Unified Theory of Climate: *Reply to Comments*

Part 1: Magnitude of the Natural 'Greenhouse' Effect

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1. Introduction

Our recent paper "*Unified Theory of Climate: Expanding the Concept of Atmospheric Greenhouse Effect Using Thermodynamic Principles. Implications for Predicting Future Climate Change*" spurred intense discussions at WUWT and Tallbloke's Talkshop websites. Many important questions were raised by bloggers and two online articles by Dr. Ira Glickstein (here) and Dr. Roy Spencer (here). After reading through most responses, it became clear to us that that an expanded explanation is needed. We present our reply in two separate articles that address blog debate foci as well as key aspects of the new paradigm.

Please, consider that understanding this new theory requires a shift in perception! As Albert Einstein once noted, a new paradigm cannot be grasped within the context of an existing mindset; hence, we are constrained by the episteme we are living in. In that light, our concept requires new definitions that may or may not have exact counterparts in the current Greenhouse theory. For example, it is crucial for us to introduce and use the term *Atmospheric Thermal Effect* (*ATE*) because: (*a*) The term *Greenhouse Effect* (*GE*) is inherently misleading due to the fact that the free atmosphere, imposing no restriction on convective cooling, does not really work as a closed greenhouse; (*b*) ATE accurately conveys the physical essence of the phenomenon, which is the *temperature boost* at the surface due to the presence of atmosphere; (*c*) Reasoning in terms of ATE vs. GE helps broaden the discussion beyond radiative transfer; and (*d*) Unlike GE, the term *Atmospheric Thermal Effect* implies *no* underlying physical mechanism(s).

We start with the undisputable fact that the atmosphere provides *extra warmth* to the surface of Earth compared to an *airless* environment such as on the Moon. This prompts two basic questions: (1) *What is the magnitude of this extra warmth, i.e. the size of ATE* ? and (2) *How does the atmosphere produce it, i.e. what is the physical mechanism of ATE* ? In this reply we address the first question, since it appears to be the crux of most people's difficulty and needs a resolution before proceeding with the rest of the theory (see, for example, Lord Monckton's WUWT post).

2. Magnitude of Earth's Atmospheric Thermal Effect

We maintain that in order to properly evaluate ATE one must compare Earth's average near-surface temperature to the temperature of a spherical celestial body with *no* atmosphere at the same distance from the Sun. Note that, we are not presently concerned with the composition or infrared opacity of the atmosphere. Instead, we are simply trying to quantify the *overall* effect of our atmosphere on the surface thermal environment; hence the comparison with a similarly illuminated *airless* planet. We will hereafter refer to such planet as an equivalent Planetary Gray Body (PGB).

Since temperature is proportional (linearly related) to the internal kinetic energy of a system, it is theoretically perfectly justifiable to use *mean* global surface temperatures to quantify the ATE. There are two possible indices one could employ for this:

a) The absolute difference between Earth's mean temperature (T_s) and that of an equivalent PGB (T_{gb}), i.e. ATE = $T_s - T_{gb}$; or

b) The ratio of T_s to T_{gb}. The latter index is particularly attractive, since it normalizes (standardizes) ATE with respect to the top-of-atmosphere (TOA) solar irradiance (S_o), thus enabling a comparison of ATEs among planets that orbit at various distances from the Sun and receive different amounts of solar radiation. We call this non-dimensional temperature ratio a *Near-surface Thermal Enhancement* (ATEn) and denote it by $N_{TE} = T_s \,/\, T_{gb}$. In theory, therefore, N_{TE} should be equal or greater than 1.0 ($N_{TE} \geq 1.0$). Please, note that ATEn is a *measure* of ATE.

It is important to point out that the current GE theory measures ATE not by temperature, but by the amount of absorbed infrared (IR) radiation. Although textbooks often mention that Earth's surface is 18K-33K warmer than the Moon thanks to the 'greenhouse effect' of our atmosphere, in the scientific literature, the *actual* effect is measured via the *amount* of outgoing infrared radiation *absorbed* by the atmosphere (e.g. Stephens et al. 1993; Inamdar & Ramanathan 1997; Ramanathan & Inamdar 2006; Houghton 2009). It is usually calculated as a difference (occasionally a ratio) between the total average infrared flux emanating at the surface and that at the top of the atmosphere. Defined in this way, the average atmospheric GE, according to satellite observations, is between 157 and 161 W m^{-2} (Ramanathan & Inamdar 2006; Lin et al. 2008; Trenberth et al. 2009). In other words, the current theory uses *radiative* flux units instead of *temperature* units to quantify ATE. This approach is based on the preconceived notion that GE works by *reducing* the rate of surface infrared cooling to space. However, measuring a phenomenon with its *presumed cause* instead by its *manifest effect* can be a source of major confusion and error as demonstrated in our study. Hence, we claim that the proper assessment of ATE depends on an accurate estimate of the mean surface temperature of an equivalent PGB (T_{gb}).

2.1. Estimating the Mean Temperature of an Equivalent Planetary Gray Body

There are two approaches to estimate T_{gb} – a theoretical one based on known physical relationships between temperature and radiation, and an empirical one relying on observations of the Moon as the closest natural gray body to Earth.

According to the Stefan-Boltzmann (SB) law, any physical object with a temperature (T, ^oK) above the absolute zero emits radiation with an intensity (I, W m^{-2}) that is proportional to the 4th power of the object's absolute temperature:

$$I = \epsilon \sigma T^4 \qquad (1)$$

where ϵ is the object's thermal emissivity/absorptivity ($0 \leq \epsilon \leq 1$), and σ = 5.6704×10^{-8} W m^{-2} K^{-4} is the SB constant. A theoretical blackbody has ϵ = 1.0, while real solid objects such as rocks usually have $\epsilon \approx 0.95$. In principle, Eq. (1) allows for an accurate calculation of an object's equilibrium temperature given the amount of *absorbed* radiation by the object, i.e. $T = (I/\epsilon\sigma)^{0.25}$.

The *spatially averaged* amount of solar radiation absorbed by the Earth-Atmosphere system ($\overline{S_a}$, W m^{-2}) can be accurately computed from TOA solar irradiance (S_o) and planetary albedo (α_p) as

$$\overline{S_a} = \frac{S_o}{4}\left(1 - \alpha_p\right) \qquad (2)$$

where S_o the TOA shortwave flux (W m^{-2}) incident on a plane *perpendicular* to the solar rays. The factor ¼ serves to distribute the solar flux incident on a flat surface to a sphere. It arises from the fact that the surface area of a sphere ($4\pi R^2$) is 4 times larger than the surface area of a disk (πR^2) of the same radius (R). Hence, it appears logical that one could estimate Earth's average temperature in the absence of ATE from $\overline{S_a}$ using the SB law. i.e.

$$T_\mathrm{e} = \left[\frac{S_o\left(1 - \alpha_p\right)}{4\epsilon\sigma}\right]^{\frac{1}{4}} \qquad (3)$$

Here T_e (K) is known as the *effective emission* temperature of Earth. Employing typical values for $S_o = 1{,}362$ W m^{-2} and $\alpha_p = 0.3$ and assuming $\epsilon = 1.0$, Eq. (3) yields $T_e = 254.6$K. This is the basis for the widely quoted 255K (-18C) *mean* surface temperature of Earth *in the absence* of a 'greenhouse effect', i.e. if the atmosphere were missing or 'completely transparent' to IR radiation. This temperature is also used to define the so-called *effective emission height* in the troposphere (at about 5 km altitude), where the bulk of Earth's outgoing long-wave radiation to space is assumed to emanate from. Since Earth's mean surface temperature is 287.6K (+14.4C), the present theory estimates the size of ATE to be 287.6K - 254.6K = 33K. However, as pointed out by other studies, this approach suffers from a serious logical error. Removing the atmosphere (or even just the water vapor in it) would result in a much lower planetary albedo, since clouds are responsible for most of Earth's shortwave reflectance. Hence, one must use a different albedo (α_o) in Eq. (3) that *only* quantifies the actual surface reflectance. A recent analysis of Earth's global energy budget by Trenberth et al. (2009) using satellite observations suggests $\alpha_o \approx 0.12$. Serendipitously, this value is quite similar to the Moon bond albedo of 0.11 (see Table 1 in our original paper), thus allowing evaluation of Earth's ATE using our natural satellite as a suitable PGB proxy. Inserting α_o = 0.12 in Eq. (3) produces $T_e = 269.6$K, which translates into an ATE of only 18K (i.e. 287.6 - 269.6 = 18K).

In summary, the current GE theory employs a simple form of the SB law to estimate the magnitude of Earth's ATE between 18K and 33K. The theory further asserts that the Moon average temperature is 250K to 255K despite the fact that using the correct lunar albedo (0.11) in Eq. (3) produces ≈270K, i.e. a15K to 20K higher temperature! Furthermore, the application of Eq. (3) to calculate the *mean* temperature of a sphere runs into a fundamental *mathematical problem* caused by Hölder's inequality between non-linear integrals (e.g. Kuptsov 2001). What does this mean? Hölder's inequality applies to certain non-linear functions and states that, in such functions, the use of an arithmetic *average* for the independent (input) variable will *not* produce a correct *mean* value of the dependent (output) variable. Hence, due to a non-linear relationship between temperature and radiative flux in the SB law (Eq. 3) and the variation of absorbed radiation with latitude on a spherical surface, one *cannot* correctly calculate the mean temperature of a unidirectionally illuminated planet from the amount of *spatially averaged* absorbed radiation defined by Eq. (2). According to Hölder's inequality, the temperature calculated from Eq. (3) will *always* be significantly *higher* than the *actual* mean temperature of an airless planet. We can illustrate this effect with a simple example.

Let's consider two points on the surface of a PGB, P_1 and P_2, located at the exact same latitude (say 45°N) but at opposite longitudes so that, when P_1 is fully illuminated, P_2 is completely shaded and vice versa (see Fig. 1). If the PGB is orbiting at the same distance from the Sun as Earth and solar rays were the only source of heat to it, then the equilibrium temperature at the illuminated point would be $T_1 = [S_o (1-\alpha_o)\cos\theta/\epsilon\sigma]^{0.25}$ = 349.6K (assuming a solar zenith angle $\theta = 45°$), while the temperature at the shaded point would be T_2 = 0 (since it receives no radiation due to $\cos\theta < 0$). The *mean* temperature between the two points is then $T_m = (T_1 + T_2)/2$ = 174.8K. However, if we try using the *average radiation* absorbed by the two points $S_m = \{[S_o (1-\alpha_o)\cos\theta] + 0\}/2$ = 423.7 W m^{-2} to calculate a mean temperature, we obtain $T_e = [S_m/\epsilon\sigma]^{0.25}$ = 234.2K. Clearly, T_e is *much* greater than T_m ($T_e \gg T_m$), which is a result of Hölder's inequality.

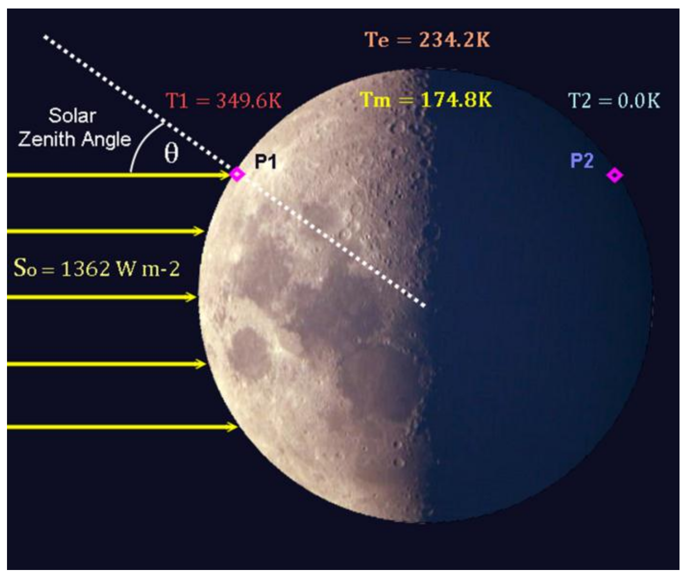

Figure 1. Illustration of the effect of Hölder's inequality on calculating the mean surface temperature of an airless planet. See text for details.

The take-home lesson from the above example is that calculating the *actual mean* temperature of an airless planet requires *explicit integration* of the SB law over the planet surface. This implies *first* taking the 4th root of the absorbed radiative flux at each point on the surface and *then* averaging the resulting temperature field rather than trying to calculate a mean temperature from a spatially averaged flux as done in Eq. (3).

Thus, we need a new model that is capable of predicting T_{gb} more robustly than Eq. (3). To derive it, we adopt the following reasoning. The equilibrium temperature T_i at any point i on the surface of an airless planet is determined by the incident solar flux, and can be approximated (assuming uniform albedo and ignoring the small heat contributions from tidal forces and interior radioactive decay) as

$$T_i = \begin{cases} \left[\dfrac{S_o\,(1-\alpha_o)}{\epsilon\sigma}\cos\theta_i\right]^{1/4} & \text{if } 0 \le \theta_i < \dfrac{\pi}{2} \\ 0 & \text{if } \dfrac{\pi}{2} \le \theta_i \le \pi \end{cases} \qquad (4)$$

where θ_i is the solar zenith angle (radian) at point i, which is the angle between solar rays and the axis normal to the surface at that point (see Fig. 1). Upon substituting $\mu = \cos\theta_i$, the planet's *mean* temperature (T_{gb}) is thus given by the spherical integral of T_i, i.e.

$$T_{gb} = \frac{1}{4\pi}\int_0^{2\pi}\int_{-1}^{1} T_i \;\mathrm{d}\mu\,\mathrm{d}\varphi$$

$$= \frac{1}{4\pi}\int_0^{2\pi}\int_0^{1} \sqrt[4]{\frac{S_o\,(1-\alpha_o)\,\mu}{\epsilon\sigma}}\;\mathrm{d}\mu\,\mathrm{d}\varphi$$

$$= \frac{1}{4\pi}\left[\frac{S_o\,(1-\alpha_o)}{\epsilon\sigma}\right]^{0.25}\int_0^{2\pi}\int_0^{1} \mu^{0.25}\;\mathrm{d}\mu\,\mathrm{d}\varphi$$

$$= \frac{2}{5}\left[\frac{S_o\,(1-\alpha_o)}{\epsilon\sigma}\right]^{0.25} \qquad (5)$$

Comparing the final form of Eq. (5) with Eq. (3) shows that $T_{gb} \ll T_e$ in accordance with Hölder's inequality. To make the above expression physically more realistic, we add a small constant c_s = 0.0001325 W m^{-2} to S_o, so that when S_o = 0.0, Eq. (5) yields T_{gb} = 2.72K (the irreducible temperature of Deep Space), i.e:

$$T_{gb} = \frac{2}{5}\left[\frac{(S_o + c_s)(1-\alpha_o)}{\epsilon\sigma}\right]^{0.25} \qquad (6)$$

In a recent analytical study, Smith (2008) argued that Eq. (5) only describes the mean temperature of a non-rotating planet and that, if axial rotation and thermal capacity of the surface are explicitly accounted for, the average temperature of an airless planet would approach the effective emission temperature T_e. It is beyond the scope of the current article to mathematically prove the fallacy of this argument. However, we will point out that increasing the *mean* equilibrium temperature of a physical body always requires a *net* input of *extra* energy. Adding axial rotation to a stationary planet residing in a vacuum, where there is no friction with the external environment does *not* provide any *additional* heat energy to the planet surface. Faster rotation and/or higher thermal inertia of the ground would only facilitate a more efficient spatial distribution of the absorbed solar energy, thus increasing the *uniformity* of the resulting temperature field across the planet surface, but could *not* affect the *average* surface temperature. Hence, Eq. (6) correctly describe (within the assumption of albedo uniformity) the global mean temperature of any airless planet, be it rotating or non-rotating.

Inserting typical values for Earth and Moon into Eq. (6), i.e. S_o = 1,362 W m-2, α_o = 0.11, and ϵ = 0.955, produces T_{gb} = 154.7K. This estimate is about 100K *lower* than the conventional black-body temperature derived from Eq. (3) implying that Earth's ATE (i.e. the GE) is *several times larger* than currently believed! Such a result, although mathematically justified, requires independent empirical verification due to its profound implications for the current GE theory. As noted earlier, the Moon constitutes an ideal proxy PGB in terms of its location, albedo, and airless environment, against which the thermal effect of Earth's atmosphere could be accurately assessed. Hence, we now turn our attention to the latest temperature observations of the Moon.

2.2. NASA's *Diviner* Lunar Radiometer Experiment

In June 2009, NASA launched its Lunar Reconnaissance Orbiter (LRO), which carries (among other instruments) a Radiometer called *Diviner*. The purpose of Diviner is to map the temperature of the Moon surface in unprecedented detail employing measurements in 7 IR channels that span wavelengths from 7.6 to 400 μm. Diviner is the first instrument designed to measure the full range of lunar surface temperatures, from the hottest to the coldest. It also includes two solar channels that measure the intensity of reflected solar radiation enabling a mapping of the lunar shortwave albedo as well (for details, see the *Diviner* Official Website at http://www.diviner.ucla.edu/).

Although the Diviner Experiment is still in progress, most thermal mapping of the Moon surface has been completed and data are available online. Due to time constraints of this article, we did not have a chance to analyze Diviner's temperature data ourselves. Instead, we elected to rely on information reported by the Diviner Science Team in peer-reviewed publications and at the Diviner website.

Data obtained during the LRO commissioning phase reveal that the Moon has one of the most extreme thermal environments in the solar system. Surface temperatures at low latitudes soar to 390K (+117C) around noon while plummeting to 90-95K (-181C), i.e. almost to the boiling point of liquid oxygen, during the long lunar night (Fig. 2). Remotely sensed temperatures in the equatorial region agree very well with direct measurement conducted on the lunar surface at 26.1° N by the Apollo 15 mission in early 1970s (see Huang 2008). In the polar regions, within permanently shadowed areas of large impact craters, Diviner has measured some of the coldest temperatures ever observed on a celestial body, i.e. down to 25K-35K (-238C to -248C). It is important to note that planetary scientists have developed detailed process-based models of the surface temperatures of Moon and Mercury some 13 years ago (e.g. Vasavada et al. 1999). These models are now being successfully validated against Diviner measurements (Paige et al. 2010b; Dr. M. Siegler at UCLA, personal communication).

What is most interesting to our discussion, however, are the *mean* temperatures at various lunar latitudes, for these could be compared to temperatures in similar regions on Earth to evaluate the size of ATE and to verify our calculations. Figure 3 depicts typical diurnal courses of surface temperature on the Moon at four latitudes (adopted from Paige et. al 2010a). Figures 4A & 4B

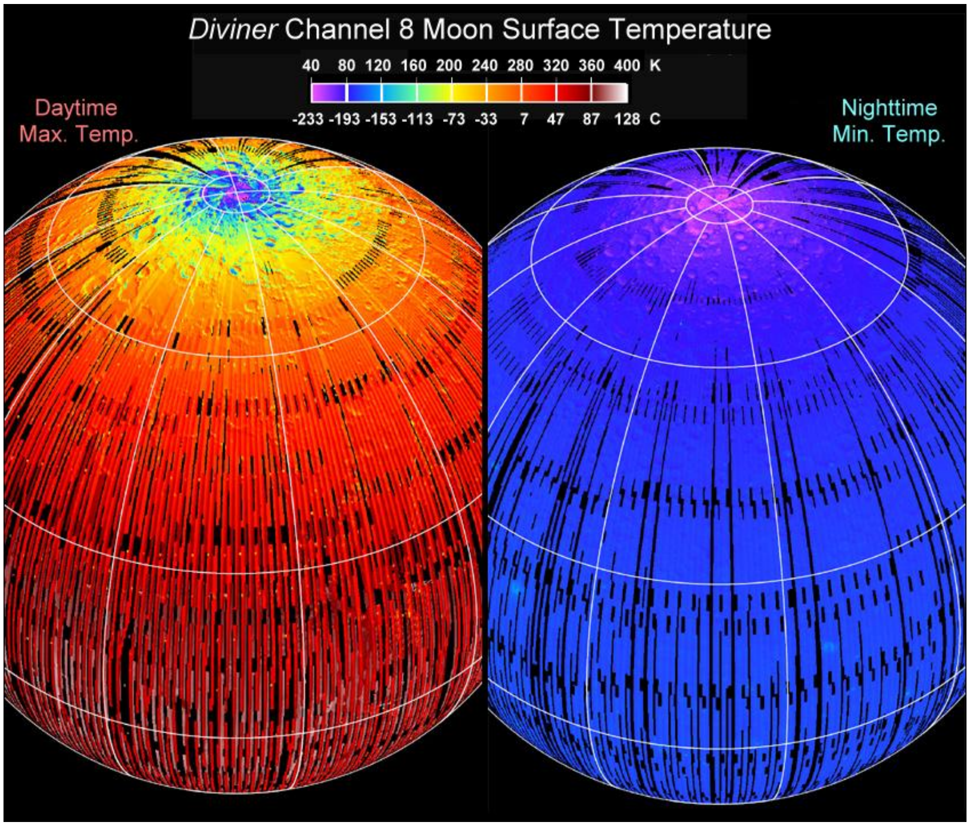

Figure 2. Thermal maps of the Moon surface based on NASA's Diviner infrared measurements showing daytime *maximum* and nighttime *minimum* temperature fields (Source: [Diviner Web Site]).

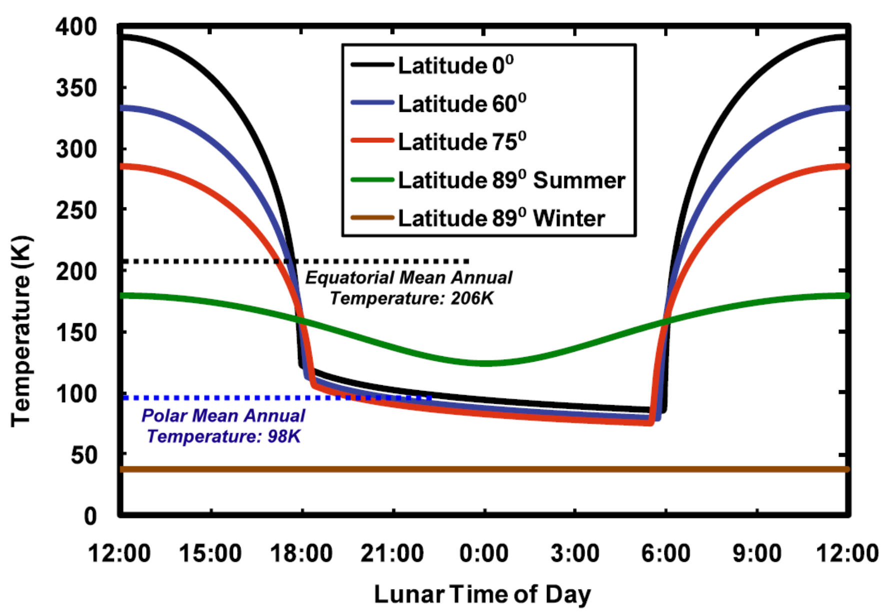

Figure 3. Typical diurnal variations of the Moon surface temperature at various latitudes. Local time is expressed in lunar hours which correspond to 1/24 of a lunar month. At 89◦ latitude, diurnal temperature variations are shown at summer and winter solstices (adopted from Paige et al. 2010a). Dashed lines indicate annual means at the lunar equator and at the poles.

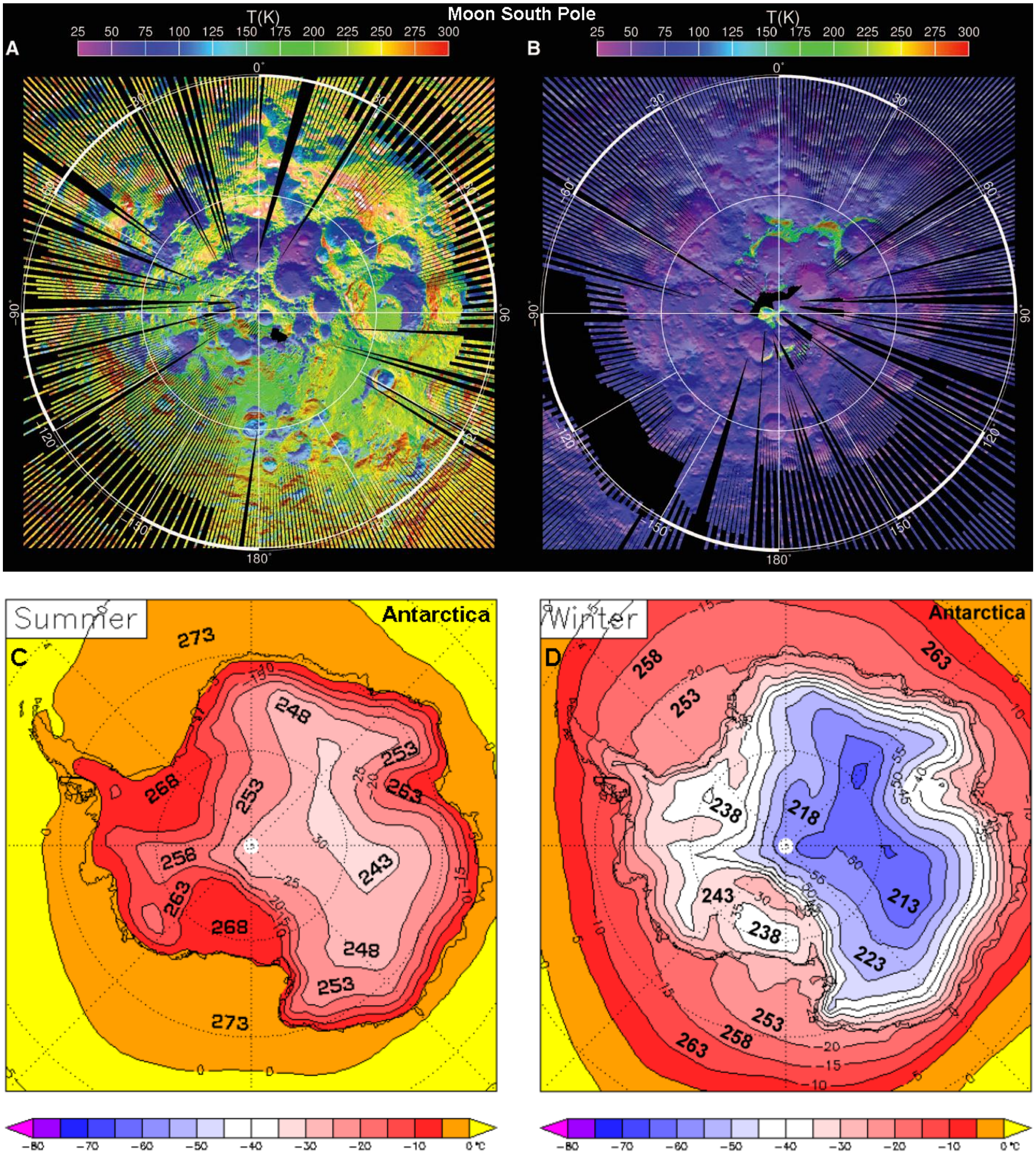

Figure 4. Temperature maps of the South Pole of the Moon and Earth: (**A**) Daytime temperature field at peak illumination on the Moon; (**B**) Nighttime temperature field on the Moon; (**C**) Mean summer temperatures over Antarctica; (**D**) Mean winter temperatures over Antarctica. Numbers shown in bold on panels (**C**) and (**D**) are temperatures in ^{o}K. Panels (**A**) and (**B**) are produced by the *Diviner* Lunar Radiometer Experiment (Paige et al. 2010b). Antarctica maps are from Wikipedia (http://en.wikipedia.org/wiki/Antarctic_climate). Comparison of surface temperatures between Moon's South Pole and Antarctica suggests a thermal enhancement by the Earth atmosphere (i.e. a 'Greenhouse Effect') of about 107K in the summer and 178K in the winter for this part of the Globe.

display temperature maps of the Moon South Pole during daytime peak illumination and at night (Paige et. al 2010b). Since the Moon has a small obliquity (axial tilt) of only 1.54° and a slow rotation, the average diurnal temperatures are similar to seasonal temperature means. These data along with information posted at the *Diviner* Science webpage indicate that *mean* temperature at the lunar-surface ranges from 98K (-175C) at the poles to 206K (-67C) at the equator. This encompasses pretty well our theoretical estimate of 154.7K for the Moon *mean global* temperature produced by Eq. (6). In the coming months, we will attempt to calculate more precisely Moon's actual mean temperature from Diviner measurements. Meanwhile, data published by NASA planetary scientists clearly show that the value 250K-255K adopted by the current GE theory as Moon's average global temperature is grossly exaggerated, since such high temperature means do *not* occur at *any* lunar latitude! Even the Moon equator is 44K - 49K cooler than that estimate. This value is inaccurate, because it is the result of an improper application of the SB law to a sphere while assuming the wrong albedo (see discussion in Section 2.1 above)!

Similarly, the mean global temperatures of Mercury (440K) and Mars (210K) reported on the NASA Planetary Fact Sheet are also *incorrect*, since they have been calculated from the same Eq. (3) used to produce the 255K temperature for the Moon. We urge the reader to verify this claim by applying Eq. (3) with data for solar irradiance (S_o) and bond albedo (α_o) listed on the fact sheet of each planet while setting $\epsilon = 1$. This is the reason that, in our original paper, we used 248.2K for Mercury, since that temperature was obtained from the theoretically correct Eq. (6). For Mars, we adopted means calculated from regional data of near-surface temperature and pressure retrieved by the Radio Science Team at Stanford University employing remote observations by the Mars Global Surveyor spacecraft. It is odd to say the least that the author of NASA's Planetary Fact Sheets, Dr. David R. Williams, has chosen Eq. (3) to calculate Mars' average surface temperature while ignoring the large body of high-quality direct measurements available for the Red Planet!?

So, what is the real magnitude of Earth's Atmospheric Thermal Effect?

Table 1. Estimated Atmospheric Thermal Effect for equator and the poles based on observed surface temperatures on Earth and the Moon and using the lunar surface as a proxy for Earth's theoretical gray body. Data obtained from Diviner's Science webpage, Paige at al. (2010b), Figure 4, and Wikipedia:Oymyakon.

Region / *Temperature Type*	Earth Temperature T_e (K)	Moon Temperature T_{gb} (K)	Atmospheric Thermal Effect $T_e - T_{gb}$ (K)
Equator, *Mean*	299	206	**93**
North Pole, *Mean*	256	98	**158**
South Pole, *Mean*	241	98	**143**
North Pole, *Record Low*	202 Oymyakon, Siberia, 1924	25 Hermite Crater	**177**
South Pole, *Record Low*	184 Vostok Station, Antarctica	29 Paige et al. (2010b)	**155**

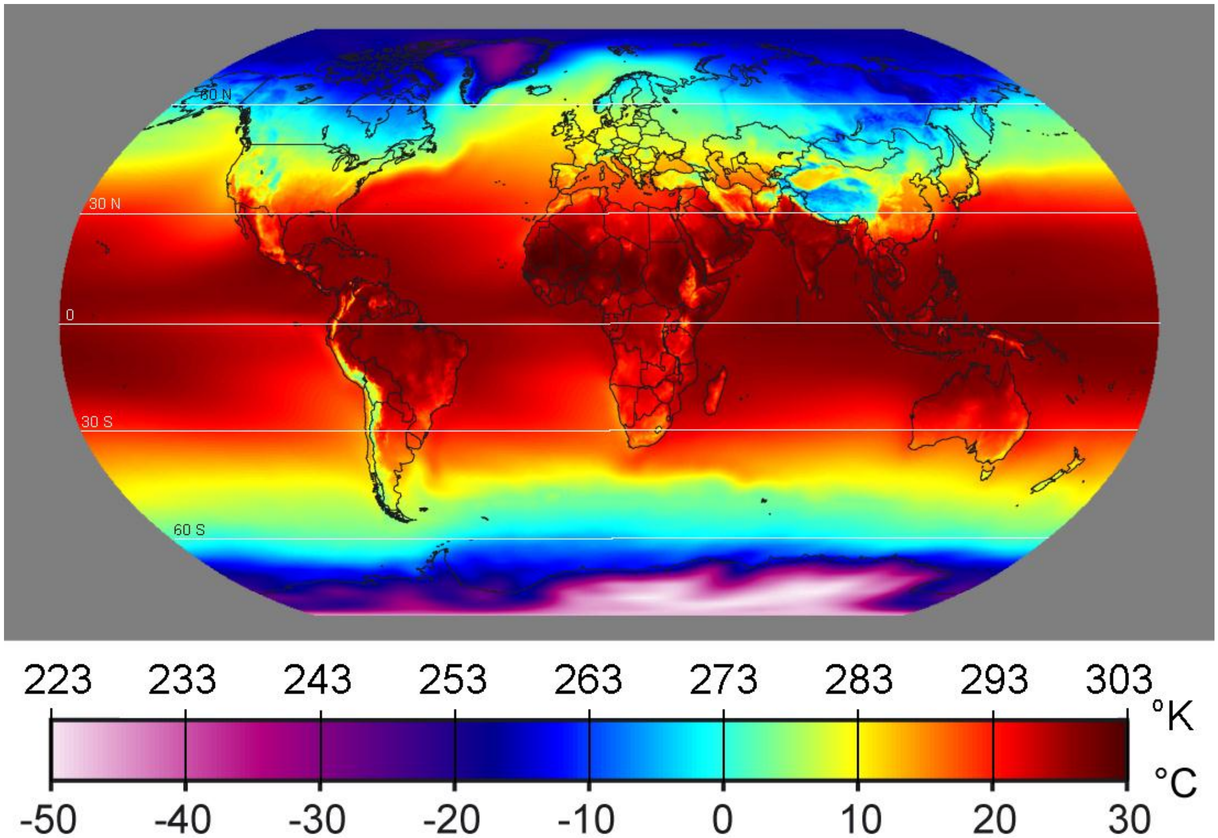

Figure 5. Earth's mean annual near-surface temperature according to Wikipedia (Geographic Zones: http://en.wikipedia.org/wiki/Geographical_zone).

Table 1 shows observed mean and record-low surface temperatures at similar latitudes on Earth and on the Moon. The ATE is calculated as a difference between Earth and Moon temperatures assuming that the Moon represents a perfect PGB proxy for Earth. Figure 5 displays a global map of Earth's mean annual surface temperatures to help the reader visually verify some of the values listed in Table 1. The results of the comparison can be summarized as follows:

The Atmospheric Thermal Effect, presently known as the natural *Greenhouse* Effect, varies from 93K at the equator to about 150K at the poles (the latter number represents an average between North- and South- Pole ATE mean values, i.e. (158+143)/2 =150.5. This range encompasses quite well our theoretical estimate of 133K for the Earth's overall ATE derived from Eq. (6), i.e. 287.6K – 154.7K = 132.9K.

Of course, further analysis of the Diviner data is needed to derive a more precise estimate of Moon's mean surface temperature and verify our model prediction. However, given the published Moon measurements, it is clear that the widely quoted value of 33K for Earth's mean ATE (GE) is profoundly misleading and wrong!

3. Conclusion

We have shown that the SB Law relating radiation intensity to temperature (Eq. 1 & 3) has been incorrectly applied in the past to predict mean surface temperatures of celestial bodies including Mars, Mercury, and the Moon. Due to Hölder's inequality between non-linear integrals, the effective emission temperature computed from Eq. (3) is always significantly higher than the actual (arithmetic) mean temperature of an airless planet. This makes the planetary *emission temperature* T_e produced by Eq. (3) *physically incompatible* with any real measured temperatures on Earth's surface or in the atmosphere. By using a proper integration of the SB Law over a sphere, we derived a new formula (Eq. 6) for estimating the average temperature of a planetary gray body (subject to some assumptions). We then compared the Moon mean temperature predicted by this formula to recent thermal observations and detailed energy budget calculation of the lunar surface conducted by the NASA Diviner Radiometer Experiment. Results indicate that Moon's average temperature is *likely* very close to the estimate produced by our Eq. (6). At the same time, Moon measurements also show that the current estimate of 255K for the lunar average surface temperature widely used in climate science is *unrealistically high*; hence, further demonstrating the inadequacy of Eq. (3). The main result from the Earth-Moon comparison (assuming the Moon is a perfect gray-body proxy of Earth) is that the Earth's ATE, also known as natural Greenhouse Effect, is 3 to 7 times *larger* than currently assumed. In other words, the current GE theory underestimates the extra atmospheric warmth by about 100K! In terms of *relative* thermal enhancement, the ATE translates into N_{TE} = 287.6/154.7 = 1.86.

This finding invites the question: How could such a huge (> 80%) thermal enhancement be the result of a handful of IR-absorbing gases that collectively amount to less than 0.5% of total atmospheric mass? We recall from our earlier discussion that, according to observations, the atmosphere only absorbs 157 - 161 W m^{-2} long-wave radiation from the surface. Can this small flux increase the temperature of the lower troposphere by more than 100K compared to an airless environment? The answer obviously is that the observed temperature boost near the surface *cannot* be possibly due to that atmospheric IR absorption! Hence, the evidence suggests that the lower troposphere contains *much more* kinetic energy than radiative transfer alone can account for! The thermodynamics of the atmosphere is governed by the Gas Law, which states that the internal kinetic energy and temperature of a gas mixture is also a function of pressure (among other things, of course). In the case of an isobaric process, where pressure is constant and independent of temperature such as the one operating at the Earth surface, it is the *physical force* of atmospheric pressure that can only *fully* explain the observed near-surface thermal enhancement (N_{TE}). But that is the topic of our next paper… Stay tuned!

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