UNIFIED THEORY OF CLIMATE

On the Physical Nature of the Atmospheric Greenhouse Effect: A New Perspective and its Implications for Understanding Climate Change

Basic Science of Climate Change
Sep 7-8, 2018
Porto, Portugal

Ned Nikolov, Ph.D. & Karl Zeller, Ph.D.
Fort Collins CO, USA; *Twitter:* @NikolovScience

1. INTRODUCTION

Recent studies revealed that Global Climate Models (GCMs) have significantly overestimated the Planet's warming since 1979 failing to predict the observed halt of global temperature rise over the past 17 years. (e.g. McKitrick et al. 2010). No consensus currently exists as to why the warming trend ceased past 1998 despite a continued increase in atmospheric CO_2 concentration. Moreover, the CO_2-temperature relationship shows significant inconsistencies across different time scales. In addition, GCM projections heavily depend on the presence of positive feedbacks, while satellite observations indicate that the climate system is likely governed by strong negative feedbacks (Lindzen & Choi 2009; Spencer & Braswell 2010). At the same time, there is a mounting political pressure for Cap-and-Trade legislation and a global carbon tax, while scientists and entrepreneurs propose *geo-engineering* solutions to cool the Planet involving large-scale physical manipulation of the upper atmosphere. This situation calls for a thorough reexamination of the present climate-change paradigm; hence, the reason for our study.

2. THE GREENHOUSE EFFECT: REEXAMINING THE BASICS

According to current theory, the natural Greenhouse Effect (GE) is a *radiative phenomenon* caused by heat-trapping gases in the atmosphere such as CO_2 and water vapor assumed to *reduce* the rate of surface infrared cooling to space by *absorbing* outgoing long-wave (LW) emissions and *re-radiating* part of them *back*, thus increasing the total energy flux toward the surface. This is thought to boost the Earth's temperature by 18K—33K compared to a gray body with no absorbent atmosphere such as the Moon; hence making our Planet habitable. Figure 1 illustrates this concept using a simple two-layer system known as the Idealized Greenhouse Model (IGM). In this popular example, S is the TOA solar irradiance, A is the Earth shortwave albedo, T_s is the surface temperature, T_e is the Earth's *effective emission* temperature often equated with the mean temperature of middle troposphere, ϵ is emissivity, and σ is the Stefan-Boltzmann (S-B) constant.

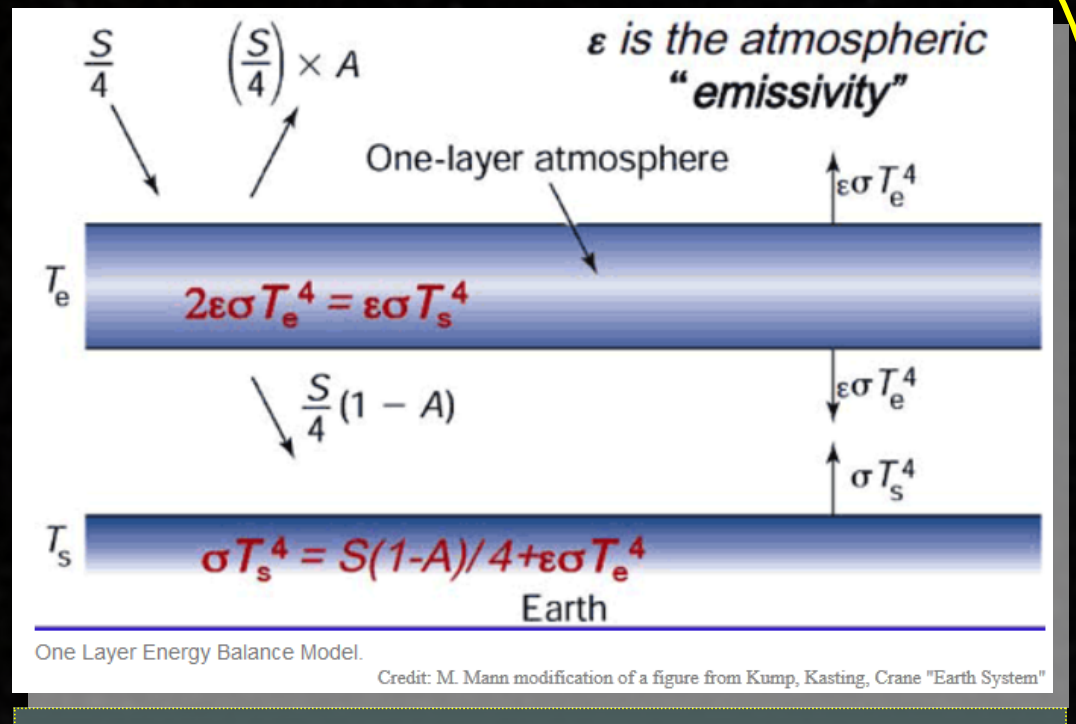

Figure 1. The *Greenhouse Effect* as taught at Universities around the World (diagram from the website of the Penn State University's Department of Meteorology).

2.1. Issues with the Current GE Concept:

A) Magnitude of the Natural Greenhouse Effect. GE is often quantified as a difference between Earth's actual *mean* global surface temperature (T_s = 287.4 K) and *average* temperature of our planet without an atmosphere (T_{gb}), i.e. GE = $T_s - T_{gb}$. In the current theory, T_{gb} is equated with the effective radiating temperature (T_e) calculated from the S-B law using Eq. (1). However, this is mathematically *incorrect* (Volokin & ReLleez 2014). Due to Hölder's inequality between integrals, T_e is not a physical temperature for a sphere, and it is incompatible with any *measurable* temperatures on an airless planet. To be correct T_{gb} must be calculated via spherical integration of the planetary temperature field using Eq. (2) instead, where S_o is the solar irradiance, μ is the cosine of incident solar angle, α_{gb} is the average surface albedo, and η_e = 0.00971 is the fractional regolith heat storage. Due to with Hölder's inequality, $T_{gb} \ll T_e$. As a result, GE is *much larger* than 33 K. Equation (2) reveals that our atmosphere boosts Earth's mean surface temperature by 90.5 K. This raises the question: *Can a handful of atmospheric trace gases (< 0.5%) trap enough radiant heat to cause such a huge thermal enhancement at the surface ?* Thermodynamics tells us that this not possible.

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

$$T_{gb} = \frac{1}{4\pi}\int_0^{2\pi}\left\{\int_0^1\left[\frac{(1-\eta_e)\,S_o(1-\alpha_{gb})\,\mu}{\epsilon\sigma}\right]^{\frac{1}{4}}d\mu + \int_{-1}^{0}\left[\frac{-\eta_e\,S_o(1-\alpha_{gb})\mu}{\epsilon\sigma}\right]^{\frac{1}{4}}d\mu\right\}d\varphi = \frac{2}{5}\left[\frac{S_o(1-\alpha_{gb})}{\epsilon\sigma}\right]^{0.25}\left[(1-\eta_e)^{0.25}+0.932\,\eta_e^{0.25}\right] \qquad (2)$$

B) The Role of Convection. The conceptual model in Fig. 1 can be mathematically described by the *simultaneous* Equations (3), where ν_a is the atmospheric fraction of total shortwave absorption. Figure 2 depicts the solution to Eq. (3) for a range of atmospheric emissivity (ϵ) assuming S_o = 1361 W m^{-2} and ν_a =0.326 (Trenberth et al. 2009). Increase atmospheric emissivity does *indeed* cause a warming at the surface as stated by the current theory. However, Eq. (3) is *physically incomplete*, because it does *not* account for convection, which occurs *simultaneously* with radiative transfer. Adding a convective term to (3) (i.e. Eq. 4) dramatically alters the solution by collapsing the difference between T_s, T_a and T_e virtually erasing the GE (Fig. 3.)

$$\begin{cases}\frac{S_o}{4}(1-\alpha_p)(1-\nu_a)+\epsilon\sigma T_a^4-\sigma T_s^4=0\\ \frac{S_o}{4}(1-\alpha_p)\nu_a+\epsilon\sigma T_s^4-2\epsilon\sigma T_a^4=0\end{cases} \qquad (3)$$

$$\begin{cases}\frac{S_o}{4}(1-\alpha_p)(1-\nu_a)+\epsilon\sigma T_a^4-\sigma T_s^4-c_p\rho(T_s-T_a)g_{bH}=0\\ \frac{S_o}{4}(1-\alpha_p)\nu_a+\epsilon\sigma T_s^4+c_p\rho(T_s-T_a)g_{bH}-2\epsilon\sigma T_a^4=0\end{cases} \qquad (4)$$

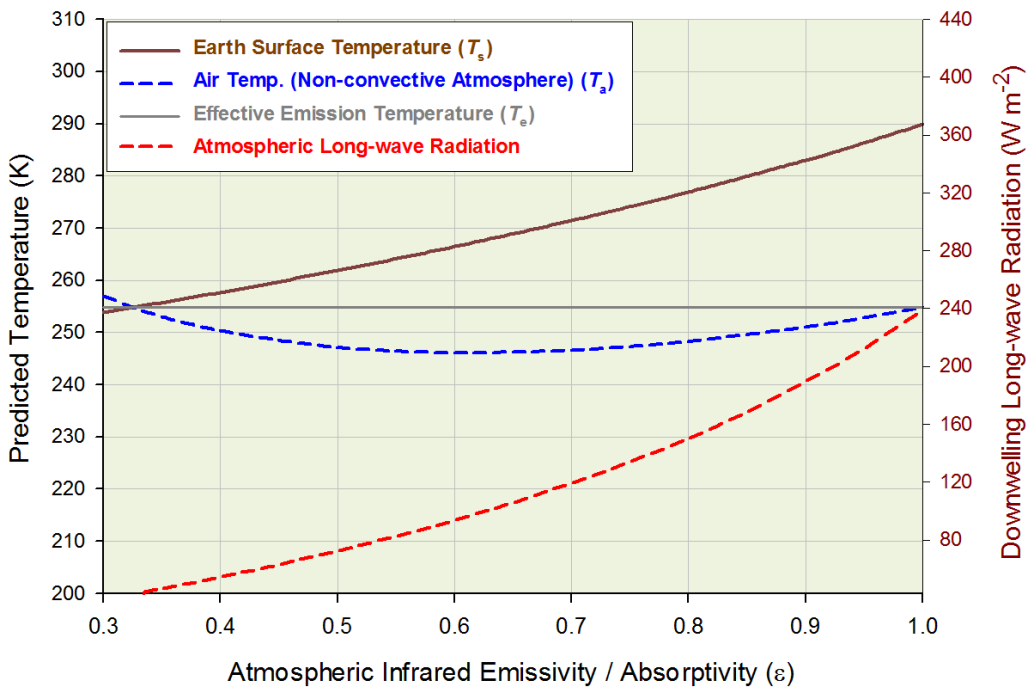

Figure 2. Solution to the two-layer model in Eq. 3 for T_s and T_a as a function of atmospheric emissivity assuming a *non-convective* atmosphere. Also shown is the predicted down-welling LW flux, $L_d \le$ 239 W m^{-2}.

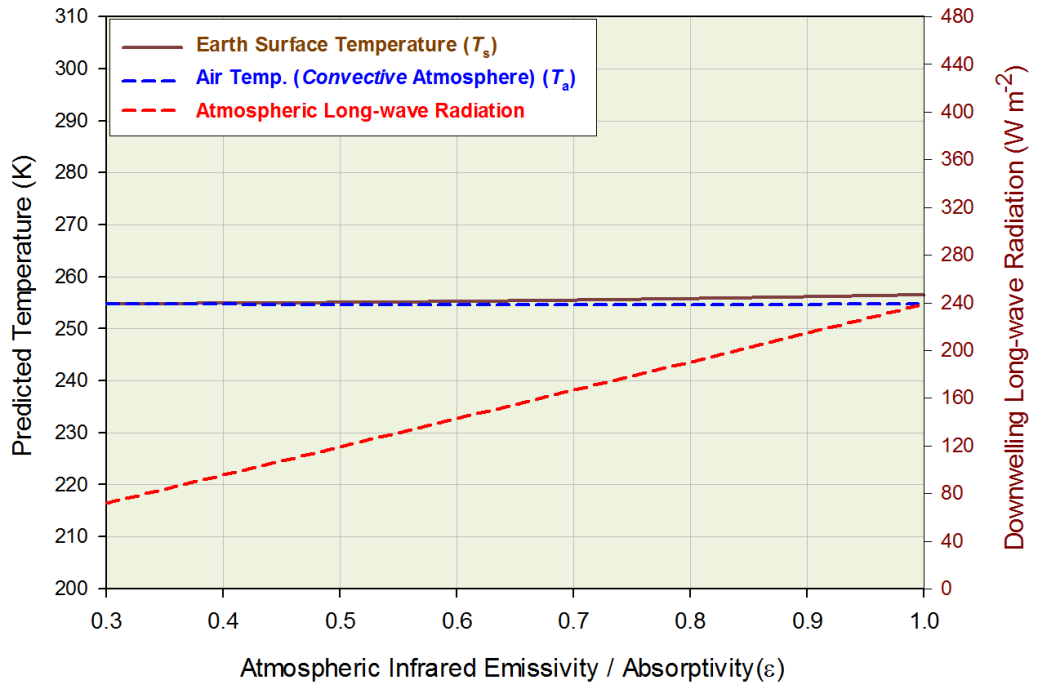

Figure 3. Solution to the two-layer model in Eq. 4 for T_s and T_a as a function of atmospheric emissivity assuming a *convective* atmosphere. Also shown is the predicted down-welling LW flux, $L_d \le$ 239 W m^{-2}.

This occurs because convective cooling is *orders* of magnitude *more efficient* that radiative cooling. These results do not change when using a multi-layer model. In radiative transfer (RT) models, T_s increases with ϵ *not* as a result of heat trapping by greenhouse gases, but due to the *lack* of convective terms in the RT system of equations. Modern GCMs do *not* solve *simultaneously* for radiative transfer and convection. Such a *decoupling* of the combined heat/radiative transport is the *core* reason for the projected surface warming by GCMs in response to increasing tropospheric greenhouse-gas concentrations.

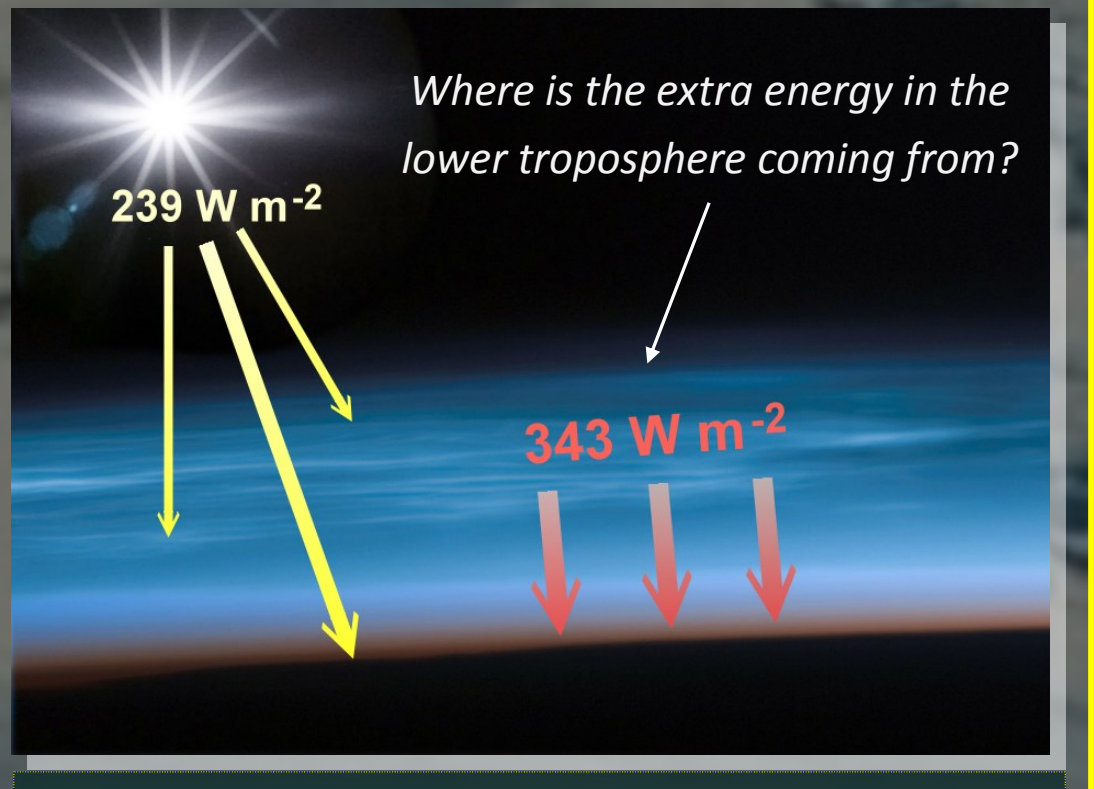

Figure 4. According to observations, the Earth-Atmosphere System absorbs on average a net solar flux of 239 W m^{-2}, while the lower troposphere alone emits 343 W m^{-2} thermal radiation toward the surface.

C) Evidence for Extra Kinetic Energy in the Troposphere. Observations show (Stephens et al. 2012) that the down-welling LW radiation emitted from the lower troposphere exceeds the total solar flux absorbed by the Earth-Atmosphere System some 44% (Fig. 4). This implies that the lower atmosphere contains *more* kinetic energy than supplied by the Sun. Radiative transfer alone cannot explain this paradox, which points to the presence of a non-radiative thermal enhancement in the lower troposphere.

3. ATMOSPHERIC THERMAL ENHANCEMENT (ATE)

Previous studies have noted that the term *Greenhouse Effect* is a misnomer when applied to the atmosphere, since real greenhouses retain heat through an entirely different mechanism compared to the free atmosphere, i.e. by physically trapping air masses and restricting convective heat exchange. Hence, we propose a new term instead, *Near-surface Atmospheric Thermal Enhancement* (ATE) defined as a *non-dimensional ratio* (N_{TE}) of the planet actual mean surface air temperature (T_s, K) to the average temperature of an equivalent airless body (T_{gb}, K) receiving the *same* solar irradiance, i.e. $N_{TE} = T_s / T_{gb}$. This new definition emphasizes the essence of GE, i.e. the *temperature boost* at the surface due to the presence of an atmosphere. To estimate T_{gb} we employed Eq. (2) assuming an airless albedo α_{gb} = 0.136 and a surface emissivity ϵ = 0.98 based on Moon data provided by NASA Diviner Experiment. Using S_o = 1361 W m^{-2} (Kopp & Lean 2011) in Eq. (2) yields T_{gb} = 197.1 K and N_{TE} = 287.4/197.1 = 1.46 for Earth. This prompts the question: *What mechanism enables our atmosphere to boost the planet surface temperature some 46% above that of an equivalent airless body such as the Moon ?*

3.1. Climate Implications of the Ideal Gas Law

The average thermodynamics of most planetary atmospheres is well described by the Ideal Gas Law (IGL):

$$PV = nRT \qquad (5)$$

where P is pressure (Pa), V is the gas volume (m^3), n is the gas amount (mole), R = 8.314 J K^{-1} mol^{-1} is the universal gas constant, and T is the gas temperature (K). Equation (5) has three characteristics that are chiefly important to this discussion: *a)* the product $P \times V$ defines the internal *kinetic* energy of a gas that produces its temperature; *b)* the linear relationship in Eq. (5) guarantees that an *average* global temperature can *accurately* be estimated from planetary *means* of surface pressure and air volume (or density) in contrast to the non-linear relationship between temperature and radiative fluxes in Eq. (1) ; *c)* on a planetary scale, pressure of the lower troposphere is effectively an *independent* variable in Eq. (5), since it is only a function of gravity (g), total atmospheric mass (M_{at}), and surface area (A_s), i.e. $P_s = g\,M_{at}/A_s$. Hence, over non-geological time scales, the near-surface atmospheric dynamics is governed by *nearly isobaric* processes on average, i.e. processes operating under nearly *constant* pressure. This isobaric tropospheric thermodynamics implies that the average atmospheric volume varies in a *fixed* proportion with changes to average surface air temperature following the Charles/Gay-Lussac Law, i.e. T_s/V = const. This can be written in terms of the average air density ρ (kg m^{-3}) as

$$\rho T_s = \text{const.} = P_s\,M\,/\,R \qquad (6)$$

where P_s is the mean surface air pressure (Pa) and M is the molecular mass of air (kg mol^{-1}). Eq. (6) reveals an important characteristic of the average thermodynamic process near the surface, i.e. a variation of global pressure due to either an increase or a decrease of total atmospheric mass will alter *both* temperature and atmospheric density. What is presently unknown, however, is the *differential effect* of a global pressure change on each variable. We offer a solution to this in Section 3.3. Equations (5) and (6) imply that pressure *directly* controls the kinetic energy and temperature of an atmosphere. Under equivalent solar insolation, a higher surface pressure (resulting from a larger atmospheric mass) would produce a warmer troposphere, while a lower pressure would result in a cooler troposphere. At the limit, a zero pressure would yield the planet's *airless* surface temperature.

The thermal effect of pressure is demonstrated on a cosmic scale by the process of star formation, where gravity-induced rise of gas pressure boosts the temperature of an interstellar cloud to the threshold of a nuclear fusion. At a planetary scale, the effect is manifest in Chinook (foehn) winds, where an *adiabatically* heated downslope airflow can raise local temperature by 20-30 C in a matter of hours. This prompts a question: *Could air pressure be responsible for the observed thermal enhancement at the Earth surface presently known as a 'Natural Greenhouse Effect'?* To answer this we must analyze the relationship between N_{TE} and key atmospheric variables including pressure over a *wide* range of planetary environments. Fortunately, our solar system offers a suitable spectrum of celestial bodies for such an analysis.

3.2. Planetary Data Set

Planetary bodies were selected for our analysis based on three criteria: 1) presence of a solid surface with at least traces of atmosphere; 2) availability of reliable data on surface temperature, total pressure, atmospheric composition etc. preferably from direct measurements; and 3) representation of a wide range of atmospheric and radiative conditions. This approach resulted in the selection of three planets, i.e. *Venus, Earth,* and *Mars*, and three natural satellites - *Moon* of Earth, *Titan* of Saturn, and *Triton* of Neptune. Each celestial body was described by 8 parameters listed in Table 1.

Table 1. Planetary data used to analyze the physical nature of the Atmospheric Near-Surface Thermal Enhancement (N_{TE}). Information was gathered from multiple official sources using cross-referencing. The bottom three rows of data were estimated as part of this study using equations discussed in the text.

Parameter	Venus	Earth	Moon	Mars	Titan	Triton
Average distance to the Sun, (AU)	0.7233	1.0	1.0	1.5237	9.582	30.070
TOA average solar irradiance, (W m^{-2})	2,601.3	1,360.9	1,360.9	586.2	14.8	1.5
Bond albedo, (decimal fraction)	0.900	0.294	0.136	0.250	0.265	0.650
Global average atmospheric surface pressure (Pa)	9,300,000.0 ± 100,000	98,550.0 ± 6.5	2.96×10^{-10} ± 10^{-9}	685.4 ± 14.2	146,700.0 ± 100	4.0 ±1.2
Average near-surface atmospheric density, (kg m^{-3})	65.868 ± 0.44	1.193 ± 0.002	2.81×10^{-15} ±9.4×10^{-15}	0.019 ± 3.2×10^{-4}	5.161 ± 0.03	3.45×10^{-4} ± 9.2×10^{-5}
Chemical composition of the lower atmosphere (% of volume)	96.5 CO_2 3.48 N_2 0.02 SO_2	77.89 N_2 20.89 O_2 0.932 Ar 0.248 H_2O 0.040 CO_2	26.7 ^{4}He 26.7 ^{20}Ne 23.3 H_2 20.0 ^{40}Ar 3.3 ^{22}Ne	95.32 CO_2 2.70 N_2 1.60 Ar 0.13 O_2 0.08 CO 0.021 H_2O	95.1 N_2 4.9 CH_4	99.91 N_2 0.060 CO 0.024 CH_4
Molar mass of the lower atmosphere, (kg mol^{-1})	0.0434	0.0289	0.0156	0.0434	0.0274	0.0280
Observed Global Mean Annual Surface Temperature (K)	737.0 ± 3.0	287.4 ± 0.5	197.35 ± 0.9	190.56 ± 0.7	93.7 ± 0.6	39.0 ± 1.0

The airless surface temperature of each body was estimated from Eq. (2) using published data on solar irradiance for that body and assuming α_{gb} = 0.13, η_e = 0.00971, and ϵ = 0.98 (based on NASA data from the Moon). The mean surface temperature and air pressure of Mars were calculated from Viking observations and remote sensing data retrieved via radio occultation by the Radio Science Team (RST) at Stanford University using observations by the Mars Global Surveyor (MGS) spacecraft between 1999 and 2005.

REFERENCE:

Nikolov N, Zeller K (2017) New insights on the physical nature of the atmospheric greenhouse effect deduced from an empirical planetary temperature model. *Environ Pollut Climate Change* 1: 112. doi:10.4172/2573-458X.1000112

3.3. Physical Nature of ATE (GE)

A dimensional analysis of the interplanetary data in Table 1 yielded no meaningful relationships between ATE (N_{TE}) and variables such as total absorbed solar radiation or the amount of greenhouse gases in planetary atmospheres. However, we discovered that the T_s / T_{gb} ratio was strongly related to the total atmospheric surface pressure (P) with a nearly perfect regression fit (Fig. 5) via the following nonlinear function:

$$\frac{T_s}{T_{gb}} = \exp\left[0.174205\left(\frac{P}{P_r}\right)^{0.150263} + 1.83121\times10^{-5}\left(\frac{P}{P_r}\right)^{1.04193}\right] \qquad (7)$$

where P_r is a reference pressure (triple-point of water). The tight relationship in Fig. 5 suggests a *causal* effect of pressure on N_{TE}, which is theoretically supported by the Gas Law. Also, the P_s-N_{TE} curve in Fig. 5 strikingly resembles the response of the temperature/potential temperature ratio (T/θ) to altitudinal changes of pressure described by the well-known Poisson formula derived from IGL (Fig. 6). Such a similarity in responses indicates that both N_{TE} and θ embody the effect of a pressure-controlled *adiabatic* heating, even though the two mechanisms are physically quite different. This leads to a logical conclusion that the so-called '*Natural Greenhouse Effect*' is in fact a *Pressure-induced Thermal Enhancement* (PTE) independent of atmospheric composition.

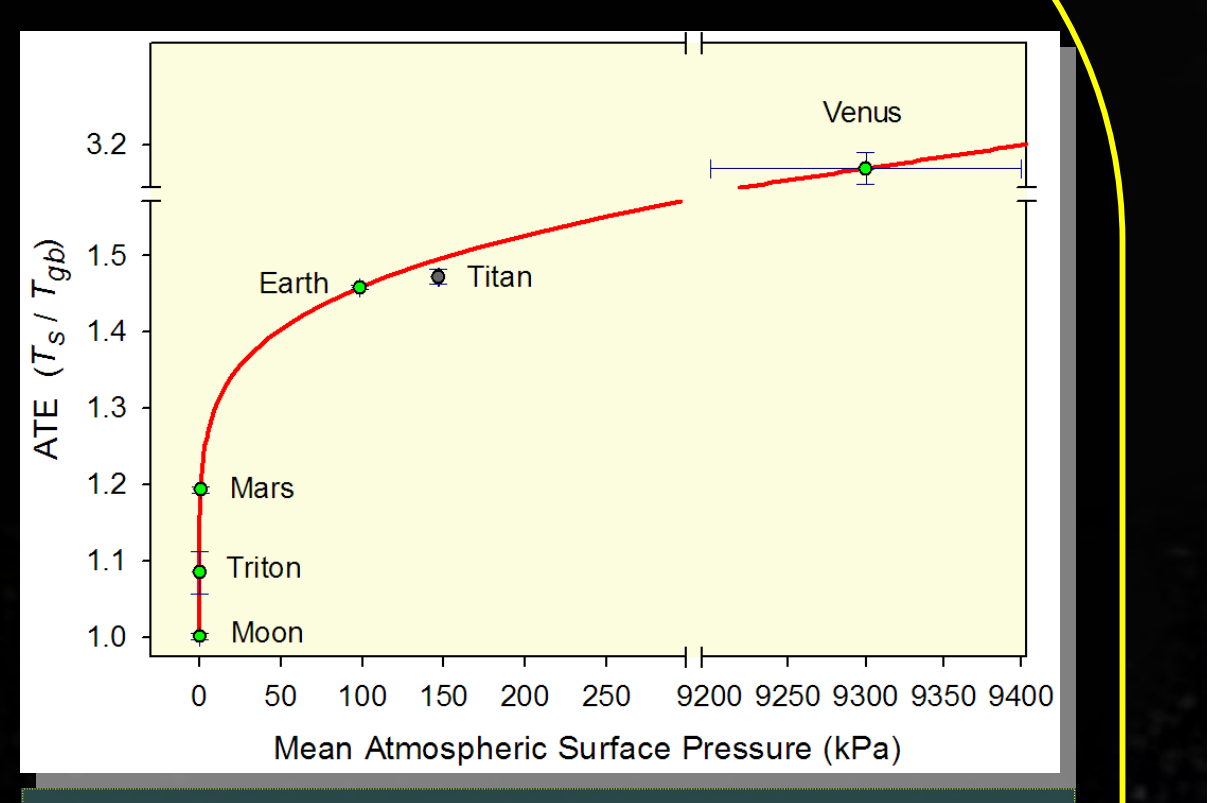

Figure 5. Near-surface Atmospheric Thermal Enhancement (T_s /T_{gb}) as a function of mean total surface pressure (P) for 8 celestial bodies shown in Table 1. See Eq. (7) for the exact mathematical formula.

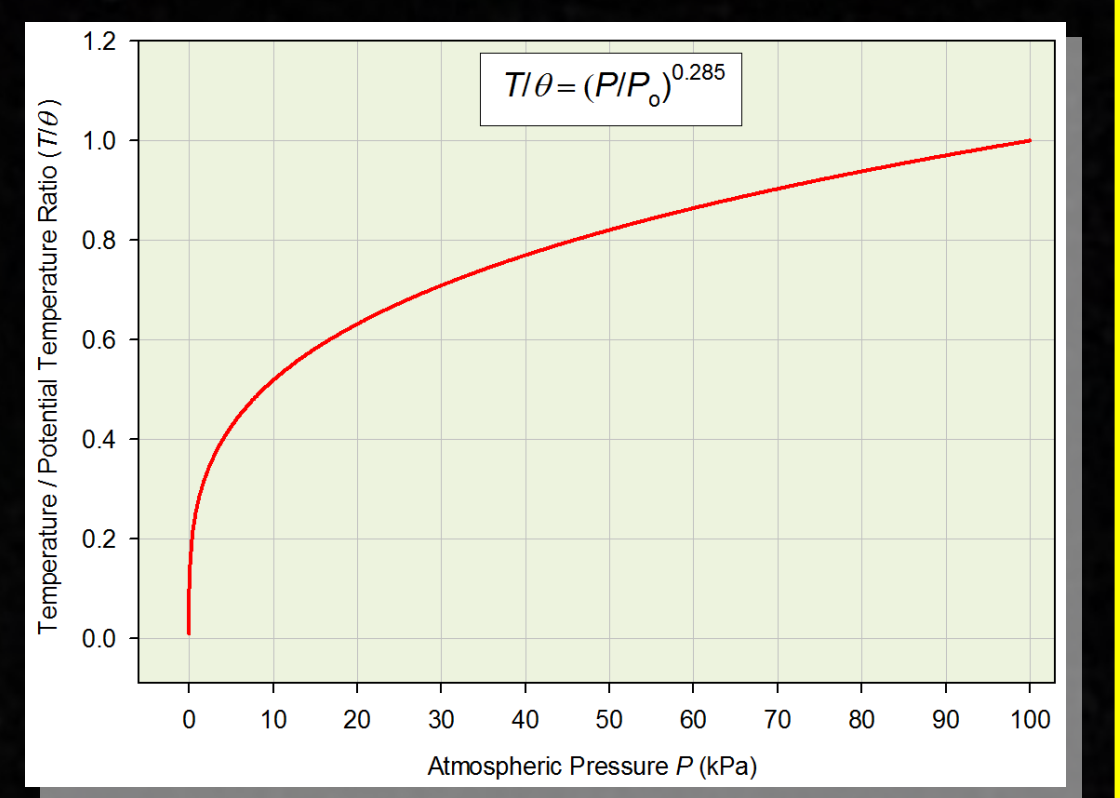

Figure 6. Temperature / potential temperature ratio as a function of atmospheric pressure according to the Poisson formula based on the Gas law (P_o = 100 kPa.) Note the similarity with the curve in Fig. 5.

N_{TE} should *not* be confused with actual energy, however, since it defines the *relative* (*fractional*) increase of a planet's surface temperature above that of an equivalent airless body. Pressure is *not* energy. However, pressure provides the *force* that *enhances* (*amplifies*) the kinetic energy supplied by an external source such as the Sun. This is because energy (Joule) is fundamentally a *force* applied over a unit distance. Hence, the relative thermal effect of pressure requires an external source of heating in order to manifest as an *actual* energy. Thus, Earth and Titan have similar N_{TE} values, yet their absolute surface temperatures are very different due to a vastly different solar irradiance. While pressure (P) controls the magnitude of the thermal enhancement factor, solar heating determines the average atmospheric volume (V), and the product PV defines the *total kinetic energy* and *temperature* of the lower troposphere. Therefore, for any solar insolation, the N_{TE} factor gives rise to an *extra* kinetic energy in the lower atmosphere *beyond* the amount supplied by the Sun. This *additional energy* is responsible for keeping the Earth surface 90.4 K warmer than it would be in the absence of atmosphere, and is the source for the 44% surplus down-welling LW radiation observed in the lower troposphere (see Section 2.1 C). Therefore, the atmosphere does *not* act as a 'blanket' reducing the surface infrared cooling to space as assumed by the current theory, but it enhances the energy received from the Sun through the *force* of pressure.

Equation (7) allows us to derive a simple yet robust formula for predicting any planet's mean surface temperature as a function of only *two* variables – solar irradiance (S) and mean atmospheric surface pressure (P), i.e.

$$T_s = 32.44\,S^{0.25}\exp\left[0.174205\left(\frac{P}{P_r}\right)^{0.150263}\right]\exp\left[1.83121\times10^{-5}\left(\frac{P}{P_r}\right)^{1.04193}\right] \qquad (8)$$

Equation (8) nearly *completely* explains the variation of T_s among analyzed celestial bodies, thus providing a needed function to parse the effect of a global pressure change on the dependent variables ρ and T_s in Eq. (6).

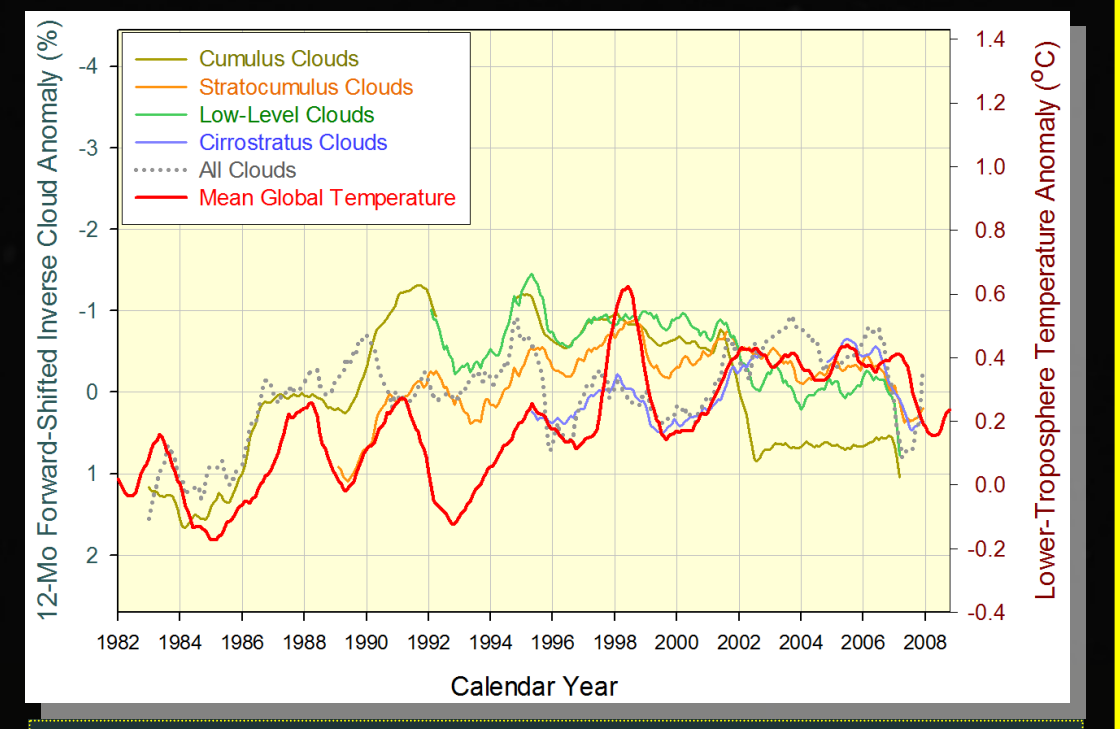

Figure 7. Dynamics of global temperature and 12-month forward shifted cloud cover types from satellite observations. Cloud changes appear to have been the driver of temperature variations during the past 30 years.

4. IMPLICATIONS OF THE NEW ATE CONCEPT

The hereto discovered emergent relationship (8) has paradigm-altering implications for the climate theory, e.g.

A) Global surface temperature is *independent* of the down-welling LW flux known as *greenhouse* or *back* radiation, since both quantities derive from the *same* pool of atmospheric kinetic energy maintained by solar heating and air pressure. Global variations of the downward LW flux caused by changes in tropospheric opacity have no impact on surface temperature, since they are offset by shifts in the rate of surface convective cooling.

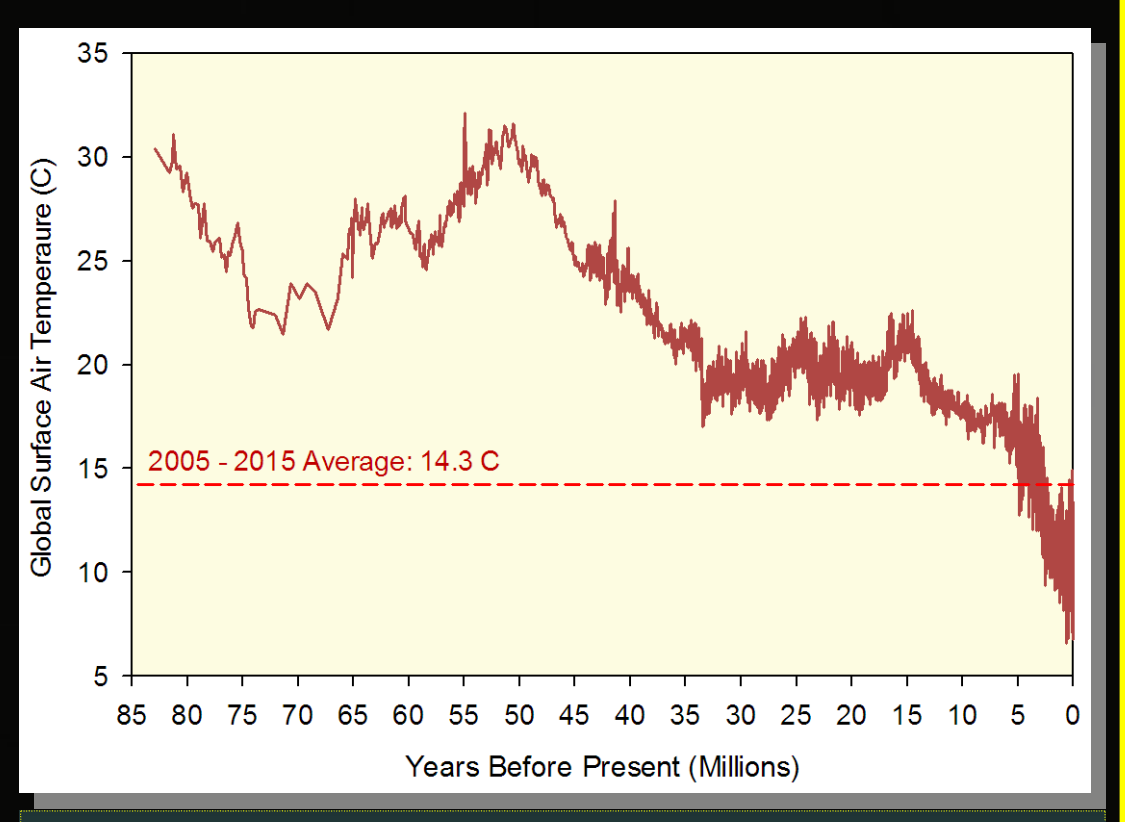

Figure 8. Evolution of Global surface temperature for the past 83 My reconstructed from ^{18}O proxies in marine sediments (Hansen et al. 2013; Linnert et al. 2014).

B) Modifying chemical composition of the atmosphere *cannot* alter the system's internal kinetic energy, hence the size of ATE (GE). This is supported by the Gas Law and the fact that planets of vastly different atmospheric composition follow the same P_s-N_{TE} relationship (Fig. 5). The lack of impact by atmospheric composition on surface temperature is explained via the compensating effect of convective cooling on *back* radiation discussed above.

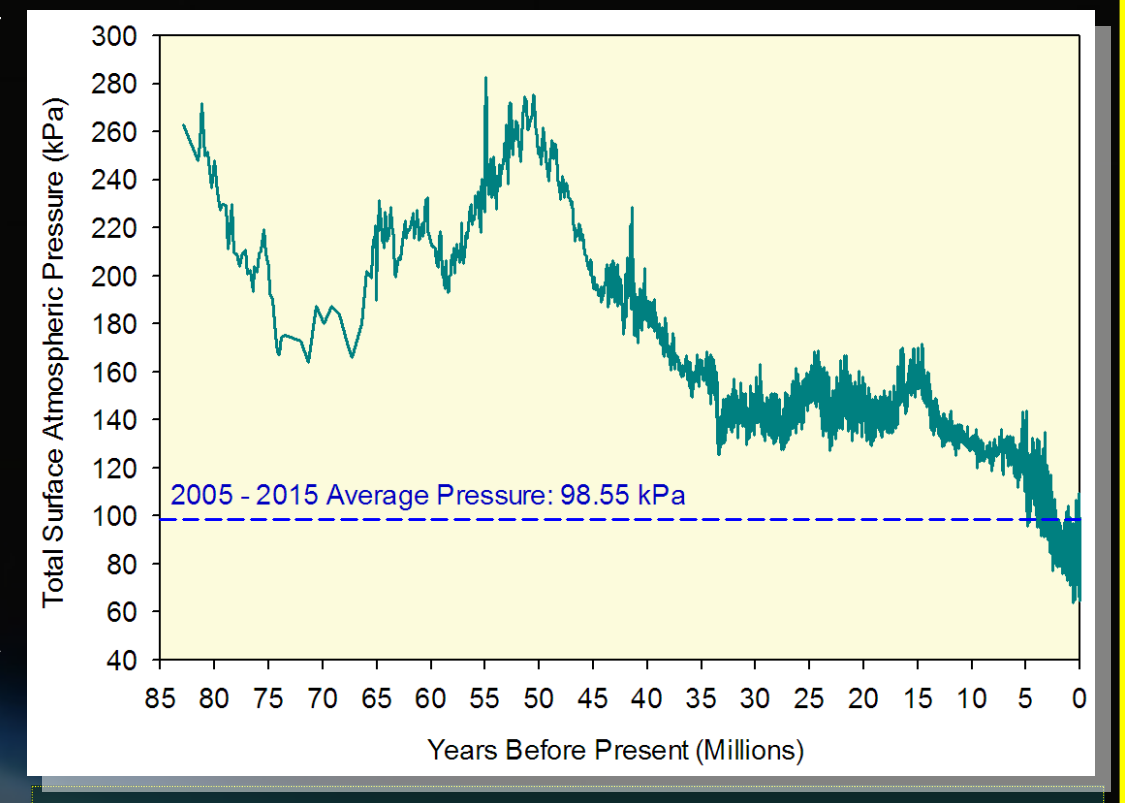

Figure 9. Modeled dynamics of surface atmospheric total pressure for the past 83 My based on the temperature record in Fig. 8 and Eq. (8).

C) Equation (8) implies that a planetary albedo is largely a *product* of the climate system rather than a driver of it. This is because the bulk of the albedo reflects the system's kinetic energy supplied by the Sun and amplified by atmospheric pressure. However, secular variations of solar magnetic activity can cause small changes in planetary albedo via influencing 2%-4% of global cloud cover. These cloud-cover changes produce ± 1 K semi-periodic fluctuations of global surface temperature on a time scale of decades to centuries as indicated by recent satellite observations (Fig. 7) .

D) Large climatic shifts evident in the geological record such as a 17 K *directional* cooling of the Globe during the past 51 million years (Fig. 8) can now be explained via changes in Earth's atmospheric mass and total pressure induced by tectonic activity and mantle degasing (Fig. 9). Thus far, climate science has not considered variations in atmospheric pressure as a plausible driver of global climate change. All paleo-climatic studies using GCMs implicitly assume that pressure has been constant over tens of millions of years, and only look at variations in atmospheric CO_2 concentration as a viable driver. However, some features of past climates such as significantly reduced equator-to-pole temperature gradients observed in ancient 'greenhouse' worlds cannot be explained by mechanisms of the radiative greenhouse theory. These features are quantitatively well described, though, by the hereto proposed pressure-controlled atmospheric thermal effect and a changing atmospheric mass through time.