A new scheme of accounting for the non-radiative heat fluxes in the radiative transfer of atmospheric thermal photons Anastassia M. Makarieva, Victor G. Gorshkov, Petersburg Nuclear Physics Institute, 188300, Gatchina, St. Petersburg, Russia Full text at www.biotic-regulation.pl.ru/egu2007

1. Radiative transfer equation: Implicit assumptions and validity for solar and laser radiation

$$\boldsymbol{m} \frac{\partial I(z, \boldsymbol{m})}{\partial z} = -\frac{1}{l(z)} \{ I(z, \boldsymbol{m}) - S(z) \} \quad (z \text{ counted along the direction of the flux})$$
$$\boldsymbol{m} \frac{\partial I(\boldsymbol{t}, \boldsymbol{m})}{\partial \boldsymbol{t}} = +I(\boldsymbol{t}, \boldsymbol{m}) - S(\boldsymbol{t}), \qquad d\boldsymbol{t} \equiv -\frac{dz}{l(z)}, \qquad (1)$$

l(z) is photon mean free path length. Putting m = 0 in (1), one obtains:

$$S(\boldsymbol{t}) = I(\boldsymbol{t}, 0).$$

(2)

Irreversibility of absorption means that the medium does not emit photons of the same length as absorbed, so that S(t) = I(t,0) = 0. In this case Eq. (1) solves as

 $I(\mathbf{t}) = I(0) e^{-t}$, $T(\mathbf{t})$ [transmissivity] $\equiv I(\mathbf{t})/I(0) = e^{-t}$. (3) Equation (1) is only physically meaningful for intensity within an infinitely small solid angle, i.e. an angle much smaller than all the other solid angles measured in the considered problem (Milne 1930).

Conventional radiative transfer equation contains implicit assumptions, which make it valid for description of only particular types of radiative transfer, like laser or direct solar radiation, which (I) propagate with practically no angular divergence in space, close to m = 1, and (II) are irreversibly absorbed by the medium. Transfer of thermal photons is principally different.

2. What is absorption saturation? Is it relevant to the areenhouse effect?

Relationship (3) is used to measure the dependence of the molecular absorption cross-section $\mathbf{s} = [nl(z)]^{-1}$ at different radiation frequencies on concentration n of absorber molecules. Due to pressure broadening of absorption lines, transmissivity $T(n) = \int e^{-t} d\mathbf{n}$ and absorptivity A(n) = 1 - T(n) are related to *n* in different ways dependent on the magnitude of the latter, from linear dependence at small n to square-root and logarithmic dependence at large n. The central part of the absorption contour, which widens towards the wings of the absorption profiles with growing n due to pressure broadening, ceases to depend on concentration with growing n. This is interpreted as saturation of absorption. All these dependencies arise in consequence of the exponential decline of intensity with growing t, Eq. (3).

3. Random walk of atmospheric thermal photons

Thermal radiation of the Earth's surface is characterized by maximum entropy. Thermal photons do not disappear, but only change their direction after interaction with molecules of the greenhouse substances. Some part of them return back to the surface, where the energy density of thermal photons increases. Thermal photons propagate in all directions at all values of **m** in (1). Source function S(t) differs from intensity by an additive intensity-independent magnitude, as is clear from Eq. (2). The right-hand part of Eq. (1) ceases to depend on intensity; and namely this fact determines the diffusional, linear character of the propagation of thermal radiation. The conventional isolation of intensity in the right-hand part of Eq. (1) becomes a misleading mathematical manipulation, as it distorts the physical meaning of the investigated processes. Moreover, intensity in Eq. (1) has no physical meaning for thermal photons, as it is unmeasurable for infinitely small solid angles, for which Eq. (1) is mathematically valid.

 A_1 A_2 ____ A_k _ _ _ _ _

 $n \xrightarrow{\frac{2}{3}F_s} A_n$ \mathbf{Ear}

Flux of photons exchanging energy between any two adjacent

$$\frac{F_e}{F_s} \equiv T, \quad T =$$

(4).

function at surface temperature t_s , s_{si} is the absorption cross-section at the surface, h_i is atmospheric scale height.

Within each absorption band, in the presence of non-radiative heat fluxes as well as in their absence, the greenhouse effect grows linearly with increasing concentrations of greenhouse substances, showing no saturation.

Thermal radiation transfer does not retain any traces of the exponential behavior of intensity as described by Eq. (3). The notions of transmissivity and absorptivity, defined with use of the exponent e^{-t} , lose their meaning. The dependencies of any physical variables on concentrations of greenhouse substances, that were based on the e^{-t} exponent, like square-root, logarithmic, etc., disappear as well. Such dependencies cannot therefore determine how the greenhouse effect varies with changing concentrations of greenhouse substances.

4. Random-walk transfer of thermal radiation does not depend on the variance of photon free path length, which can be therefore set to zero.

Positive and negative deviations of random free path lengths from the mean value cancel each other during random walk. Mean length l_c of photon free path between two consecutive collisions of photon with molecules of the absorber and mean length l of photon free path from an arbitrary point in

space to the first collision with a molecule are related as: $l = l_c/2$

5. Account of non-radiative heat fluxes using random-walk scheme

Energy conservation for each layer:

$$F_{0}^{+} = F_{e}$$

$$F_{0}^{+} = \frac{2}{3}F_{1}^{+} = F_{e}, F_{0}^{-} = 0, A_{0} = 0$$

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$$F_{0}^{+} = \frac{2}{3}F_{1}^{+} + \frac{2}{3}F_{1}^{-} = \frac{2}{3}F_{2}^{+} + \frac{2}{3}F_{0}^{-} + A_{1}$$

$$F_{1}^{-} = \frac{2}{3}F_{2}^{+} + \frac{2}{3}F_{1}^{-} = \frac{2}{3}F_{3}^{+} + \frac{2}{3}F_{0}^{-} + A_{1}$$

$$F_{2}^{-} = \frac{2}{3}F_{2}^{+} + \frac{2}{3}F_{2}^{-} = \frac{2}{3}F_{3}^{+} + \frac{2}{3}F_{1}^{-} + A_{2}$$

$$F_{2}^{-} = \frac{2}{3}F_{2}^{+} + \frac{2}{3}F_{1}^{-} + A_{2}$$

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 \leftarrow Geometry of radiative transfer between layers of thickness l_c at zero variance of photon free path length between two consecutive collisions.

Here $A_k > 0$ is the additional flux of radiative energy, which originates in the k-th layer after the non-radiative fluxes of sensible and latent heat and solar radiation absorbed within this layer dissipate into thermal

radiation;
$$\sum_{k=1}^{n} A_k = A$$
 is the total flux of

sensible and latent heat and solar radiation undergoing dissipation in the atmospheric column; F_e is the incoming flux of solar radiation absorbed at the surface equal to the outgoing thermal radiation flux into space.

Continuous representation:

$$\frac{d^2 F^+(\mathbf{t})}{d\mathbf{t}^2} = -\frac{3}{4} A(\mathbf{t}); \quad \frac{4}{3} \frac{dF^+(\mathbf{t})}{d\mathbf{t}} \bigg|_{\mathbf{t}\to 0} = F^+(0);$$

$$A = \int_0^{t_s} A(\mathbf{t}) d\mathbf{t}, \quad k = \mathbf{t}/2 \text{ [see (4)]}; \quad A(\mathbf{t}) = \frac{1}{2} A_k;$$

$$F^+(\mathbf{t}_s) = \left(1 + \frac{3}{4} \mathbf{t}_s\right) F_e - \frac{3}{4} \int_0^{t_s} d\mathbf{t}' \int_0^{t'} A(\mathbf{t}'') d\mathbf{t}'' \quad .$$

$$F^+(\mathbf{t}_s) = (1 + K\mathbf{t}_s) F_e; \quad K_{\text{observed}} = 0.55.$$

layers is equal to 2/3 of the radiative flux within the layer. 6. Greenhouse effect dependence on greenhouse gases concentrations for the whole thermal radiation spectrum

Transmissivity of atmospheric thermal radiation $T \equiv F_{e}/F_{s}$, the inverse magnitude of which determines the planetary greenhouse effect, within each *i*-th absorption band of spectral width Δv_i decreases linearly with increasing amount n_{si} of atmospheric greenhouses substances. This dependence is not related to pressure broadening.

$$\sum T_i, \quad T_i = \frac{\boldsymbol{d}_i}{1 + K\boldsymbol{t}_{si}}, \quad \boldsymbol{t}_{si} = n_{si} c_{si}, \quad \boldsymbol{d}_i = \frac{\Delta \boldsymbol{n}_i F_p(\boldsymbol{n}_i, \boldsymbol{t}_s)}{F_s}, \quad \sum \boldsymbol{d}_i = 1, \ c_i = \boldsymbol{s}_{si} h_i, \text{ where } F_p \text{ is Planck}$$