Journal of Physics Special Topics

A4_7 The greenhouse effect on Venus

T. M. Conlon, J. F. Barker and J. C. Coxon

Department of Physics and Astronomy, University of Leicester. Leicester, LE1 7RH.

Feb 14th, 2011.

Abstract

This article investigates the greenhouse effect on Venus and ascertains whether it is wholly responsible for the very high Venusian surface. The temperature of Venus turns out to be 482 K (including any greenhouse effects), which is far below the observed surface temperature of Venus, implying other factors at work to increase the surface temperature, but still demonstrating the ability of the greenhouse effect to raise the surface temperature of a planet by at least tens of degrees.

Introduction

Venus is the second planet from the Sun and as such it could be expected that its surface temperature would lie somewhere between that of the closest planet (Mercury at 440 K [1]) and the third planet (Earth at 254 K [2]). In reality however it is the hottest planet in the solar system with an average surface temperature of about 750 K [3]. This is often attributed to carbon dioxide induced warming, which would be an example of a greenhouse effect (as its atmosphere is composed mainly of CO_2 [4]) and in the debate over climate change on Earth, Venus is often cited as an example of global warming and used as a warning to us on Earth to change the current habit of burning large quantities of fossil fuels to generate the energy our society thrives on. It is however worth asking the question as to whether this is a fair assessment of not.

Greenhouse effect

For the purposes of the discussion that follows, it is worth addressing what the greenhouse effect actually is. If a body is at a certain temperature T, it will radiate energy which will follow a spectrum (assuming black body radiation) that obeys Wien's law (eq. (1)), with λ being the wavelength of peak radiative emission and b a constant (2.90×10^{-3} m K [5]). A planet is at a different temperature to the Sun, so the wavelength of peak emission will also be different. The idea of the greenhouse effect is that there are gases in the atmosphere of a planet (for example carbon dioxide) that are transparent to the wavelength of radiation from the Sun, but not to that re-radiated from the planet. The radiation from the planet will thus be either absorbed by or reflected back from the atmosphere, further heating the planet.

$$\lambda = \frac{b}{T}. \quad (1)$$

Discussion

The equation for the amount of power incident on a planet from the Sun is given in Eq. (2) [6], with a the albedo of the planet, S_0 the solar constant (power density) at the distance of the planet from the Sun, A the cross-sectional area of the planet and P_i the incident power. One can also calculate the power radiated from a body at a temperature T by using Stefan-Boltzmann's law Eq. (3)), with ε the emissivity of the body and σ the Stefan-Boltzman constant (5.67×10^{-8} W m^{-2} K^{-4} [5]). It should then be possible to equate Eq. (2) and Eq. (3), rearrange and solve for T to obtain the temperature of Venus. This however does not take into account any greenhouse effect present on the planet.

$$P_i = (1-a)S_0 A. \quad (2)$$

$$P_r = A\varepsilon\sigma T^4. \quad (3)$$

The work required in order to properly take into account the absorption of various wavelengths of radiation by the Venusian atmosphere is far beyond the remit of this review, but it is possible to obtain an effective emissivity for the planet which does take into account any such effects in addition to accounting for an wavelength dependence of the emissivity. For Venus, this figure is 0.30 [7] (assuming a carbon dioxide atmosphere). Performing the above substitution and rearranging for T, one obtains Eq. (4).

$$T = \left(\frac{(1-a)S_0}{\varepsilon\sigma}\right)^{\frac{1}{4}}. \quad (4)$$

Putting the relevant values into Eq. (4), (Venus has an albedo of 0.65 [8] and a solar constant of 2620 W m^{-2} [8]), one ascertains that the surface temperature of Venus (taking greenhouse effects into account) should be 482 K. This would make it the hottest planet in the Solar system, but it would not account for Venus' present temperature. It would thus seem that the greenhouse effect alone cannot account for the observed temperature of Venus, but is certainly responsible for a marked temperature increase over that which would be otherwise expected.

Conclusion

The theoretical temperature of Venus was calculated to be 482 K, including the greenhouse effect and as this is obviously nowhere near the actual temperature of Venus of around 750 K [3], it would seem to imply that other factors are at work and that the high temperature on Venus is not solely due to the greenhouse effect. Having said this, it is also apparent that the presence of carbon dioxide has (via the process of the greenhouse effect) been responsible for making the surface of Venus hotter than it would otherwise be.

REFERENCES

[1] http://nssdc.gsfc.nasa.gov/planetary/factsheet/mercuryfact.html
[2] http://nssdc.gsfc.nasa.gov/planetary/factsheet/earthfact.html
[3] http://hypertextbook.com/facts/2000/GeorgeRyabov.shtml
[4] http://nssdc.gsfc.nasa.gov/planetary/factsheet/venusfact.html
[5] G. Woan, *The Cambridge Handbook of Physics Formulas*, (Cambridge University Press, 2000), Ch. 1
[6] M. Voice, *The Greenhouse Effect and Climate Change*, Lecture course, La Trobe University, 2009
[7] www.biocab.org/Temperature_of_Venus.pdf
[8] http://www.imcce.fr/vt2004/en/fiches/fiche_n13_eng.html