LETTERS TO PROGRESS IN PHYSICS

Calculation of Outgoing Longwave Radiation in the Absence of Surface Radiation of the Earth

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Based on the observed equilibrium at the surface of the earth, it is argued that almost no infrared radiation would be emitted by the surface of the earth that is in physical contact with the nearest isothermic air layer. By assuming the outgoing longwave radiation is the cumulative upward thermal radiation by the air, an analytic formula with four dependent observables is proposed which is used for the first time to calculate the effective air emissivities at different lapse rates in the troposphere. Given the observed global mean outgoing longwave radiation 239 W m^{-2} and the stable tropospheric lapse rate 6.5 T km^{-1}, the calculated effective air emissivity near the surface is 0.135, in agreement with early experimental observations.

1 Introduction

It has been recently shown that the earth is capable of self-regulating outgoing infrared radiation without changing the long-term global mean surface temperature [1]. In line with this study, it becomes clear that the radiation cooling at the surface seems unrealistically overestimated. Since 1896, it has been assumed that the surface of the earth emits infrared at radiation flux close to 390 W m^{-2}, similar to a blackbody at its thermal equilibrium temperature 288 K in vacuum, based on a model atmosphere that is physically separated from the surface [2,3]. Nevertheless, it could be argued that the widely used assumption cannot be justified in the presence of the isothermic gaseous atmosphere that is physically attached to the surface. At such a thermodynamic equilibrium, the net energy transfer between the condensed-matter surface and the nearest layer of air should be negligible if not zero. This implies that the surface infrared radiation should be absent as far as the long-term global climate stability is concerned, which is supported by recent experimental measurements that the proportion of the non-radiative heat and mass transfer at the sea level is close to 99.6% [4]. In light of this argument, an analytical formula is introduced to directly calculate the outgoing longwave radiation (OLR) in the absence of the surface infrared radiation as reported in this Letter.

2 Formulation

In the absence of the atmosphere, the thermal temperature of vacuum space is close to 4 K. Under this condition, the terrestrial infrared radiation intensity can be described by the Stefan-Boltzmann law,

$$I = \sigma T_S^4 \,. \tag{1}$$

where σ is the Stefan-Boltzmann constant, T_S is the thermal equilibrium temperature of the condensed-matter surface that is approximated as a blackbody. However, (1) becomes invalid as the temperature gradient should be zero at the surface in the presence of the gaseous atmosphere. Thus, it is reasonable to assume that the OLR is merely the cumulative thermal radiation by the atmosphere from different isothermic layers. Further, it is assumed that the effective air emissivity ϵ is scaled by the air density, viz.

$$\epsilon = \epsilon_0 \, \frac{\rho}{\rho_0} \,. \tag{2}$$

where ρ is the air density with its value at the surface ρ_0 = 1.225 kg m^{-3}, respectively; ϵ_0 is the atmospheric emissivity measured near the surface. To be specific, the vertical air density distribution in this study is written as

$$\rho = \rho_0 \, \exp(-0.135z) \,. \tag{3}$$

where z is the altitude in km. The assumption (2) is consistent with the fact that the air thermal radiation must vanish in the absence of air molecules in the atmosphere. By approximating each thin atmospheric layer as isothermic with its local thermal equilibrium temperature, the OLR in W m^{-2} observable at the top of the atmosphere can be formulated in terms of the Stefan-Boltzmann law by the following integral

$$\text{OLR} = \int_0^\infty \epsilon \, \sigma T_a^4 dz \,. \tag{4}$$

where T_a denotes the atmospheric temperature at different altitudes.

3 Calculation

To proceed further, the troposphere and the stratosphere from the ground to altitude 85 km are divided into four parts whose vertical temperature distributions can be approximated as a step-wise linear function based on the International Standard Atmosphere [5]. Substituting (2) and (3) into (4) and integrating in each of the four parts yields

$$\text{OLR} = \epsilon_0 \, \sigma \, (A + B + C + D) \,, \tag{5}$$

where

$$A = \int_0^a (T_S - Lz)^4 \exp(-0.135z)\, dz \tag{6}$$

$$B = \int_a^{20} (210)^4 \exp(-0.135z)\, dz \tag{7}$$

$$C = \int_{20}^{50} (164 + 2.3z)^4 \exp(-0.135z)\, dz \tag{8}$$

$$D = \int_{50}^{85} (389 - 2.2z)^4 \exp(-0.135z)\, dz\,, \tag{9}$$

where L denotes the lapse rate in the troposphere, the altitude a is dependent of L. Notice that $T_a = T_S$ at the surface in (6). It is apparent that the OLR is determined by two variables, the lapse rate and the effective air emissivity close to the surface when the surface temperature is fixed. It is found that the integration is nearly a constant above 85 km, as the air density exponentially decreases with the altitude. For the lapse rate 6.5 K km^{-1}, the calculated effective air emissivity near the surface is 0.135. The range of the calculated effective air emissivity, 0.12 to 0.16, for the lapse rates between 4 K km^{-1} and 10.5 K km^{-1} is consistent with some early observed atmospheric emissivities [6].

Using the observed long-term global mean OLR value, 239 W m^{-2}, the explicit dependence of the effective emissivity on the lapse rate can be fitted with a linear function with $R^2 = 0.996$,

$$\epsilon_0 = 0.0065L + 0.091\,. \tag{10}$$

By way of extrapolation, it is predicted that the effective emissivity of the atmosphere near the surface is 0.091 as the troposphere becomes isothermic. Besides, when the effective air emissivity and the lapse rate are fixed at 0.135 and 6.5 K km^{-1}, respectively, it is found that the calculated OLR also linearly depends on the surface temperature with $R^2 = 0.999$, viz.

$$\mathrm{OLR} = 3.24\, T_S - 695.49\,, \tag{11}$$

which gives the gradient

$$\frac{d(\mathrm{OLR})}{dT_S} = 3.24\,\mathrm{W\,m^{-2}K^{-1}}\,. \tag{12}$$

4 Discussion and conclusion

To explore the implications of the zero surface radiation hypothesis, the outgoing thermal radiation by the air is formulated and quantitatively calculated in the absence of the surface infrared radiation. Based on the calculation, it appears that long-term global climate stability might be simply explained in relation to the tropospheric lapse rate, adjustable by changing the water vapor in the troposphere, that provides a natural mechanism to control the OLR for the earth to re-emit the absorbed solar radiation back to outer space while keeping the global mean surface temperature constant. Further, it is revealed that the four coupled variables, namely OLR, effective air emissivity, the tropospheric lapse rate, and the surface temperature, are *linearly* dependent on each other, as shown in (10) and (11). So far, the linear dependence of the monthly mean OLR on the sea surface temperature (SST) has been observed on several locations [7], but the theoretical interpretations in terms of water vapor feedback and speculated emergent properties seem complicated and confined to the cloud-free observations [8]. By way of contrast, (11) is simply deduced from the hypothesis that the surface radiation is zero.

Without invoking the greenhouse effect, it seems the current global energy balance can be quantitatively explained, i.e. the solar shortwave radiation at the surface, 161 W m^{-2}, is completely transferred into the atmosphere by means of convection and conduction and then is thermally radiated by the atmosphere into outer space, together with the shortwave absorption by the atmosphere at 78 W m^{-2}, which makes the OLR at the top of the atmosphere equal to

$$161 + 78 = 239\,\mathrm{W\,m^{-2}}$$

as observed [3]. Further experimental observations both in lab and in space are necessary for further evaluating this proposed description with fundamental implications for understanding the long-term global climate stability.

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