There is no Radiative Greenhouse Effect

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June 14, 2017

Abstract: The derivation of the radiative greenhouse effect is shown, explaining what it represents, how it functions, and how it compares to other conceptions of a greenhouse effect. The derivation is shown to be based on unphysical and unrealistic foundational premises, and leads to (perhaps necessarily) physical implications which violate the laws of thermodynamics and mathematics.

I. The Fundamental Approach

One of the most common exercises in undergraduate astronomy is to calculate the effective temperature of the Earth, given all of the relevant physical parameters. The concept of effective temperature is discussed and defined by Gray [1] (pg. 2) is his discussion of stellar photospheres:

> "[A] physical variable strongly affecting the nature of the atmosphere is its characteristic temperature. Typically the temperature drops by somewhat more than a factor of 2 from the bottom to the top of the photosphere, and instead of choosing a temperature at some depth to characterise the temperature parameter, it is customary to use the effective temperature. The effective temperature is defined in terms of the total power per unit area radiated by the star,
>
> $$\int_0^\infty F_v dv = \sigma T_{eff}^4 \qquad [\{1\}]$$
>
> where the total radiant power per unit area is given by the integral and [] $\sigma = 5.67 \times 10^{-8}$ W/m^2 per K^4. Here F_v is the flux leaving the stellar surface []. Equation [{1}] has the form of the Stefan-Boltzmann law, [] making T_{eff} the temperature of a black body having the same power output per unit area as the star. But the distribution of power across the spectrum may differ dramatically from a blackbody at the same effective temperature."

Note that effective temperature is not a physical temperature which must necessarily be measured at any particular location, or altitude, in the atmosphere, nor is it a physical temperature which should necessarily be measured on a surface for an object with or without an atmosphere. In principle an atmosphere and/or surface could radiate so incongruently to a blackbody that its effective blackbody temperature would not physically correspond to any location in the atmosphere's temperature distribution or object's surface area at all. Thus, note the difference in meaning between the terms "effective temperature", defined above, and "physical temperature", as that which would actually be measured in-situ by local thermal equilibrium (via a thermometer for example). An "effective temperature" is in essence a fiction, and not an actual physical temperature.

And so the concept to calculate is: Given the effective temperature of the Sun, the distance of the Earth from the Sun, the absorptivity of the Earth and its emissivity, the cross-sectional area of the Earth and the Earth's total surface area, then what must be the effective temperature of the Earth? The exercise is left to the reader, with the answer coming out to approximately 255 K (-18^{0}C) from an output flux of 240 W/m^2.

Like the Sun's photosphere, the Earth's troposphere has a physical temperature distribution as a function of altitude. In the case of Earth's troposphere, for now it will only be said that "*for some reason*" it has a temperature distribution in which the bottom of the troposphere is warmest, and the top the coolest.

II. The Consensus Radiative Greenhouse Effect

The following figure (Figure 1) depicts the mechanism of the radiative greenhouse effect, which is used to explain why the bottom of Earth's troposphere is numerically higher in physical temperature as compared to Earth's effective temperature.

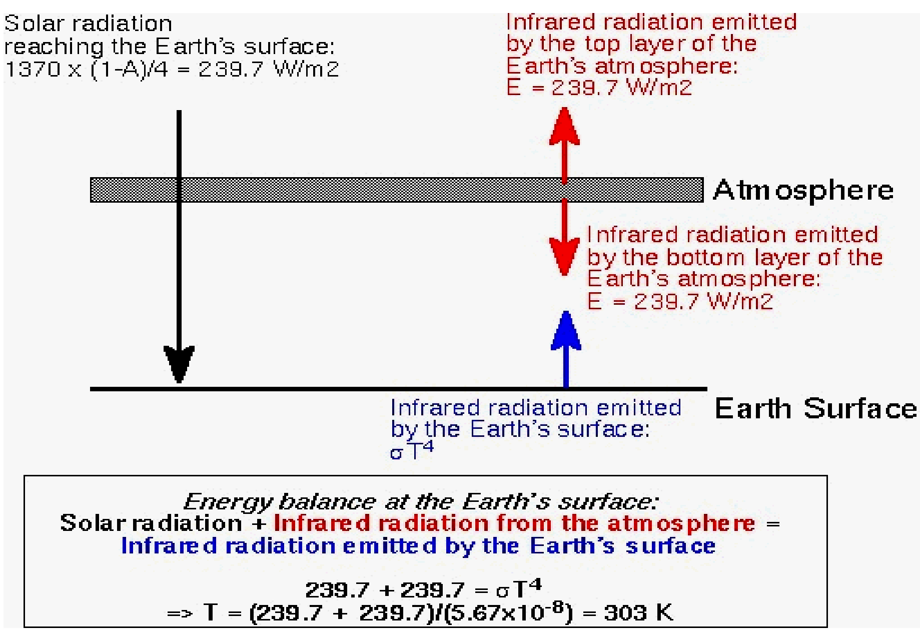


Figure 1: From the University of Washington's Department of Atmospheric Sciences:
http://www.atmos.washington.edu/2002Q4/211/notes_greenhouse.html

Several other examples of the above figure can be found in Appendix A: Consensus Listing of the Radiative Greenhouse Mechanism. The concept is that since the troposphere must emit thermal radiation, then this radiation directed towards the Earth's surface must increase the physical temperature of the lower troposphere to a value higher than the effective temperature of the Earth which is given only by the average incoming solar flux.

III. A Distinction between Greenhouse Effects

For clarity, it should be pointed out that there are two independent mechanisms of a "greenhouse effect". In the textbook "Thermal Physics" [2], in reference to the radiative greenhouse effect described in the previous section, it is stated (pg. 306):

> "[T]his mechanism is called the [radiative] greenhouse effect, even though most greenhouses depend primarily on a different mechanism (namely, limiting convective cooling)."

And so, one mechanism of a greenhouse effect is a radiative phenomenon, and hence has been labeled by the current author as a "radiative greenhouse effect", and the other mechanism is a physical phenomenon involving the physical entrapment of gas, which thus may be called a "physical greenhouse effect". The two mechanisms operate on physically distinct principles, and so should be named separately as such.

The physical greenhouse effect operating in actual greenhouses functions by preventing convective replacement of warmed air. In the open atmosphere, air warmed in contact with the sunlight-heated surface will naturally convect and rise and be replaced by cooler air from above; this limits the near-surface air temperature at the bottom of the troposphere to a lower value than if fixed air parcels were heated in place in contact with the surface. With 20% atmospheric extinction upon the solar constant of 1370 W/m^2, an incidence angle of 45 degrees, 10% albedo and 90% emissivity, a surface is heated to 69^0C from sunlight. By trapping a fixed parcel of air at the surface within its enclosure, a real greenhouse allows the air inside to be warmed to a higher temperature because its air cannot convect away to be replaced by cooler air as that air would be in the open.

IV. Practical Flaws in the Radiative Greenhouse Derivation

One flaw in the derivation of the radiative greenhouse effect is its characterization of the input solar flux to the planet's surface. The solar input value which they depict of 240 W/m^2 is actually the terrestrial output flux which is determined in the solution for the effective temperature of the Earth: that is, the effective temperature of the Earth of -18^0C is being given as the heating potential of the solar input flux on the surface of the Earth. The effective temperature of the Earth of -18^{0}C, which is a flux of 240 W/m^2, is physically not equivalent to the solar input and its heating potential. Although the total energy is conserved in such a calculation, the power emitted by the Earth does not actually occur over the same surface area as the solar power absorbed by the Earth. Terrestrial thermal power is emitted over the entire sphere, whereas solar power is absorbed over only half of the Earth: given that radiant flux and hence the equivalent radiant temperature forcing potential is a function of area (W/m^2), then the incoming solar flux cannot have the same numerical value as the emitted terrestrial flux. Conservation of energy does not require or imply that energies have the same character: that is, total energy may be conserved when factoring in the surface areas involved, but the flux density and hence heating potential of the energy does not have to be conserved. The radiative greenhouse derivation equates fluxes over equal areas for conservation of energy, rather than total energy over unequal input and output areas. The character of solar input at the Earth's surface is not a uniform flux of 240 W/m^2 or temperature heating potential of -18^{0}C on a blackbody.

The radiative greenhouse diagrams depict the Earth as a flat plane in which the incoming solar flux is distributed over the entire terrestrial surface area at once. This is unrealistic and unphysical. The Earth is not flat and nor is incoming solar power distributed evenly across Earth's entire surface area at once. If the Earth *were* flat and its entire surface area faced the Sun, as depicted in the radiative greenhouse effect derivations, then the Earth would need to be two-times distant from the Sun than it actually is in order to reduce the absorbed solar constant (via 30% albedo) from 960 W/m^2 to the 240 W/m^2 as depicted in the diagrams. This is a physical *paradox*.

Under the solar noon and an atmosphere giving 18% extinction, the solar constant of 1370 W/m^2 can induce a dark surface with high emissivity to 100^{0}C. The radiative greenhouse derivations with their 240 W/m^2 (-18^{0}C) of solar flux imply that solar power cannot, for example, melt ice of its own power.

Now although these are practical physical flaws in the derivation of the radiative greenhouse effect for planet Earth, it might be said that as far as averages go it is still a valid simplified summary of the relevant radiative energy exchanges. Is it possible that starting off with classically unrealistic, unphysical and paradoxical characterizations of a system will still lead to realistic and physical outcomes?

V. Theoretical Flaws in any Radiative Greenhouse Solution

Let us review the definition and characteristics of heat:

> "**Heat** is defined as any spontaneous flow of energy from one object to another caused by a difference in temperature between the objects. We say that "heat" flows from a warm radiator into a cold room, from hot water into a cold ice cube, and from the hot Sun to the cool Earth. The *mechanism* may be different in each case, but in each of these processes the energy transferred is called "heat"." – Thermal Physics [2](pg. 18)

“If a physical process increases the total entropy of the universe, that process cannot happen in reverse since this would violate the second law of thermodynamics. Processes that create new entropy are therefore said to be **irreversible**. […]

“Perhaps the most important type of thermodynamic process is the flow of heat from a hot object to a cold one. We saw […] that this process occurs *because* the total multiplicity of the combined system thereby increases; hence the total entropy increases also, and heat flow is always irreversible. […]

“Most of the process we observe in life involve large entropy increases are therefore highly irreversible: sunlight warming the Earth […].” – Thermal Physics [2](pg. 82)

“Heat is defined as the form of energy that is transferred across a boundary by virtue of a temperature difference or temperature gradient. Implied in this definition is the very important fact that a body never contains heat, but that heat is identified as heat only as it crosses the boundary. Thus, heat is a transient phenomenon. If we consider the hot block of copper as a system and the cold water in the beaker as another system, we recognize that originally neither system contains any heat (they do contain energy, of course.) When the copper is placed in the water and the two are in thermal communication, heat is transferred from the copper to the water, until equilibrium of temperature is established. At that point we no longer have heat transfer, since there is no temperature difference. Neither of the systems contains any heat at the conclusion of the process. It also follows that heat is identified at the boundaries of the system, for heat is defined as energy being transferred across the system boundary.” – Thermodynamics [3]

“The temperature of a body alone is what determines whether heat will be transferred from it to another body with which it is in contact or vice versa. A large block of ice at 0^0C has far more internal energy than a cup of hot water; yet when the water is poured on the ice some of the ice melts and the water becomes cooler, which signifies that energy has passed from the water to the ice.

“When the temperature of a body increases, it is customary to say that *heat* has been added to it; when the temperature decreases, it is customary to say that heat has been removed from it. When no work is done, $\Delta U = Q$, which says that the internal energy change of the body is equal to the heat transferred to it from the surroundings. One definition of heat is:

Heat is energy transferred across the boundary of a system as a result of a temperature difference only.” – Classical and Statistical Thermodynamics [4]

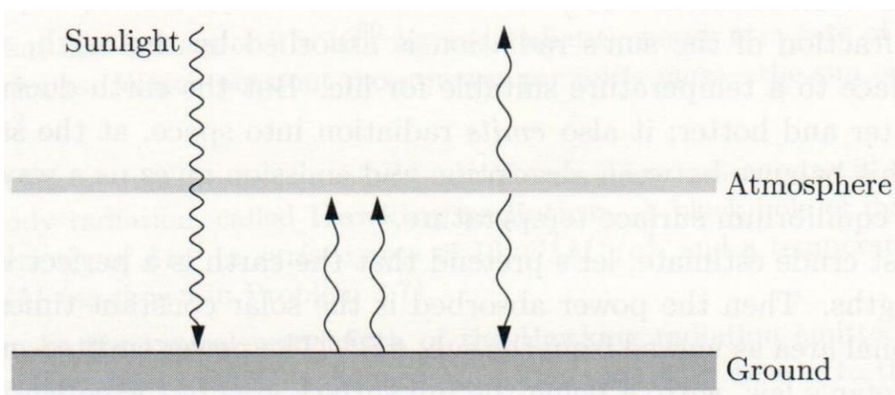
"How and why does heat energy flow? In other words, we need an expression for the dependence of the flow of heat energy on the temperature field. First we summarize certain qualitative properties of heat flow with which we are all familiar:

1. If the temperature is constant in a region, no heat energy flows.

2. If there are temperature differences, the heat energy flows from the hotter region to the colder region.

[…]" – Elementary Applied Partial Differential Equations [5]

Note the *mechanism* by which the hypothesis of a radiative greenhouse effect is said to function: the thermal radiation from the atmosphere sends energy back to the surface, and this is supposed to serve to increase the temperature further there in some way. See Appendix A for a listing of quotations referring to this process. In Schroeder's [2](pg. 306) depiction of the radiative greenhouse effect it is stated:



"Earth's atmosphere is mostly transparent to incoming sunlight, but opaque to the infrared light radiated upward by earth's surface. If we model the atmosphere as a single layer, then equilibrium requires that earth's surface receive as much energy from the atmosphere as from the sun."

The implication being made here, as in the Appendix A list of references to the effect, is that the thermal radiant emission from the atmosphere must cause the temperature of the surface to increase further. However, by which equilibrium or thermodynamics requirement(s) does it lead that the colder atmosphere would cause the warmer surface to warm further by radiant interaction?

From the definition and characteristics of *heat*, we can state that 1) radiant heat cannot and does not transfer from the cooler atmosphere to the warmer surface, and 2) heat flow out of the surface is not a conserved quantity and goes to zero to reach thermal equilibrium. And, given the Stefan-Boltzmann Law, we can also state that 3) thermal radiant energy emission from the surface can be neither stopped nor slowed down by the atmosphere since thermal radiant emission from a surface is spontaneous.

Thus, the derivation of the radiative greenhouse effect is asserting a process which does not and cannot occur. There is *no mechanism* by which the cooler atmosphere could cause the warmer surface to become warmer by radiant interaction. There are two ways to increase an object's (such as the Earth's surface) temperature: via work, and/or heat. Thermal radiant emission from the cooler atmosphere does not satisfy either of these conditions required for it to act in a heating, i.e. temperature increasing, function for the warmer surface.

A comment by Schroeder is:

> "Much of thermodynamics deals with three closely related concepts: **temperature**, **energy**, and **heat**. Much of students' difficulty with thermodynamics comes from confusing these three concepts with each other." [2](pg. 17)

Indeed, the fact that any object will spontaneously emit thermal radiant energy is being confused with what *heat* is and when energy may or may not behave *as heat*. That is, just because the atmosphere, or any object, may emit thermal radiant energy, does not mean that that energy can act as heat for another object; there is a requirement that for that energy to act as heat, it must come from a warmer object. If it can't act as heat, then it can't serve in any way known to thermodynamics to increase temperature.

VI. Conclusion

Logical consistency is found in that if one begins with a false representation of reality, then one will end with false conclusions or assertions about reality. That is, the radiative greenhouse mechanism which arises out of a flat Earth model with no day and night with "cold" sunshine for input and which presents a physical paradox in what must be the distance of the Earth to the Sun, ends with a violation of the physics of heat flow and thus the laws of thermodynamics.

Further, independent of beginning with a false representation of reality, the postulate of the radiative greenhouse effect that a cooler object can induce a warmer object to become warmer still by radiant energy exchange is not consistent with the laws of thermodynamics and the definition and character of heat.

A lingering question remaining is thus: why is the bottom of the troposphere warmer than the rest of the troposphere? If we consider that the total energy of a parcel of gas in the troposphere is given by its internal thermal energy plus its gravitational potential energy [6], then we have $U = mC_pT + mgh$, where U is the total energy, m the mass of the parcel, C_p its specific heat capacity, g is the gravitational force constant at Earth's surface, and h the height of the parcel above the surface. When in thermal equilibrium then $dU = 0$ and it is trivial to solve that $dT/dh = -g/C_p$; that is, the troposphere should generally have a temperature distribution where temperature decreases in value with height above the surface. The value of $-g/C_p$ with $g = 9.8\ m/s^2$ and $C_p = 1.0\ J/g/K$ for air results in the known "dry lapse rate" for the troposphere of approximately -9.8 K/km.

It is a necessary consequence of mathematics that the average of a sequential distribution will not be found at its extremities, and therefore, the bottom of the troposphere will necessarily be warmer than any average temperature state of the troposphere, independent of any expectation for what the numerical value of the average might be. It is impossible for the average temperature of the troposphere to be found at the bottom of the troposphere. If the Earth's effective temperature of -18^{o}C is to be likened to an actual average physical temperature, then this temperature will not be found at the surface of the Earth, but above it, and the near-surface temperature of the atmosphere will be warmer. Albeit the radiative greenhouse effect being incompatible with physics, the independent existence of the lapse rate negates the need to derive it.

Given that the atmosphere naturally has a temperature distribution given by conservation of energy of a gas in a gravitational field, and that the radiative greenhouse effect postulate is that its radiative mechanism should induce such a distribution, then the fact that the observed distribution is only given by $-g/C_p$ (for dry air) is further evidence that the radiative mechanism is not in effect. And so the effect that the radiative greenhouse mechanism is supposed to produce does not manifest empirically, as could be expected given that the effect doesn't exist theoretically.

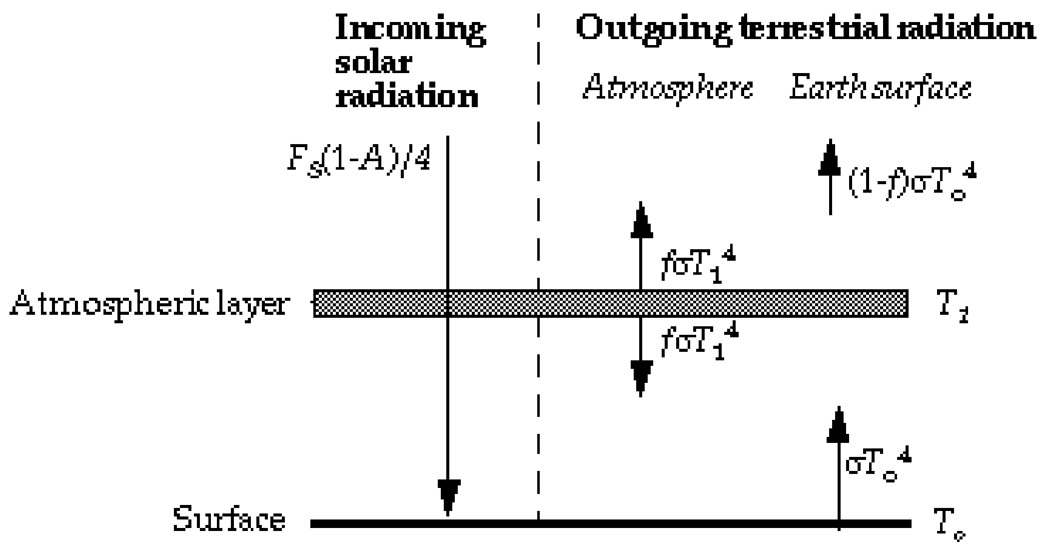
The derivation of the postulate of the radiative greenhouse mechanism is found to be based on unrealistic and unphysical representations of reality. Whether this basis is used for the derivation or not, the postulate of a radiative greenhouse mechanism is found to violate the laws of thermodynamics. Not surprisingly, the effect which the mechanism is supposed to produce is not observed in the atmospheric temperature distribution.

Funding

This research received no funding from any agency in the public, commercial, or not-for-profit sectors.

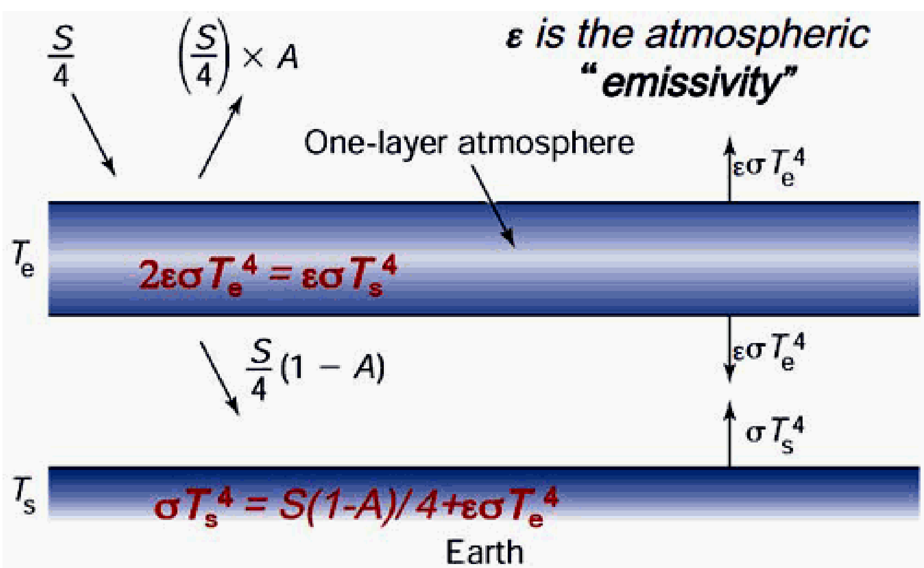
Appendix A: Consensus Listing of the Radiative Greenhouse Mechanism

Harvard University



http://acmg.seas.harvard.edu/people/faculty/djj/book/bookchap7.html

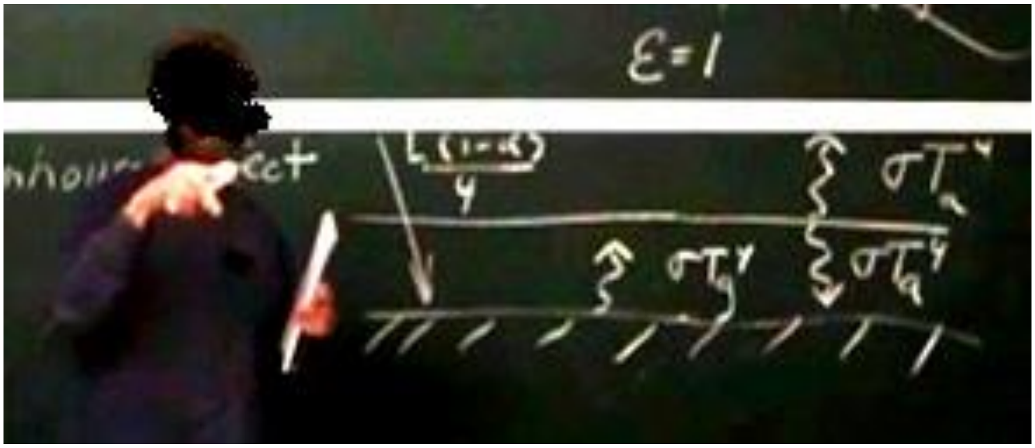
Pennsylvania State University



https://www.e-education.psu.edu/meteo469/node/198

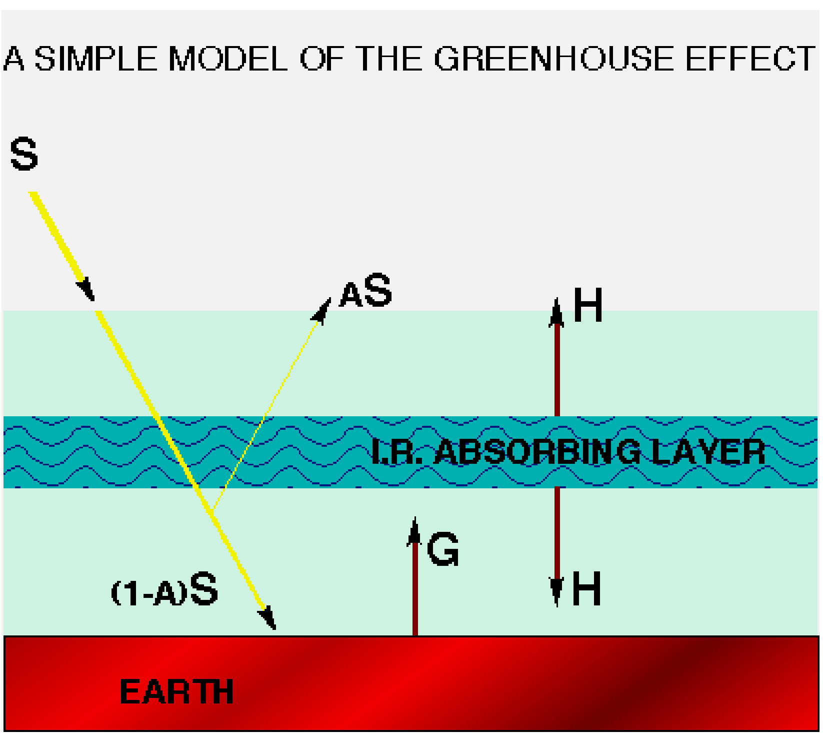
University of Chicago

Found in Chapter 3, lecture 5 video lecture: *The Greenhouse Effect*.



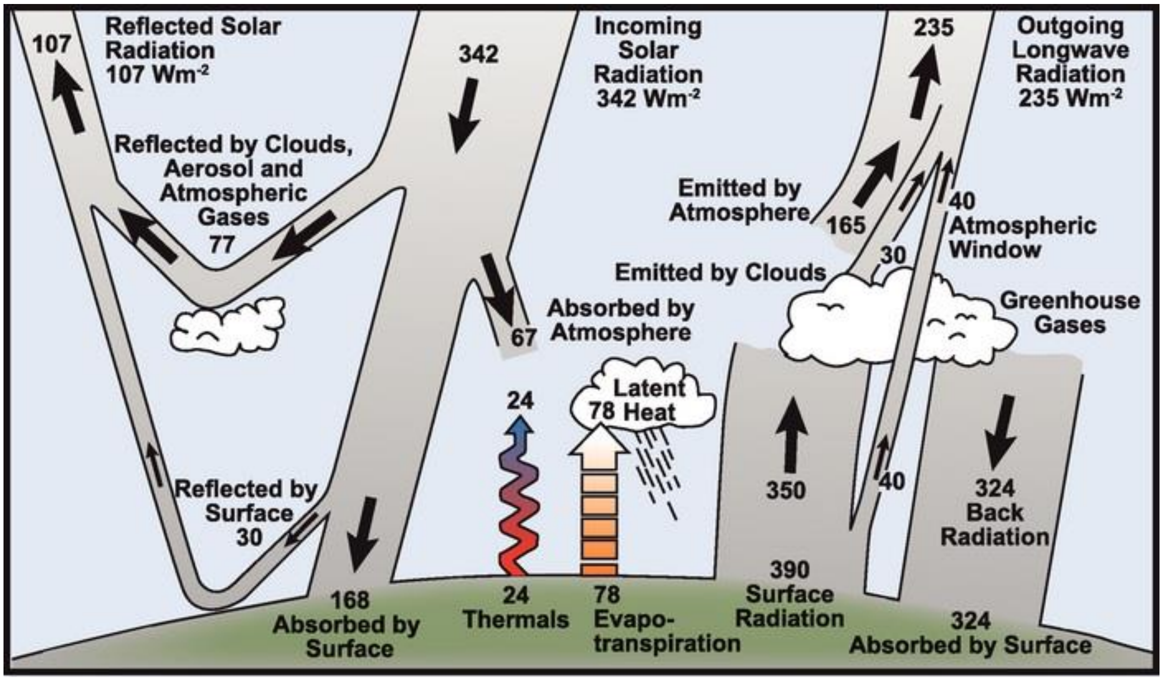
http://mindonline.uchicago.edu/media/psd/geophys/PHSC_13400_fall2009/lecture5.mp4

Columbia University



http://eesc.columbia.edu/courses/ees/climate/lectures/gh_kushnir.html

Kiehl & Trenberth, "Earth's Annual Global Mean Energy Budget" Bulletin of the American Meteorological Society



http://journals.ametsoc.org/doi/abs/10.1175/1520-0477(1997)078%3C0197%3AEAGMEB%3E2.0.CO%3B2

NASA

"Why is this process called "The Greenhouse Effect?" The Sun heats the ground and greenery inside the greenhouse, but the glass absorbs the re-radiated infra-red and returns some of it to the inside."

http://www-istp.gsfc.nasa.gov/stargaze/Lsun1lit.htm

Hunan University, China

"Light from the sun includes the entire visible region and smaller portions of the adjacent UV and infrared regions. Sunlight penetrates the atmosphere and warms the earth's surface. Longer wavelength infrared radiation is radiated from the earth's surface. A considerable amount of the outgoing IR radiation is absorbed by gases in the atmosphere and reradiated back to earth. The gases in the atmosphere that act like glass in a greenhouse are called greenhouse gases."

http://jpkc.lzjtu.edu.cn/hjhx/jpkc/7.ppt

Appalachian State University, North Carolina

"Our atmosphere is a selective filter since it is transparent to some wavelengths and absorbs others. The greenhouse effect occurs when the energy absorbed is not all radiated because of the filtering of the atmosphere. Some of the earth's radiated energy is reflected back to the surface. Consequently the earth's atmosphere has an increased temperature. This process is much like the action of glass in a greenhouse."

http://www.physics.appstate.edu/courses/FirstExamReview.rtf

The University of the Western Cape, South Africa

"A greenhouse is made entirely of glass. When sunlight (shortwave radiation) strikes the glass, most of it passes through and warms up the plants, soil and air inside the greenhouse. As these objects warm up they give off heat, but these heat waves have a much longer wavelength than the incoming rays from the sun. This longwave radiation cannot easily pass through glass, it is re-radiated into the greenhouse, causing everything in it to heat up. Carbon dioxide is the pollutant most responsible for increased global warming."

http://www.botany.uwc.ac.za/envfacts/facts/gwarming.htm

The Institute for Educational Technology, Italy

"Just as it happens in a greenhouse where the function carbon dioxide performs in the atmosphere is played by glass-rafters, the sun's energy arrives down at the earth, where it is partially absorbed and partially reflected. Such reflected heat, however, is reflected again, by glass as for the greenhouse, by carbon dioxide as for the atmosphere, down on earth: it is as if a part of the heat were entrapped, thus determining a growth of temperature on the ground."

http://www.itd.cnr.it/ge8/rivista/inglese/num_2/galil3.htm

The Austrian JI/CDM- Programme

"The Earth's atmosphere is comparable to a glass roof of a greenhouse: the short-wave solar radiation passes through nearly unhindered and warms the Earth's surface. From the Earth's surface, the short-wave radiation is partly absorbed and partly reflected back as long-wave thermal radiation. However, this long-wave thermal radiation cannot pass the atmosphere unhindered due to the greenhouse gases but is partly reflected back again to the Earth's surface."

http://www.ji-cdm-austria.at/en/portal/kyotoandclimatechange/ourclimate/greenhouseeffect/

U.S. Department of the Interior, U.S. Geological Survey

"The gases that encircle the Earth allow some of this heat to escape into space, but absorb some and reflect another portion back to the Earth. The process is similar in Mountain View, only, the greenhouse there is made of glass instead of gas."

http://hvo.wr.usgs.gov/volcanowatch/1998/98_10_22.html

RealClimate

"The factor of two for the radiation emitted from the atmosphere comes in because the atmosphere radiates both up and down."

http://www.realclimate.org/index.php/archives/2007/04/learning-from-a-simple-model/

ThinkQuest Education Foundation

"In a greenhouse, heat from the sun enters the glass. The heat in the form of infra-red light bounces and heads back up towards the glass. The glass then allows only some of this heat to escape, but reflects back another portion. This heat remains bouncing within the greenhouse. In the case of planet Earth, there is no glass, but there is an atmosphere which retains heat or releases heat."

http://library.thinkquest.org/11353/greenhouse.htm

UK government website:

"After gas molecules absorb radiation, they re-emit it in all directions. Some of the infrared radiation absorbed by gases in the atmosphere is therefore re-radiated out towards space and eventually leaves the atmosphere, but some is re-radiated back towards the Earth, warming the surface and lower atmosphere (illustrated by the 'back radiation' term in Figure 2). This warming is known as the greenhouse effect and the gases that are responsible for it are known as greenhouse gases."

http://www.bis.gov.uk/go-science/climatescience/greenhouse-effect

Boston University

"A simple greenhouse effect model

A. Glass represents the 'normal' greenhouse effect on earth and is at top of atmosphere

B. Solar shortwave radiation S largely makes it to surface

C. For energy balance, top of glass must send S back out

D. Greenhouse gases don't have a preferred direction; <u>they send S units in both directions – up and down</u>

E. Thus, the surface of the earth receives 2S due to the greenhouse effect – instead of 1S if there were no atmosphere!

F. Thermal radiation emitted from earth = 2S "

http://people.bu.edu/nathan/ge510_06_6.pdf

VII. References

[1] D. F. Gray, The Observation and Analysis of Stellar Photospheres, Cambridge University Press, 1992.

[2] D. V. Schroeder, Thermal Physics, Addison Wesley Longman, 2000.

[3] G. J. V. Wylen, Thermodynamics, John Wiley & Sons, 1960.

[4] A. H. Carter, Classical and Statistical Thermodynamics, Prentice-Hall, 2001.

[5] R. Haberman, Elementary Applied Partial Differential Equations: With Fourier Series and Boundary Value Problems, Prentice-Hall, 1998.

[6] H. Jelbring, "The "Greenhouse Effect" as a Function of Atmospheric Mass," *Energy & Environment,* vol. 14, no. 2 & 3, 2003.