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Atmospheric Chemistry and Physics Discussions

Interactive comment on “Height of convective layer in planetary atmospheres with condensable and non-condensable greenhouse substances” *by* A. M. Makarieva et al.

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We respond to the specific comments made by Anonymous Referee #2.

1) The referee points out that at large optical depth the upward flux $F^+(\tau)$ is more dependent on the local thermal emission at a high altitude than on surface flux which seems to the referee inconsistent with Eddington’s approximation

$$F^+(\tau) = F_e(1 + k\tau), \;\; k = \frac{3}{4}; \;\; F_s^+ = F_e(1 + k\tau_s). \tag{1}$$

where F_e is the upward thermal flux emitted into space.

However, there is no contradiction here. At large optical depth the upward flux at any

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local point does indeed originate in the atmosphere, this is obvious. But this does not imply that the relation with the surface flux is lost. As long as the atmosphere is largely transparent with respect to solar radiation, the latter dissipates into thermal radiation at the Earth's surface. Thus, thermal flux originates at the surface and is transferred to higher altitudes in the atmosphere, as described by Schwarzschild's radiative transfer equation. The recurrent character of radiation transfer, where radiation emitted within any atmospheric layer of depth $\tau \approx 1$ is determined by the sum of radiative fluxes coming to this layer from below and from above, dictates the relationship between radiation at the lower and higher altitudes at any value of optical depth, including surface $(F^+ \equiv F_s, \tau = \tau_s)$ and the top of the atmosphere $(F^+ \equiv F_e, \tau = 0)$. As is well-known in radiative transfer physics, Eq. (1) becomes increasingly accurate with growing τ, but is accurate within around 10% at small τ as well (Michalas and Michalas, 1984; Gorshkov and Makarieva, 2002).

2) The referee asks how we have derived the relation

$$\frac{\tau}{\tau_s} = \frac{p}{p_s} \tag{2}$$

where p and p_s is the air pressure in the atmosphere and at the surface. The referee presumes that Eq. (2) is based on the assumption of pressure broadening for extinction coefficient.

This is incorrect. The above relationship is a direct consequence of the equation of state for atmospheric air and the equation of hydrostatic equilibrium, two basic premises widely used in climatic studies (see, e.g., Ramanathan and Coakley, 1978). They combine into the well-known relation (Eq. (2.4) in the paper):

$$\frac{dp}{dz} = -\frac{p}{h}; \qquad h \equiv \frac{RT}{Mg}. \tag{3}$$

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Using (3), the equation of state $p = NRT$, and the definition of optical depth τ (Michalas and Michalas, 1984):

$$\tau \equiv \int_z^\infty \frac{dz'}{l(z')}, \quad \tau_s \equiv \int_0^\infty \frac{dz'}{l(z')}, \tag{4}$$

where $l(z)$ is the average free path length of thermal photons at height z, $l(z) \equiv [N(z)\Sigma]^{-1}$, Σ is the molar cross-section of absorption of thermal photons by one mole of the greenhouse substance, $N(z)$ is the molar concentration of this substance at height z, and performing some elementary mathematics, Eq. (2) is readily obtained.

A related formula the referee discusses

$$\frac{\tau_L}{\tau_{sL}} = \frac{p_L}{p_{sL}}, \tag{5}$$

where low index L denotes optical depth and partial pressure of atmospheric water vapor, is obtained on the basis of the observation that, although water vapour is not in hydrostatic equilibrium in the terrestrial atmosphere (Weaver and Ramanathan 1995), the vertical distribution of water vapor in the atmosphere is compressed as compared to the case of hydrostatic equilibrium by a factor β which is nearly independent of altitude. This interesting effect is in detail discussed in the paper.

Formula (5) is entirely unrelated to pressure broadening either.

The referee is sceptical about the formula

$$\frac{\tau_L}{\tau_{sL}} \approx \left(\frac{p}{p_s}\right)^{\beta_s}, \tag{6}$$

noting that in the atmosphere "the relation between water vapour pressure and total

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pressure generally cannot be so well defined". In support of this statement the referee notes that water vapour pressure has very little impact on total pressure.

This logic is misleading. For example, changes in CO_2 partial pressure have very limited impact on total pressure as well. Nevertheless, as is well-known, in the well-mixed atmosphere in hydrostatic equilibrium the ratio of partial pressures at height z and near the surface for minor non-condensable air constituents like CO_2 are equal to the corresponding ratios for atmospheric air.

Formula (6) is obtained for the mean planetary values of atmospheric water vapor pressure and total pressure on the basis of well-established physical regularities, including the observed linearity of vertical temperature gradient, constancy of the gravitational field of Earth and the saturation curve for water vapour. Water vapour pressure and total pressure appear to be interconnected through these regularities. This interconnection is described by Eq. (6), which is valid for any values of the ratio p_L/p (i.e. is independent of the absolute magnitude of water vapor mixing ratio).

Again, Eq. (6) has no relation to pressure broadening.

3) The referee notes the "water vapor pressure at the surface, τ_{sL}, is the partial pressure produced by the accumulated water vapor above the surface and it has no necessary connection to the saturation vapor pressure corresponding to a surface temperature".

This statement opposes the available evidence on the atmospheric water content and its dependence on surface temperature. Calculating the total atmospheric water content (which corresponds to water vapor partial pressure at the surface) with the use of Clausius-Clapeyron equation, Raval and Ramanathan (1989) obtained a 20% agreement of the calculations with the satellite measurements. They further explicitly noted that this good agreement is a consequence of atmospheric water content (and, hence, water vapor partial pressure at the surface) "being largely determined by surface tem-

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perature", in agreement with the conclusions of many other studies, see, e.g., (Prabhakara et al., 1982).

This result is physically transparent – as far as water vapor partial pressure drops exponentially (and, hence, very rapidly) with height, the major contribution into the total water amount comes from the lower atmosphere, where the impact of surface temperature is deciding.

4) The referee states that under terrestrial conditions there is no empirical evidence for the outgoing thermal radiation to decrease exponentially with increasing surface temperature and considers this fact as disproving the results of our paper.

The fact that on the modern Earth the outgoing radiation into space increases with surface temperature is very well known and was numerically evaluated in many studies (Raval and Ramanathan, 1995; Stephens and Greenwald, 1991a,b; Gorshkov and Makarieva 2002). However, terrestrial climate dynamics is not of purely physical nature. On the real Earth, the climate is severely impacted by the biological and ecological factors the importance of which has started to be recognised only very recently (see, e.g., Foley et al., 2003). In particular, the transparency of the surface waters which determines penetration of solar radiation and, ultimately, temperature of the oceanic surface, is under full biotic control (Sathyendranath et al., 1991). Hence, on the real Earth climatic change will proceed differently as compared to a lifeless planet covered by liquid ocean. As far as the dynamics of the OLR change with surface temperature is a major determinant of climate stability (Gorshkov and Makarieva, 2002; Alley et al., 2003), it is important to reveal the mechanisms that are responsible for the observed long-term climatic stability, in order to ensure that these mechanisms (that virtually keep the planet habitable) are not undermined in the course of the on-going anthropogenic transformation of the planet (Gorshkov et al. 2004).

It is therefore necessary to study separately the basic physical mechanisms of climate change, to decouple them from ecological and biological ones, which will make the

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impact of both more straightforwardly assessible. In our paper we pursue namely this goal. In models that are numerically fitted to describe the existing climate the impact of various physical mechanisms cannot escape being obscured by the procedure of artificial fitting, in the course of which the unknown relationships between the studied variables have to be postulated with no independent physical analysis of their validity.

With regard to empirical support of our approach, we note that our equations do not contain a single fitting parameter – we exclusively operate with directly measurable variables. In the absence of any artificial procedures improving correlation between the theory and observations, our approach accurately reproduces in numerical terms the observed height of convection on Venus and the maximum height of convection on Earth, which is found in the tropics. It also allows to explain the difference in the height of convection between the tropical and polar zones on Earth.

When referring to our study, the referee repeatedly uses the phrase "toy model". We entirely disagree that the study of basic physical mechanisms underlying important climatic phenomena can be considered in these terms. In our study we explicitly show that several published climatic models are based on invalid physical assumptions, which render the results of these models incorrect, independent of their intricacy and the number of involved parameters.

References

Alley, R. B., Marotzke, J., Nordhaus, W. D., Overpeck, J. T., Peteet, D. M., Pielke, R. A., Jr., Pierrehumbert, R. T., Rhines, P. B., Stocker, T. F., Talley, L. D. and Wallace, J. M.: Abrupt Climate Change. Science, 299, 2005–2010, 2003.

Foley, J. A., Costa, M. H., Delire, C., Ramankutty, N. and Snyder, P.: Green surprise? How terrestrial ecosystems could affect earth's climate. Front. Ecol. Environ., 1, 38–44, 2003.

Gorshkov, V. G., Makarieva, A. M. and Gorshkov, V. V.: Revising the fundamentals of

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ecological knowledge: The biota-environment interaction. Ecological Complexity, 1, in press, 2004.

Gorshkov, V. G. and Makarieva, A. M.: Greenhouse effect dependence on atmospheric concentrations of greenhouse substances and the nature of climate stability on Earth, Atmos. Chem. Phys. Discuss., 2, 289–337, 2002.

Michalas, D. and Michalas, B. W.: Foundations of radiation hydrodynamics, Oxford Univ. Press, New York, 1984.

Prabhakara, C., Chang, H. D. and Chang, T. C.: Remote Sensing of Precipitable Water over the Oceans from Nimbus 7 Microwave Measurements. J. Appl. Meteor., 21, 59-68, 1982.

Ramanathan, V. and Coakley J. A.: Climate modeling through radiative-convective models, Rev. Geophys. Space Phys., 16, 465–489, 1978.

Raval, A. and Ramanathan, V.: Observational determination of the greenhouse effect, Nature, 342, 758–761, 1989.

Sathyendranath, S., Gouveia, A. D., Shetye, S. R., Ravindran, P. and Platt, T.: Biological control of surface temperature in the Arabian Sea, Nature, 349, 54–56, 1991.

Stephens, G. L. and Greenwald, T. J.: The Earth's radiation budget and its relation to atmospheric hydrology 1. Observations of the clear sky greenhouse effect, J. Geophys. Res., 96D, 15311–15324, 1991a.

Stephens, G. L. and Greenwald, T. J.: The Earth's radiation budget and its relation to atmospheric hydrology 2. Observation of cloud effects, J. Geophys. Res., 96D, 15325–15340, 1991b.

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