as it may, from physics principles, we can and shall define a boundary for the Earth's atmosphere.

To that end, if — as is the case, the Earth system is a gravitationally bound system, the boundary of the Earth's atmosphere can then be defined as being the surface where the inward gravitational force, $\mathcal{F}_{\mathrm{g}}(t)$, acting on a unit mass, $m_{*}(t)$, of the Earth's atmosphere is equal to the outward thermal force, $\mathcal{F}_{\mathrm{th}}(t)$, emanating from the Earth's atmospheric thermal pressure, $\mathcal{P}_{\mathrm{atm}}^{\mathrm{min}}(t)$: where $\mathcal{P}_{\mathrm{atm}}^{\mathrm{min}}(t)$ is the atmospheric pressure at the said boundary — at time, t. The unit mass, $m_{*}(t)$, of air, is the usual *molar mass of air*, and, at present: $m_{*}(t_0) = 0.0289644\,\mathrm{kg}\cdot\mathrm{mol}^{-1}$. Of the molar mass of air, if $m_{\mathrm{atm}}(t)$ is the total mass of the Earth's atmosphere and $N_{\mathrm{atm}}(t)$ is the total number of molecules making up this atmosphere, then: $m_{*}(t) = m_{\mathrm{atm}}(t)/N_{\mathrm{atm}}(t)$.

Now — we know that:

$$\mathcal{F}_{\mathrm{g}}(t) = \frac{G\mathcal{M}_{\oplus}(t)m_{*}(t)}{\mathcal{R}_{\mathrm{eff}}^{2}(t)}, \tag{14}$$

where: G, is the usual Newtonian constant of gravitation. Further, we know that: $\mathcal{F}_{\mathrm{th}}(t) = 4\pi\mathcal{R}_{\mathrm{eff}}^{2}(t)\mathcal{P}_{\mathrm{atm}}^{\mathrm{min}}(t)/N_{\mathrm{atm}}(t)$. In general, within the bounds of the Earth's atmosphere, the pressure: $\mathcal{P}_{\mathrm{atm}}(\hbar,t)$, at height: $\hbar$, at an epoch time: t, is such that: $\mathcal{P}_{\mathrm{atm}}(\hbar,t) = \mathcal{P}_{\mathrm{atm}}^{\mathrm{surf}}(t)e^{-4\hbar/\mathcal{H}_0^{\oplus}}$, where: $\mathcal{P}_{\mathrm{atm}}^{\mathrm{surf}}(t)$, is the surface pressure and: $\mathcal{H}_0^{\oplus}(t) = k_{\mathrm{B}}\mathcal{T}_{\oplus}(t)/4m_{*}(t)g_{\oplus}^{\mathrm{surf}}(t)$, is a constant. This law $[\mathcal{P}_{\mathrm{atm}}(\hbar,t) = \mathcal{P}_{\mathrm{atm}}^{\mathrm{surf}}(t)e^{-4\hbar/\mathcal{H}_0^{\oplus}}]$, is known as the *Law of Atmospheres* and is also known as the *Barometric Law* [*e.g.*, 77]. From the foregoing, it follows that:

$$\mathcal{F}_{\mathrm{th}}(t) = \frac{4\pi\mathcal{R}_{\mathrm{eff}}^{2}(t)\mathcal{P}_{\mathrm{atm}}^{\mathrm{surf}}(t)e^{-4\mathcal{H}_{\mathrm{atm}}^{\oplus}(t)/\mathcal{H}_0^{\oplus}}}{N_{\mathrm{atm}}} \tag{15}$$

In-order to calculate: $\mathcal{P}_{\mathrm{atm}}^{\mathrm{surf}}(t)$, we know that the mass, $m_{\mathrm{atm}}^{\oplus}(t)$ of the Earth's atmosphere [see *e.g.*, 78, p.13] is related to the Earth's mean global surface pressure, $\mathcal{P}_{\mathrm{atm}}^{\mathrm{surf}}(t)$, and the Earth mean surface gravitational acceleration, $g_{\oplus}^{\mathrm{surf}}(t)$, by the following formula:

$$\mathcal{P}_{\mathrm{atm}}^{\mathrm{surf}}(t) = \frac{m_{\mathrm{atm}}^{\oplus}(t)g_{\oplus}^{\mathrm{surf}}(t)}{4\pi\mathcal{R}_{\oplus}^{2}(t)} = \frac{G\mathcal{M}_{\oplus}^{\mathrm{SE}}(t)m_{\mathrm{atm}}^{\oplus}(t)}{4\pi\mathcal{R}_{\oplus}^{4}(t)}, \tag{16}$$

where: $\mathcal{M}_{\oplus}^{\mathrm{SE}}(t)$, is the mass of the solid Earth at any given time t. Given that: $\mathcal{R}_{\oplus}(t_0) \simeq 6.40\times10^{6}\,\mathrm{m}$, $g_{\oplus}^{\mathrm{surf}}(t_0) \simeq 9.80\,\mathrm{m/s^2}$, and: $\mathcal{P}_{\mathrm{atm}}^{\mathrm{surf}}(t_0) = 101.325\,\mathrm{kPa}$, one obtains for the mass of the Earth's atmosphere: $m_{\mathrm{atm}}^{\oplus}(t_0) \simeq 5.80\times10^{18}\,\mathrm{kg}$, where *here-and-after*, t_0 represents time in the present epoch. This result: $m_{\mathrm{atm}}^{\oplus}(t_0) \simeq 5.80\times10^{18}\,\mathrm{kg}$, is the widely accepted mass of the Earth's atmosphere [see *e.g.*, 78–80].

Now, substituting: $\mathcal{P}_{\mathrm{atm}}^{\mathrm{surf}}(t)$, as given in Eq. (16), into Eq. (15), we will have:

$$\begin{aligned}\mathcal{F}_{\mathrm{th}}(t) &= \frac{G\mathcal{M}_{\oplus}^{\mathrm{SE}}(t)m_{\mathrm{atm}}^{\oplus}(t)\mathcal{R}_{\mathrm{eff}}^{2}(t)e^{-4\mathcal{H}_{\mathrm{atm}}^{\oplus}(t)/\mathcal{H}_0^{\oplus}(t)}}{N_{\mathrm{atm}}(t)\mathcal{R}_{\oplus}^{4}(t)} \\ &= \frac{G\mathcal{M}_{\oplus}^{\mathrm{SE}}(t)m_{*}(t)\mathcal{R}_{\mathrm{eff}}^{2}(t)e^{-4\mathcal{H}_{\mathrm{atm}}^{\oplus}(t)/\mathcal{H}_0^{\oplus}(t)}}{\mathcal{R}_{\oplus}^{4}(t)}\end{aligned}, \tag{17}$$

where, as afore-stated: $m_{*}(t) = m_{\mathrm{atm}}^{\oplus}(t)/N_{\mathrm{atm}}(t)$, thus from the condition that at the boundary: $\mathcal{F}_{\mathrm{g}}(t) = \mathcal{F}_{\mathrm{th}}(t)$, it follows that:

[9] Founded on Saturday 14 October 1905 and headquartered in, Lausanne — Switzerland, the *Fédération Aéronautique Internationale*, is the *World Governing Body* for air sports. The FAI maintains world records for aeronautical activities including ballooning, aeromodeling, and unmanned aerial vehicles; and also for human spaceflight. *Official Website*: https://www.fai.org/

$$\frac{\mathcal{R}_{\oplus}(t)}{\mathcal{R}_{\text{eff}}(t)} = \left(\frac{\mathcal{M}_{\oplus}(t)}{\mathcal{M}_{\oplus}^{\text{SE}}(t)}\right)^{1/4} e^{-\mathcal{H}_{\text{atm}}^{\oplus}(t)/\mathcal{H}_{0}^{\oplus}(t)}. \tag{18}$$

Considering the fact that for all intent and practically purposes: $\mathcal{M}_{\oplus}(t)/\mathcal{M}_{\oplus}^{\text{SE}}(t) \sim 1$, it follows that:

$$\mathcal{R}_{\text{eff}}(t) \simeq \mathcal{R}_{\oplus}(t) e^{\mathcal{H}_{\text{atm}}^{\oplus}(t)/\mathcal{H}_{0}^{\oplus}(t)}. \tag{19}$$

Out of interest, by making use of the definition of $\mathcal{R}_{\text{eff}}(t)$ given in Eq. (13), Eq. (19) can be re-written with $\mathcal{R}_{\oplus}(t)$ as follows:

$$\mathcal{R}_{\oplus}(t) = \frac{\mathcal{H}_{\text{atm}}^{\oplus}(t)}{e^{\mathcal{H}_{\text{atm}}^{\oplus}(t)/\mathcal{H}_{0}^{\oplus}(t)} - 1}. \tag{20}$$

In the next section, we shall now link the Earth's albedo to both the supposed expansion rate of the Earth and the changing luminosity of the Sun.

6. Remedy to the Radiation Balance Equation

In the present section, we shall now act on the criticism that we have levelled against the presently accepted Solar-Earth radiation balance model that is used to derive the RB-Equation (10), where the fact that the Earth has not just an atmosphere, but, a radiation capturing atmosphere — is not taken into account. Before we can derive this new RB-Equation, we shall in §(6.1) work on the new albedo defined Eq. (12), namely that, this geometry defined albedo is susceptible to change in the case of a changing Earth radius and atmospheric height. Thereafter in §(6.2), we proceed to derive the new radiation balance equation for the Sun-Earth system under the new proposed model. In §(6.3), we ponder on the implications of this new radiation balance equation where we use this new equation to define a new value for the albedo of the Earth, *i.e.*, an albedo that solves the 32.53 °K-discrepancy between the theoretical (255.62 °K) and observed (288.15 °K) mean global temperature.

6.1. Changing Albedo

If we are to warm-up to the idea of a gravitationally bound expanding solid Earth whose atmosphere also expands in response to the expansion of the solid Earth, then, according to Eq. (12), the albedo $\mathcal{A}_{\oplus}(t)$ will change too, *i.e.*:

$$\frac{\delta\mathcal{A}_{\oplus}(t)}{\mathcal{A}_{\oplus}(t)} = -2\left(\frac{\delta\mathcal{R}_{\text{eff}}(t)}{\mathcal{R}_{\text{eff}}(t)} - \frac{\delta\mathcal{R}_{\oplus}(t)}{\mathcal{R}_{\oplus}(t)}\right). \tag{21}$$

Since according to Eq. (13): $\mathcal{R}_{\text{eff}}(t) = \mathcal{R}_{\oplus}(t) + \mathcal{H}_{\text{atm}}^{\oplus}(t)$, it follows that:

$$\frac{\delta\mathcal{R}_{\text{eff}}(t)}{\mathcal{R}_{\text{eff}}(t)} - \frac{\delta\mathcal{R}_{\oplus}(t)}{\mathcal{R}_{\oplus}(t)} = \frac{\mathcal{H}_{\text{atm}}^{\oplus}(t)}{\mathcal{R}_{\text{eff}}(t)}\left[\frac{\delta\mathcal{H}_{\text{atm}}^{\oplus}(t)}{\mathcal{H}_{\text{atm}}^{\oplus}(t)} - \frac{\delta\mathcal{R}_{\oplus}(t)}{\mathcal{R}_{\oplus}(t)}\right]. \tag{22}$$

From Eq. (19), we also have that:

$$\frac{\delta\mathcal{R}_{\text{eff}}(t)}{\mathcal{R}_{\text{eff}}(t)} - \frac{\delta\mathcal{R}_{\oplus}(t)}{\mathcal{R}_{\oplus}(t)} = \frac{\delta\mathcal{H}_{\text{atm}}^{\oplus}(t)}{\mathcal{H}_{0}^{\oplus}(t)}\left[\frac{\delta\mathcal{H}_{\text{atm}}^{\oplus}(t)}{\mathcal{H}_{\text{atm}}^{\oplus}(t)} - \frac{\delta\mathcal{H}_{0}^{\oplus}(t)}{\mathcal{H}_{0}^{\oplus}(t)}\right] \tag{23}$$

Given that: $\mathcal{H}_{0}^{\oplus}(t) = k_{\text{B}}\mathcal{T}_{\oplus}(t)/4m_{*}(t)g_{\oplus}^{\text{surf}}(t)$, and assuming steady mean global surface temperatures over the *eons* for the Earth system, *i.e.*: $\delta\mathcal{T}_{\oplus}(t) = 0$, we will have:

$$\begin{aligned}\frac{\delta\mathcal{H}_{0}^{\oplus}(t)}{\mathcal{H}_{0}^{\oplus}(t)} &= \frac{\delta m_{\text{atm}}(t)}{m_{\text{atm}}(t)} + \frac{\delta\mathcal{M}_{\oplus}^{\text{SE}}(t)}{\mathcal{M}_{\oplus}^{\text{SE}}(t)} + 2\left(\frac{\delta\mathcal{R}_{\oplus}(t)}{\mathcal{R}_{\oplus}(t)}\right) \\ &= -\kappa\left(\frac{\delta\mathcal{R}_{\oplus}(t)}{\mathcal{R}_{\oplus}(t)}\right)\end{aligned}, \tag{24}$$

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where in this Eq. (24), we have made the reasonably good assumption: $\delta\mathcal{M}_{\oplus}^{\rm SE}(t)/\mathcal{M}_{\oplus}^{\rm SE}(t) \sim 0$, and that: $\delta m_{\rm atm}(t)/m_{\rm atm}(t) = -(2+\kappa)\delta\mathcal{R}_{\oplus}(t)/\mathcal{R}_{\oplus}(t)$, and: κ is here some dimensionless parameter yet to be determined.

Now, substituting: $\delta\mathcal{H}_0^{\oplus}(t)/\mathcal{H}_0^{\oplus}(t)$, as given in Eq. (24) into Eq. (23), we will have:

$$\frac{\delta\mathcal{R}_{\rm eff}(t)}{\mathcal{R}_{\rm eff}(t)} - \frac{\delta\mathcal{R}_{\oplus}(t)}{\mathcal{R}_{\oplus}(t)} = \frac{\mathcal{H}_{\rm atm}^{\oplus}(t)}{\mathcal{H}_0^{\oplus}(t)}\left[\frac{\delta\mathcal{H}_{\rm atm}^{\oplus}(t)}{\mathcal{H}_{\rm atm}^{\oplus}(t)} + \kappa\left(\frac{\delta\mathcal{R}_{\oplus}(t)}{\mathcal{R}_{\oplus}(t)}\right)\right]. \tag{25}$$

Further, equating the right handside of Eq. (22) to the right handside of Eq. (25), and re-arranging thereafter, we obtain:

$$\frac{\delta\mathcal{R}_{\oplus}(t)}{\mathcal{R}_{\oplus}(t)} = -\left[\frac{\mathcal{R}_{\rm eff}(t) - \mathcal{H}_0^{\oplus}(t)}{\kappa\mathcal{R}_{\rm eff}(t) + \mathcal{H}_0^{\oplus}(t)}\right]\frac{\delta\mathcal{H}_{\rm atm}^{\oplus}(t)}{\mathcal{H}_{\rm atm}^{\oplus}(t)}. \tag{26}$$

We can re-write this Eq. (26), as:

$$\frac{\delta\mathcal{H}_{\rm atm}^{\oplus}(t)}{\mathcal{H}_{\rm atm}^{\oplus}(t)} = -\left[\frac{\kappa\mathcal{R}_{\rm eff}(t) + \mathcal{H}_0^{\oplus}(t)}{\mathcal{R}_{\rm eff}(t) - \mathcal{H}_0^{\oplus}(t)}\right]\frac{\delta\mathcal{R}_{\oplus}(t)}{\mathcal{R}_{\oplus}(t)}, \tag{27}$$

thus, substituting this into Eq. (22), we will have:

$$\frac{\delta\mathcal{R}_{\rm eff}(t)}{\mathcal{R}_{\rm eff}(t)} - \frac{\delta\mathcal{R}_{\oplus}(t)}{\mathcal{R}_{\oplus}(t)} = -\frac{(1+\kappa)\mathcal{H}_{\rm atm}^{\oplus}(t)}{\mathcal{R}_{\rm eff}(t) - \mathcal{H}_0^{\oplus}(t)}\frac{\delta\mathcal{R}_{\oplus}(t)}{\mathcal{R}_{\oplus}(t)}. \tag{28}$$

We can re-write this Eq. (28), as:

$$\frac{\delta\mathcal{R}_{\rm eff}(t)}{\mathcal{R}_{\rm eff}(t)} - \frac{\delta\mathcal{R}_{\oplus}(t)}{\mathcal{R}_{\oplus}(t)} = -\frac{(1+\kappa)\xi_{\oplus}(t)}{1+\xi_{\oplus}(t) - \mathcal{H}_0^{\oplus}(t)/\mathcal{R}_{\oplus}(t)}\frac{\delta\mathcal{R}_{\oplus}(t)}{\mathcal{R}_{\oplus}(t)}, \tag{29}$$

where, $\xi_{\oplus}(t)$, is defined as:

$$\xi_{\oplus}(t) = \frac{\mathcal{H}_{\rm atm}^{\oplus}(t)}{\mathcal{R}_{\oplus}(t)}. \tag{30}$$

From Eq. (12), it follows from Eq. (30), that:

$$\mathcal{A}_{\oplus}(t) = \frac{1}{[1+\xi_{\oplus}(t)]^2}. \tag{31}$$

thus, removing $\xi_{\oplus}(t)$ in Eq. (28) through Eq. (31), we will have:

$$\frac{\delta\mathcal{R}_{\rm eff}(t)}{\mathcal{R}_{\rm eff}(t)} - \frac{\delta\mathcal{R}_{\oplus}(t)}{\mathcal{R}_{\oplus}(t)} = \frac{(1+\kappa)\left[1-\sqrt{\mathcal{A}_{\oplus}(t)}\right]}{1-\mathcal{H}_0^{\oplus}(t)\sqrt{\mathcal{A}_{\oplus}(t)}/\mathcal{R}_{\oplus}(t)}\frac{\delta\mathcal{R}_{\oplus}(t)}{\mathcal{R}_{\oplus}(t)}, \tag{32}$$

Now, assuming[10]: $\kappa \ll 1$ (or perhaps that: $\kappa \simeq 0$), and substituting this together with: $\delta\mathcal{R}_{\rm eff}(t)/\mathcal{R}_{\rm eff}(t) - \delta\mathcal{R}_{\oplus}(t)/\mathcal{R}_{\oplus}(t)$ [as given in Eq. (32)], into Eq. (21), we will have:

$$\frac{\delta\mathcal{A}_{\oplus}(t)}{\mathcal{A}_{\oplus}(t)} = \frac{2\left[1-\sqrt{\mathcal{A}_{\oplus}(t)}\right]}{1-\mathcal{H}_0^{\oplus}(t)\sqrt{\mathcal{A}_{\oplus}(t)}/\mathcal{R}_{\oplus}(t)}\frac{\delta\mathcal{R}_{\oplus}(t)}{\mathcal{R}_{\oplus}(t)}. \tag{33}$$

We now proceed to derive the new radiation balance equation.

6.2. New Radiation Balance Equation

From the resultant gravity of the criticism levelled against the RB-Equation (10), there is need for one to take into account the Earth's atmosphere. To that end, if we are to take into account the fact that the Earth has an atmosphere that this atmosphere aids in the

[10] This assumption that: $\kappa \ll 1$, implies that $\mathcal{H}_0^{\oplus}(t)$ has not changed appreciably over time [*i.e.*: $\delta\mathcal{H}_0^{\oplus}(t)/\mathcal{H}_0^{\oplus}(t) \sim 0$], it has remained constant. This assumption is not unreasonable. We will prove this in the complimentary reading: [81].

capture of some of the incoming Solar radiation, it follows that for the effective power $\mathcal{P}_{\oplus}^{\text{abs}}(r,t)$ absorbed by the Earth — instead of it being given by Eq. (6), it will be given by:

$$\mathcal{P}_{\oplus}^{\text{abs}}(r,t) = \pi[1 - \mathcal{A}_{\oplus}(t)]\mathcal{F}_{\odot}(r,t)\mathcal{R}_{\text{eff}}^2(t). \tag{34}$$

The difference between Eq. (6) and (34) is the effective radius. We have replaced $\mathcal{R}_{\oplus}$ in Eq. (6) with $\mathcal{R}_{\text{eff}}(t)$ in Eq. (34).

For the total energy emitted per unit effective surface area of the Earth, the left handside of Eq. (7) will not change, so that the new energy balance will now be given by:

$$4\pi\epsilon_{\oplus}\sigma_0\mathcal{T}_{\oplus}^4(t)\mathcal{R}_{\oplus}^2(t) = \pi[1 - \mathcal{A}_{\oplus}(t)]\mathcal{F}_{\odot}(r,t)\mathcal{R}_{\text{eff}}^2(t), \tag{35}$$

hence, Eq. (35) reduces to:

$$4\epsilon_{\oplus}\sigma_0\mathcal{T}_{\oplus}^4(t) = \left[\frac{1 - \mathcal{A}_{\oplus}(t)}{\mathcal{A}_{\oplus}(t)}\right]\frac{\mathcal{L}_{\odot}(t)}{4\pi r_{\oplus}^2(t)}. \tag{36}$$

Further, Eq. (36) reduces to:

$$\mathcal{T}_{\oplus}(t) = \left(\frac{1 - \mathcal{A}_{\oplus}(t)}{4\epsilon_{\oplus}\sigma_0\mathcal{A}_{\oplus}(t)}\right)^{\frac{1}{4}}\left(\frac{\mathcal{L}_{\odot}(t)}{4\pi r_{\oplus}^2(t)}\right)^{\frac{1}{4}}. \tag{37}$$

We can re-write this Eq. (37), as:

$$\mathcal{T}_{\oplus}(t) = \left(\frac{1 - \mathcal{A}_{\oplus}(t)}{4\epsilon_{\oplus}\mathcal{A}_{\oplus}(t)}\right)^{\frac{1}{4}}\left(\frac{\mathcal{R}_{\odot}(t)}{r_{\oplus}(t)}\right)^{\frac{1}{2}}\mathcal{T}_{\odot}(t). \tag{38}$$

The obvious difference in the revised radiation balance Eq. (37) and the original radiation balance Eq. (10), is the factor $1/\mathcal{A}_{\oplus}^{1/4}(t)$. This factor $[1/\mathcal{A}_{\oplus}^{1/4}(t)]$, together with the fact that the new (geometric) albedo changes [Eq. (33)] with respect to a change in the solid Earth's radius and as-well as a change in the atmospheric height, is all that we need in-order for a plausible solution to the *FYS-Paradox*. Before we can do that, we will first have to solve the said 32.53 °K-discrepancy between the theoretical (255.62 °K) and observed (288.15 °K) mean global temperature.

6.3. Implications

In Eq. (37), we have a new RB-Equation whose albedo is no longer the surface albedo that is determined by the physical and chemical composition of the material making up the solid Earth. The new (geometric) albedo [Eq. (12)] is now the ratio of the effective blocking surface area $[4\pi\mathcal{R}_{\oplus}^2(t)]$ to that of the total cross-sectional $[4\pi\mathcal{R}_{\text{eff}}^2(t)]$ of the Earth system. In-order to determine the new albedo, we have know the height, $\mathcal{H}_{\text{atm}}^{\oplus}(t_0)$, of the Earth's atmosphere. At present, we have no way of determining this and even if there was a way, it would be difficult in practice. However, be that as it may, we could — in theory — determine, $\mathcal{H}_{\text{atm}}^{\oplus}(t_0)$, by assuming that the present day value of the Earth's geometric albedo [as defined in Eq. (12)] is just right to give the Earth system the observed 288.15 °K- mean global surface temperature. So doing, we obtain:

$$\mathcal{A}_{\oplus}(t_0) = 0.48, \tag{39}$$

from which we obtain: $\xi_{\oplus}(t_0) = 0.45$, hence:

$$\mathcal{H}_{\oplus}(t_0) = 0.45\mathcal{R}_{\oplus}(t_0) = 2860\,\text{km}. \tag{40}$$

What is interesting about the geometric albedo [Eq. (39)] here obtained, is that it is not far off from the measured geometric albedo for the Earth system. According to Mallama *et al.* [82]'s most recent measurement, the geometric albedo of the Earth is ~ 0.43. Mallama *et al.* [82]'s measurement is a measure of the ratio of a planet's actual brightness as seen from the Light source to that of an idealized flat, fully reflecting, diffusively scattering disk with the same cross-section. It can only embolden one's confidence to know that our calculated geometric albedo is very close ($\sim$ 12% difference) to that derived from measurements where our calculated albedo has been derived on the simple requirement that our unknown albedo, must yield the observed mean global surface temperature of 288.15 °K.

Therefore, if one accepts the above suggestion to resolving the already thought to be resolved 32.53 °K-discrepancy between the theoretical (255.62 °K) and observed (288.15 °K) mean global temperature obtained using the old Eq. (11), then, what follows in the next section will be much more acceptable as a solution to the *FYS-Paradox* because the values that we have here derived, fit *hand-in-glove* like a jigsaw puzzle, with the currently measured values of the expansion of the solid Earth.

7. Earth as a Delicate Incubator

Life is not only dear but delicate and *requires steady* and *predictable conditions* for it to *flourish* — this, at least one can infer from the fact that the *Ice Age* was caused by a seemingly paltry drop of only $\lesssim 1\%$ in the mean global temperature, that is, a ~ 3.00 °K change in the global average surface temperature. What about a $\lesssim 1\%$ increase? Can this not bring about an age of heat waves as we presently are experiencing? The delicacy of life is further strengthened by the fact that evidence points to the Earth as has having maintained steady temperature over the last 3.20 ± 0.70 billions years or so. Had things been slightly or any different, perhaps, the diversity of life witnessed on Earth today may not have been. So the question persists: How did the Earth manage the *sustenance* of steady average global temperatures over such a long period of time? Surely, some subtle mechanism must have been at play and must still be at play today — *i.e.*, a mechanism that sees to it that steady average global temperatures obtain. In-order for us to explain this seemingly ponderous state of affairs of the Earth's 'mysterious' sustenance of steady average global temperatures over such a long period of time, we shall set-forth what appears to us, as, a reasonable hypothesis.

7.1. Radiation Balance Equilibrium Hypothesis

At the very least, it surely is not outrageous nor outlandish but, very much logical and imaginative, to entertain the idea that, the Earth has maintained at each point in time since the *Archaean eon*, the state [*i.e.*, Eq. (8)] of radiation balance with the Sun. Taking this as a given fact, in-order to explain the *sustenance* of steady average global temperatures since the *Archaean eon* up-till the present *Anthropocene epoch*, we can elevate Eq. (8) to the status of a hypothesis, wherein, this state of balance between the Sun's radiation and energy output of the Earth system, is a conserved state, the meaning of which is that:

$$\delta\mathcal{P}_{\oplus}^{\mathrm{abs}}(t) = \delta\mathcal{P}_{\oplus}^{\mathrm{emit}}(t). \tag{41}$$

What Eq. (41) really means or implies, is that, any change (be it positive or negative) in the Solar output power, will be met by an equal, but opposite, compensatory change in the re-radiated energy out by the Earth system — thanks to the Earth's malleable albedo which can change to suit the new radiation levels. This very important Eq. (41), we shall call the *Radiation Balance Equilibrium Hypothesis* (RBE-Hypothesis). In the next subsection, we shall evaluate this Eq. (41).

7.2. Consequence

From the foregoing, steady average global temperatures imply steady average effective global surface temperature $\mathcal{T}_{\oplus}(t)$, *i.e.*, $\delta\mathcal{T}_{\oplus}(t) = 0$, thus applying the RBE-Hypothesis to Eq. (36), it directly leads to:

$$\frac{\delta\mathcal{L}_{\odot}(t)}{\mathcal{L}_{\odot}(t)} - 2\left(\frac{\delta r_{\oplus}(t)}{r_{\oplus}(t)}\right) = \frac{\mathcal{A}_{\oplus}(t)}{1-\mathcal{A}_{\oplus}(t)}\frac{\delta\mathcal{A}_{\oplus}(t)}{\mathcal{A}_{\oplus}(t)}. \tag{42}$$

Substituting: $\delta\mathcal{A}_{\oplus}(t)/\mathcal{A}_{\oplus}(t)$, as given in Eq. (33) into Eq. (42), we will have:

$$\frac{\delta\mathcal{L}_{\odot}(t)}{\mathcal{L}_{\odot}(t)} = \frac{2\left(1-\sqrt{\mathcal{A}_{\oplus}(t)}\right)}{[1-\mathcal{A}_{\oplus}(t)]\left[1+\xi_{*}^{\oplus}(t)\sqrt{\mathcal{A}_{\oplus}(t)}\right]}\frac{\delta\mathcal{R}_{\oplus}(t)}{\mathcal{R}_{\oplus}(t)} - 2\left(\frac{\delta r_{\oplus}(t)}{r_{\oplus}(t)}\right), \tag{43}$$

where in Eq. (43), we have set: $\xi_{*}^{\oplus}(t) = \mathcal{H}_{0}^{\oplus}(t)/\mathcal{R}_{\oplus}(t)$. Since we know that: $\mathcal{H}_{0}^{\oplus}(t_0) = k_{\mathrm{B}}\mathcal{T}_{\oplus}(t_0)/4m_{*}(t_0)g_{\oplus}^{\mathrm{surf}}(t_0)$, and given that: $g_{\oplus}^{\mathrm{surf}}(t_0) = 9.80\,\mathrm{m/s^2}$, $\mathcal{T}_{\oplus}(t_0) = 288.15\,^{\circ}\mathrm{K}$, and, $m_{*}(t_0) = 0.0289644\,\mathrm{kg\cdot mol^{-1}}$, it follows that: $\mathcal{H}_{0}^{\oplus}(t) = 4.23\,\mathrm{km}$, hence:

$$\xi_{*}^{\oplus}(t_0) = 6.61\times 10^{-4}. \tag{44}$$

Alternatively, we can re-write Eq. (43) in-terms of $\delta\mathcal{R}_{\oplus}(t)/\mathcal{R}_{\oplus}(t)$, where we will have:

$$\frac{\delta\mathcal{R}_{\oplus}(t)}{\mathcal{R}_{\oplus}(t)} = \frac{[1-\mathcal{A}_{\oplus}(t)]\left[1+\xi_{*}^{\oplus}(t)\sqrt{\mathcal{A}_{\oplus}(t)}\right]}{2\left(1-\sqrt{\mathcal{A}_{\oplus}(t)}\right)}\left[\frac{\delta\mathcal{L}_{\odot}(t)}{\mathcal{L}_{\odot}(t)} - 2\left(\frac{\delta r_{\oplus}(t)}{r_{\oplus}(t)}\right)\right]. \tag{45}$$

This Eq. (45), connects the Earth's mean radial expansion rate $[\delta\mathcal{R}_{\oplus}(t)/\mathcal{R}_{\oplus}(t)]$, its geometric albedo $[\mathcal{A}_{\oplus}(t)]$, atmospheric height $[\xi_{*}^{\oplus}(t) = \mathcal{H}_{\mathrm{atm}}^{\oplus}(t)/\mathcal{H}_{0}^{\oplus}]$ and secular recession from the Sun $[\delta r_{\oplus}(t)/r_{\oplus}(t)]$, together with the Solar luminosity rate $[\delta\mathcal{L}_{\odot}(t)/\mathcal{L}_{\odot}(t)]$ in the case of an expanding Earth that maintains steady average global temperature — in short, an *Incubator Earth*. Now, after all the preparation, in the next subsection, we will present our suggested solution to the *FYS-Paradox*, where the Earth system is cast as an *auto-self-regulating incubator*.

7.3. Implications

What Eq. (45) [or Eq. (43)] implies is that, if the Earth where a delicate incubator of life as supposed in the previous section — *i.e.*, a delicate incubator that maintains steady average global temperatures *via* steady average effective global surface temperature $\mathcal{T}_{\oplus}(t)$ defined in Eq. (43), *i.e.*: $\delta\mathcal{T}_{\oplus}(t) = 0$, then, the Earth can do so for a steadily changing Solar luminosity by responding to this change in Solar luminosity *via* global radial expansion (or contraction) of the Earth. Actually, the expansion of the Earth is a natural means of *auto-self-regulating* the mean global temperatures.

Now, applying the values of: $\delta r_{\oplus}(t_0)/r_{\oplus}(t_0)$ [Eq. (2)], $\mathcal{A}_{\oplus}(t_0)$ [Eq. (39)], and, $\xi_{*}^{\oplus}(t_0)$ [Eq. (44)], into Eq. (45) for the case: $\delta\mathcal{L}_{\odot}(t_0)/\mathcal{L}_{\odot}(t_0) = +0.25$, we find that:

$$\frac{\delta\mathcal{R}_{\oplus}(t_0)}{\mathcal{R}_{\oplus}(t_0)} = +0.21. \tag{46}$$

and in-turn, this implies a present day Earth expansion rate $[\dot{\mathcal{R}}_{\oplus}(t_0)]$ of:

$$\dot{\mathcal{R}}_{\oplus}(t_0) = +0.43\pm 0.09\,\mathrm{mm\cdot yr^{-1}}. \tag{47}$$

Such an *impressive* — *yet* — *unsolicited* radial expansion rate of the solid Earth is — *at any rate imaginable* — in excellent agreement with the solid Earth's radial expansion rate as recently measured $(+0.45\pm 0.05\,\mathrm{mm\cdot yr^{-1}})$ by Shen *et al.* (2018, Private Communication). Penultimately — when all has been said and done, Shen *et al.* (2018, Private Communication)'s (almost tailor made) measurement $(+0.45\pm 0.05\,\mathrm{mm\cdot yr^{-1}})$ and the result Eq. (47), one way or the other, all but vindicate our thesis and model, so much so that, to they the poor in spirit, this is very much humbling for at the deepest level of physical and natural reality, this result is communicating to us a subtle fact to the effect that, the very life that we so cherish (and sometimes take for granted) is kept on a *knife-edge-balance* by the very *Laws of Nature*.

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8. General Discussion

Given the already highlighted [in: §(3)] controversy around the issue of whether or not the Earth is expanding, it is important that we here categorically state that: despite our '*strong belief*' [as expressed in the readings, 83,84] in the *Expanding Earth Hypothesis*, this reading has been presented in a manner that does not advocate (vouch) for either position of expansion or no-expansion. We have merely argued that the idea of an expanding Earth has a safe and acceptable place — *perhaps, an important one for that matter* — in the 'convoluted matrix' of possible solutions to this long standing paleoclimatology riddle of the *FYS-Paradox*. If anything, our suggestion is new insofar as solutions to this problem is concerned. At least in the wider literature that we have had the fortune to lay our hands, nowhere does one come across a solution to this problem that makes use of an EEH, this is a first.

The proposed model presents the expanding Earth as an auto self-regulating incubator which maintains steady average global temperatures by self-adjusting the boundary of the atmosphere. If the Earth is expanding as observations appear to indicate [43,58–65], then, the boundary of the Earth's atmosphere must also change in response to this solid Earth expansion. At present, the boundary of the Earth's atmosphere is not known with any exactitude thus making it difficult to check the proposed model. The *Kármán line* as the boundary of the Earth's atmosphere requires a solid Earth expansion rate of $\sim +2.60 \pm 0.60\,\mathrm{mm} \cdot \mathrm{yr}^{-1}$ and this is about seven times the latest Earth expansion rate measured by Shen *at al.* [58], thus making this boundary not favorable insofar as the proposed model and observations is concerned. If we hold the model to be true, then — according to the proposed model, Shen *at al.* [58]'s Earth's expansion of $\sim +0.36 \pm 0.06\,\mathrm{mm} \cdot \mathrm{yr}^{-1}$ requires an Earth's atmospheric height of $\sim 9860\,\mathrm{km}$. Invariably, what this would mean is that in the region $[120\,\mathrm{km} < \hbar_{\oplus}(t_0) \leq 2860\mathrm{km}]$, there must exist a very thing atmosphere that should be difficult to detect.

Conclusion

1. *In-principle*, the Expanding Earth Hypothesis can explain the so-called Faint Young Sun Paradox *via* an auto-self-regulating mechanism where the height of the Earth's atmosphere re-adjusts and in-turn the albedo changes in such a manner that it maintains constant average global temperatures for so long as the Earth is expanding and the Sun is getting brighter and brighter with time.

2. In-accordance with the proposed expanding Earth evolutionary model, Shen *at al.* [58,59]'s measurements of an Earth expansion of $\sim +0.45 \pm 0.05\,\mathrm{mm} \cdot \mathrm{yr}^{-1}$ require that the height of the Earth's atmosphere be $\sim 2860\,\mathrm{km}$, the invariable meaning of which is that in the supposed region $[120\,\mathrm{km} < \hbar_{\oplus}(t_0) \leq 2860\mathrm{km}]$, there must exist a very thin atmosphere which has so far escaped detection, since space rockets have not detected any atmosphere in this region *i.e.*, in the region beyond $\sim 120\,\mathrm{km}$.

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Abbreviations

The following abbreviations are used in this manuscript:

DORIS	Doppler Orbitography and Radio-positioning Integrated by Satellite
EEH	Expanding Earth Hypothesis
FSC	Fine-Structure Constant
FYS-Paradox	Faint Young Sun Paradox
GPS	Global Position System
ITRF	International Terrestrial Reference Frame
RB-Equation	Radiation Balance Equation
RBE-Hypothesis	Radiation Balance Equilibrium Hypothesis
SLR	Satellite Laser Ranging
VBLI	Very Long Baseline Interferometry

References

1. Feulner, G. The Faint Young Sun Problem. *Reviews of Geophysics* **2012**, *50*, 1–30. RG2006, doi:10.1029/2011RG000375.
2. Donn, W.L.; Donn, B.D.; Valentine, W.G. On the Early History of the Earth. *Geological Society of America Bulletin* **1965**, *76*, 287–306. doi:10.1130/0016-7606(1965)76[287:OTEHOT]2.0.CO;2.
3. Sagan, C.; Mullen, G. Earth and Mars: Evolution of Atmospheres and Surface Temperatures. *Science* **1972**, *177*, 52–56. doi:10.1126/science.177.4043.52.
4. Peck, W.H.; Valley, J.W.; Wilde, S.A.; Graham, C.M. Oxygen Isotope Ratios and Rare Earth Elements in 3.3 to 4.4 Ga Zircons: Ion Microprobe Evidence for High ffi^{18}O Continental Crust and Oceans in the Early Archean. *Geochimica et Cosmochimica Acta* **2001**, *65*, 4215–4229. doi:10.1016/S0016-7037(01)00711-6.
5. Rosing, M.T.; Rose, N.M.; Bridgwater, D.; Thomsen, H.S. Earliest Part of Earth's Stratigraphic Record: A Reappraisal of the >3.7 Ga Isua (Greenland) Supracrustal Sequence. *Geology* **1996**, *24*, 43–46. doi:10.1130/0091-7613(1996)024<0043:EPOESS>2.3.CO;2.
6. Kasting, J. Earth's Early Atmosphere. *Science* **1993**, *259*, 920–926. doi:10.1126/science.11536547.
7. Kasting, J.F. Long-Term Stability of the Earth's Climate. *Global and Planetary Change* **1989**, *1*, 83–95. doi:10.1016/0921-8181(89)90017-9.
8. Kiehl, J.T.; Dickinson, R.E. A study of the Radiative Effects of Enhanced Atmospheric CO_2 and CH_4 on Early Earth Surface Temperatures. *Journal of Geophysical Research: Atmospheres* **1987**, *92*, 2991–2998. doi:10.1029/JD092iD03p02991.
9. Bahcall, J.N.; Pinsonneault, M.H.; Basu, S. Solar Models: Current Epoch and Time Dependences, Neutrinos, and Helioseismological Properties. *ApJ* **2001**, *555*, 990–1012. doi:10.1086/321493.
10. Gough, D.O. Solar Interior Structure and Luminosity Variations. *Solar Physics* **1981**, *74*, 21–34. doi:10.1007/BF00151270.
11. Airapetian, S.V.; Glocer, A.; Gronoff, G.; Hébrard, E.; Danchi, W. Prebiotic Chemistry and Atmospheric Warming of Early Earth by an Active Young Sun. *Nature Geoscience* **2016**, *9*, 452–455. doi:10.1038/ngeo2719.
12. Marchi, S.; Black, B.A.; Elkins-Tanton, L.T.; Bottke, W.F. Massive Impact-Induced Release of Carbon and Sulfur Gases in the Early Earth's Atmosphere. *Earth and Planetary Science Letters* **2016**, *449*, 96–104. doi:10.1016/j.epsl.2016.05.032.
13. Martens, P.C. The Faint Young Sun and Faint Young Stars Paradox. *Proceedings of the International Astronomical Union* **2016**, *12*, 350–355. doi:10.1017/s1743921317004331.
14. Iorio, L. A Closer Earth and the Faint Young Sun Paradox: Modification of the Laws of Gravitation or Sun/Earth Mass Losses? *Galaxies* **2013**, *1*, 192–209. doi:10.3390/galaxies1030192.
15. Iorio, L. Gravitational Anomalies in the Solar System? *International Journal of Modern Physics D* **2015**, *24*, 1530015. doi:10.1142/S0218271815300153.
16. Wordsworth, R.; Pierrehumbert, R. Hydrogen-Nitrogen Greenhouse Warming in Earth's Early Atmosphere. *Science* **2013**, *339*, 64–67. doi:10.1126/science.1225759.
17. Angulo-Brown, F.; Rosales, M.A.; Barranco-Jiménez, M.A. The Faint Young Sun Paradox: A Simplified Thermodynamic Approach. *Advances in Astronomy* **2012**, *2012*, 1–10. doi:10.1155/2012/478957.
18. Rosing, M.T.; Bird, D.K.; Sleep, N.H.; Bjerrum, C.J. No Climate Paradox Under the Faint Early Sun. *Nature* **2010**, *464*, 744–747. doi:10.1038/nature08955.
19. Minton, D.A.; Malhotra, R. Assessing the Massive Young Sun Hypothesis to Solve the Warm Young Earth Puzzle. *AJ* **2007**, *660*, 1700. doi:10.1086/514331.
20. Sheldon, N.D. Precambrian Paleosols and Atmospheric CO_2 Levels. *Precambrian Research* **2006**, *147*, 148–155. doi:10.1016/j.precamres.2006.0
21. Hessler, A.M.; Lowe, D.R.; Jones, R.L.; Bird, D.K. A Lower Limit for Atmospheric Carbon Dioxide Levels 3.2 Billion Years Ago. *Nature* **2004**, *428*, 736–738. doi:10.1038/nature02471.
22. Kasting, J.F. Evolution of Earth's Atmosphere and Climate. AGU Fall Meeting Abstracts, 2004.
23. Sleep, N.H.; Zahnle, K. Carbon Dioxide Cycling and Implications for Climate on Ancient Earth. *Journal of Geophysical Research: Planets* **2001**, *106*, 1373–1399. doi:10.1029/2000JE001247.
24. Schneider, S.H. *Geosphere-Biosphere Interactions and Climate*; Cambridge University Press, 2011; pp. 90–91.

25. Claussen, E.; Cochran, V.A.; Davis, D.P. *Climate Change: Science, Strategies, and Solutions (Hardback): Pew Center on Global Climate Change*; BRILL ACADEMIC PUB, 2001. 373.
26. von Paris, P.; Rauer, H.; Grenfell, J.L.; Patzer, B.; Hedelt, P.; Stracke, B.; Trautmann, T.; Schreier, F. Warming the Early Earth—CO_2 Reconsidered. *Planetary and Space Science* **2008**, *56*, 1244–1259. doi:10.1016/j.pss.2008.04.008.
27. Villanueva, G.L.; Mumma, M.J.; Novak, R.E.; Kaufl, H.U.; Hartogh, P.; Encrenaz, T.; Tokunaga, A.; Khayat, A.; Smith, M.D. Strong Water Isotopic Anomalies in the Martian Atmosphere: Probing Current and Ancient Reservoirs. *Science* **2015**, *348*, 218–221. doi:10.1126/science.aaa3630.
28. Carr, M.H. Oceans on Mars: An Assessment of the Observational Evidence and Possible Fate. *Journal of Geophysical Research* **2003**, *108*. doi:10.1029/2002je001963.
29. Head, J.W.; Hiesinger, H.; Ivanov, M.A.; Kreslavsky, M.A.; Pratt, S.; Thomson, B.J. Possible Ancient Oceans on Mars: Evidence from Mars Orbiter Laser Altimeter Data. *Science* **1999**, *286*, 2134–2137. doi:10.1126/science.286.5447.2134.
30. Eyles, N.; Januszczak, N. 'Zipper-Rift': A Tectonic Model for Neoproterozoic Glaciations During the Breakup of Rodinia After 750 Ma. *Earth-Science Reviews* **2004**, *65*, 1–73. doi:10.1016/s0012-8252(03)00080-1.
31. Rye, R.; Kuo, P.H.; Holland, H.D. Atmospheric Carbon Dioxide Concentrations before 2.2 Billion Years Ago. *Nature* **1995**, *378*, 603–605. doi:10.1038/378603a0.
32. Shaviv, N.J. Toward a Solution to the Early Faint Sun Paradox: A Lower Cosmic Ray Flux from a Stronger Solar Wind. *Journal of Geophysical Research: Space Physics* **2003**, *108*, 1437(8pp.). 1437, doi:10.1029/2003JA009997.
33. Peale, S.J. Tidally Induced Volcanism. *Celestial Mechanics and Dynamical Astronomy* **2003**, *87*, 129–155. doi:10.1023/A:1026187917994.
34. Karoff, C.; Svensmark, H. How Did the Sun Affect the Climate When Life Evolved on the Earth? *arXiv e-prints (arXiv:1003.6043v1 [astro-ph.SR])* **2010**, p. 5pp, [arXiv:astro-ph.SR/1003.6043].
35. Graedel, T.E.; Sackmann, I.J.; Boothroyd, A.I. Early Solar Mass Loss: A Potential Solution to the Weak Sun Paradox. *Geophysical Research Letters* **1991**, *18*, 1881–1884. doi:10.1029/91GL02314.
36. Wood, B.E.; Müller, H.R.; Zank, G.P.; Linsky, J.L. *ApJ* **2002**, *574*, 412.
37. Gaidos, E.J.; Güdel, M.; Blake, G.A. *Geophys. Res. Lett.* **2000**, *27*, 501.
38. Guzik, J.A.; Cox, A.N. *ApJ* **1995**, *448*, 905.
39. Pitjeva, E. Values of Some Astronomical Parameters (AU, $G\mathcal{M}_\odot$, $\mathcal{M}_\odot$), their Possible Variations from Modern Observations, and Interrelations Between Them. Jourées 2011 Systèmes de Reference Spatio-Temporels; Schuh, H.; Böhm, T.N.; Capitaine, N., Eds. Vienna University of Technology, 2012, pp. 17–20. doi:10.1063/1.4921980.
40. Pitjeva, E.V.; Pitjev, N.P. Changes in the Sun's Mass and Gravitational Constant Estimated Using Modern Observations of Planets and Spacecraft. *Solar System Research* **2012**, *46*, 78–87. doi:10.1134/S0038094612010054.
41. Standish, E.M. The Astronomical Unit Now. Transits of Venus: New Views of the Solar System and Galaxy; Kurtz, D.W., Ed.; IAU, Cambridge University Press: UK, Cambridge, 2005; Vol. 103, *Proceedings IAU Colloquium*, pp. 365–372. pp.163-179, doi:10.1007/s10569-009-9203-8.
42. Krasinsky, G.A.; Brumberg, V.A. Secular Increase of Astronomical Unit from Analysis of the Major Planet Motions, and its Interpretation. *Celestial Mechanics and Dynamical Astronomy* **2004**, *90*, 267–288. doi:10.1007/s10569-004-0633-z.
43. Shen, W.B.; Sun, R.; Barkin, Y.; Shen, Z.Y. Estimation of the Asymmetric Vertical Variation of the Southern and Northern Hemispheres of the Earth. *Geodynamics and Tectonophysics* **2015b**, *6*, 45–61. doi:10.5800/gt-2015-6-1-0171.
44. Wegener, A.L. Die Entstehung der Kontinente. *Geologische Rundschau* **1912**, *3*, 276–292. Translation by [**?**], doi:10.1007/bf02202896.
45. Wegener, A.L. Die Herausbildung der Grossformen der Erdrinde (Kontinente und Ozeane), auf Geophysikalischer Grundlage **1912**. *58*, 185–195, 253–256, 305–309. Presented at the annual meeting of the German Geological Society, Frankfurt am Main (January 6, 1912).
46. Creer, K.M. An Expanding Earth? *Nature* **1965**, *205*, 539–544. doi:10.1038/205539a0.
47. Dearnley, R. Orogenic Fold-Belts and a Hypothesis of Earth Evolution. *Physics and Chemistry of the Earth* **1966**, *7*, 1–114. doi:10.1016/0079-1946(66)90002-4.
48. Egyed, L. Palæomagnetism and the Ancient Radii of the Earth. *Nature* **1961**, *190*, 1097–1098. doi:10.1038/1901097a0.
49. Heezen, B.C. The Deep-Sea Floor. In *International Geophysics*; Elsevier, 1962; pp. 235–288. doi:10.1016/b978-1-4832-2982-9.50014-0.
50. Carey, S.W. The Expanding Earth — An Essay Review. *Earth-Science Reviews* **1975**, *11*, 105–143. doi:10.1016/0012-8252(75)90097-5.
51. Jordan, P. *On the Possibility of Avording Ramsey's Hypothesis in Formulating a Theory of Earth Expansion in: Application of Modern Physics to the Earth and Planetary Interiors (N. A. T. O. Advanced Study Institute)*; John Wiley & Sons Ltd, 1969.
52. Beck, A.E. Energy Requirements of an Expanding Earth. *Journal of Geophysical Research* **1961**, *66*, 1485–1490. doi:10.1029/jz066i005p01485.
53. Cox, A.; Doell, R.R. Palæomagnetic Evidence Relevant to a Change in the Earth's Radius. *Nature* **1961**, *189*, 45–47. doi:10.1038/189045a0.
54. Hixon, H.W. Is the Earth Expanding or Contracting? Earth Physics and Considerations of Geological Phenomena. *Popular Astronomy* **1920**, *28*, 254–264.
55. Edwards, M.R. Indications from Space Geodesy, Gravimetry and Seismology for Slow Earth Expansion at Present — comment on "The Earth Expansion Theory and its Transition from Scientific Hypothesis to Pseudoscientific Belief" by Sudiro (2014). *History of Geo and Space Sciences* **2016**, *7*, 125–133. doi:10.5194/hgss-7-125-2016.
56. Sudiro, P. The Earth Expansion Theory and its Transition from Scientific Hypothesis to Pseudoscientific Belief. *History of Geo and Space Sciences* **2014**, *5*, 135–148. doi:10.5194/hgss-5-135-2014.

57. Burša, M.; Šidlichovský, M. On the Expanding Earth Hypothesis. *Studia Geophysica et Geodaetica* **1984**, *28*, 215–223. doi:10.1007/BF01589604.
58. Shen, W.B.; Shen, Z.; Sun, R.; Barkin, Y. Evidences of the Expanding Earth from Space-Geodetic Data Over Solid Land and Sea Level Rise in Recent Two Decades. *Geodesy and Geodynamics* **2015**, *6*, 248–252. doi:10.1016/j.geog.2015.05.006.
59. Shen, W.B.; Sun, R.; Chen, W.; Zhang, Z.; Li, J.; Han, J.; Ding, H. The Expanding Earth at Present: Evidence from Temporal Gravity Field and Space-Geodetic Data. *Annals of Geophysics* **2011**, *54*, 4694–4700. doi:10.4401/ag-4951.
60. Xu, C.; Sun, W. Earthquake-Origin Expansion of the Earth Inferred from a Spherical-Earth Elastic Dislocation Theory. *Geophysical Journal International* **2014**, *199*, 1655–1661. doi:10.1093/gji/ggu364.
61. Wu, X.; Collilieux, X.; Altamimi, Z.; Vermeersen, B.L.A.; Gross, R.S.; Fukumori, I. Accuracy of the International Terrestrial Reference Frame Origin and Earth Expansion. *Geophysical Research Letters* **2011**, *38*, L13304. doi:10.1029/2011GL047450.
62. Chen, Z. The Evolution Model of the Earth's Limited Expanding. *Chinese Science Bulletin* **2000**, *45*, 304–313. doi:10.1007/bf02909758.
63. Gerasimenko, M.D. Very Likely that Geodesy will Soon Resolve the Main Problem of the Earth Evolution: A Few New Facts. 1996, Proceedings of the 3th International Symposium 'Regularities of Structure and Evolution of Geospheres', pp. 3–6.
64. Gerasimenko, M.D. A Few Geodetic Arguments in the Favour of Hypothesis of Expanding Earth. *Far Eastern Math. Rep.* **1997**, pp. 69–79.
65. Gerasimenko, M.D. Modeling of the Change of Earth Dimenssions and Deformations from Space Tracking Data. Geod. Soc. Jap., 1993, Proceedings of the CRCM'93, pp. 215–217.
66. Scalera, G. Are Artificial Satellites Orbits Influenced by an Expanding Earth? *Annals of Geophysics* **2006**, *49*, 819–824. doi:10.4401/ag-3118.
67. Scalera, G. The Expanding Earth: A Sound Idea for the New Millennium, *in* 'Why Expanding Earth? A Book in Honour of Ott Hilgenberg'. Proceedings of the 3rd Lautenthaler Montanistisches Colloquium, Mining Industry Museum, May 26, 2001, Lautenthal (Germany), edited by G. SCALERA and K.-H- JACOB (INGV, 2003, pp. 181–232.
68. Scalera, G. Roberto Mantovani (1854-1933) and His Ideas on the Expanding Earth, as Revealed by His Correspondence and Manuscripts. *Annals of Geophysics* **2009**, *52*, 615–649. doi:10.4401/ag-4622.
69. Scalera, G. Non-Chaotic Emplacements of Trench-Arc Zones in the Pacific Hemisphere. *Annals of Geophysics* **1993**, *36*. doi:10.4401/ag-4241.
70. Marlowe, I.T.; Green, J.C.; Neal, A.C.; Brassell, S.C.; Eglinton, G.; Course, P.A. Long Chain ($n - C_{37} - C_{39}$) Alkenones in the Prymnesiophyceae. Distribution of Alkenones and Other Lipids and their Taxonomic Significance. *British Phycological Journal* **1984**, *19*, 203–216. doi:10.1080/00071618400650221.
71. Sigman, D.M.; Boyle, E.A. *Nature* **2000**, *407*, 859–869. doi:10.1038/35038000.
72. Stefan, J. Über die Beziehung zwischen der Wärmestrahlung und der Temperatur. *Sitzungsberichte der mathematisch-naturwissenschaftlichen Classe der kaiserlichen Akademie der Wissenschaften (Vienna Academy of Sciences)* **1879**, *79*, 391–428.
73. Boltzmann, L. Ableitung des Stefan'schen Gesetzes, betreffend die Abhängigkeit der Wärmestrahlung von der Temperatur aus der Electromagnetischen Lichttheorie. *Annalen der Physik* **1884**, *258*, 291–294. doi:10.1002/andp.18842580616.
74. Jin, M.; Liang, S. An Improved Land Surface Emissivity Parameter for Land Surface Models Using Global Remote Sensing Observations. *Journal of Climate* **2006**, *19*, 2867–2881. doi:10.1175/jcli3720.1.
75. Méndez, A.; Rivera-Valentín, E.G. The Equilibrium Temperature of Planets in Elliptical Orbits. *ApJL* **2017**, *837*, L1. doi:10.3847/2041-8213/aa5f13.
76. Kopp, G.; Lean, J.L. A New, Lower Value of Total Solar Irradiance: Evidence and Climate Significance. *Geophysical Research Letters* **2011**, *38*, L01706(7pp). doi:10.1029/2010gl045777.
77. Berberan-Santos, M.N.; Bodunov, E.N.; Pogliani, L. On the Barometric Formula. *Am. J. Phys.* **1997**, *65*, 404–412. doi:10.1119/1.18555.
78. Jacob, D.J. *Introduction to Atmospheric Chemistry*; Princeton University Press: Harvard University, 1999.
79. Trenberth, K.E.; Smith, L. The Mass of the Atmosphere: A Constraint on Global Analyses. *Journal of Climate* **2005**, *18*, 864–875. doi:10.1175/jcli-3299.1.
80. Verniani, F. The Total Mass of the Earth's Atmosphere. *Journal of Geophysical Research* **1966**, *71*, 385–391. doi:10.1029/JZ071i002p00385.
81. Nyambuya, G.G. Planetary Atmosphere Spin Theorem. *MNRAS (Submitted)* **2019**, ***, ***.
82. Mallama, A.; Krobusek, B.; Pavlov, H. Comprehensive Wide-Band Magnitudes and Albedos for the Planets, with Applications to exo-Planets and Planet Nine. *Icarus* **2017**, *282*, 19–33. doi:10.1016/j.icarus.2016.09.023.
83. Nyambuya, G.G. On the Expanding Earth and Shrinking Moon. *International Journal of Astronomy and Astrophysics* **2014**, *4*, 227–243. doi:10.4236/ijaa.2014.41020.
84. Nyambuya, G.G. Secular Increase in the Earth's LOD Strongly Implies that the Earth Might Be Expanding Radially on a Global Scale. *International Journal of Astronomy and Astrophysics* **2014**, *4*, 244–249. doi:10.4236/ijaa.2014.41021.