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Atmospheric
Chemistry
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Discussions

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

A. M. Makarieva et al.

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Reply to the second comment by Anonymous Referee #2

I. Pressure broadening and formulae (2.7), (3.5)

In his first comment the referee stated that relationship (2.7) in our paper

$$\frac{\tau}{\tau_s} = \frac{p}{p_s} \qquad (2.7)$$

was based on the assumption of pressure broadening for extinction coefficient. On the basis of this statement, the referee questioned the validity of (2.7) for the broad band mean optical depth. The referee also questioned the validity of a similar relationship (3.5) for water vapour

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$$\frac{\tau_L}{\tau_{sL}} = \frac{p_L}{p_{sL}}, \qquad (3.5)$$

by noting that pressure broadening is due to molecular collisions from all gases, not from water vapour molecules. In his second comment, the referee provided his derivation of (2.7) on the basis of certain assumptions about pressure broadening of the extinction coefficient.

Here we show that the referee's derivation of (2.7) is incorrect, based on a confusion of variables involved in the radiative transfer problem. We show that, contrary to the referee's statements, (2.7) and (3.5) are valid for mean optical depth τ calculated for over broad bands (including the case of grey atmosphere), where the effect of pressure broadening is negligible (absent). For optical depth τ_ν corresponding to a particular radiation frequency ν the effect of pressure broadening does not result in (2.7), as suggested by the referee in his second comment, but produces a different relationship between τ_ν and pressure.

Lorentz profile for the resonance absorption is

$$k_{\nu,\mathrm{n}} = S\frac{1}{\pi}\frac{\alpha}{(\nu-\nu_c)^2+\alpha^2}, \quad S = \int k_{\nu,\mathrm{n}} d\nu. \qquad (1)$$

Here S is the line intensity, dimension [cm^2 sec^{-1}]; $k_{\nu,\mathrm{n}} \equiv \sigma_\nu$, dimension [cm^2], is the molecular extinction coefficient (low symbol n is taken from Goody and Yung (1989)), which is equal to the absorption cross section (notation σ_ν is more widely used in theoretical physics). In vacuum $\alpha \equiv \Gamma/h$ is the natural line width, while h/Γ is the mean lifetime of the excited energy level, h is Planck constant.

With growing gas pressure the intensity of molecular collisions increases as well. This accelerates the decay of the excited states of energy levels and decreases their lifetime, thus resulting in broadening of the line width. The value of α becomes proportional to

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the amount of air molecules per unit volume, and, consequently, to air pressure, which allows to write:

$$k_{\nu,\mathrm{n}} \sim (k_{\nu,\mathrm{n}})_s \frac{p}{p_s}, \tag{2}$$

where low index s refers to the values at the planetary surface.

In the meteorological literature one operates with extinction coefficients of different dimensions, including molecular extinction coefficient $k_{\nu,\mathrm{n}} \equiv \sigma_\nu$ [dimension cm^2] and volume extinction coefficient $k_{\nu,\mathrm{v}} = nk_{\nu,\mathrm{n}} \equiv l^{-1}$ [dimension cm^{-1}], where n is concentration of molecules and l is photon's mean free path length. Thus, $k_{\nu,\mathrm{n}} \equiv \sigma_\nu$ and $k_{\nu,\mathrm{v}} \equiv l^{-1}$ are different physical variables. They are related to optical depth τ_ν as

$$\tau_\nu = \int\limits_z^\infty \frac{dz}{l(z)} = \int\limits_z^\infty k_{\nu,\mathrm{v}}(z)dz = \int\limits_z^\infty n(z)k_{\nu,\mathrm{n}}(z)dz \neq \int\limits_z^\infty k_{\nu,\mathrm{n}}(z)dz. \tag{3}$$

If one neglects the temperature changes within the convective layer (which is about 10%) one can put approximately $n(z) \approx \dfrac{p(z)}{kT_s}$. This allows to write $p(z) = p_s e^{-z/H}$ and, using Eq. (2), we obtain for (3):

$$\frac{\tau_\nu}{(\tau_\nu)_s} \approx \frac{\int\limits_z^\infty p^2 dz}{\int\limits_0^\infty p^2 dz} = \left(\frac{p}{p_s}\right)^2. \tag{4}$$

(Note the principal difference between Eq. (4) for τ_ν obtained from pressure broadening and Eq. (2.7) for τ obtained from the condition of hydrostatic equilibrium, see Eq. (8) below.)

In his second comment, the referee, omitting the low indices in the extinction coefficients and confusing volume and molecular extinction coefficients (i.e. two different physical variables σ_ν and l^{-1}), puts into the definition of τ_ν molecular extinction coefficient $k_{\nu,n} \equiv \sigma_\nu$ from Eq. (2) but without multiplying it by n. The referee thus obtains an incorrect relationship (cf. Eq. (4)):

$$\tau_\nu \neq \tau_\nu^{'} \equiv -\int_\infty^z k_{\nu,\mathrm{n}} dz, \qquad \frac{\tau_\nu^{'}}{(\tau_\nu^{'})_s} = \frac{p}{p_s}, \tag{5}$$

where $\tau_\nu^{'}$ thus defined by the referee has the dimension of [cm^3] and has nothing to do with dimensionless optical depth τ_ν.

In our paper we operate, as the referee correctly pointed out in his first comment, with mean absorption cross-sections $\sigma \equiv \Sigma/N_A$ (N_A is Avogadro number) for broad bands which include many spectral lines:

$$\sigma \equiv \frac{\sum_i S_i}{\Delta\nu}, \qquad \tau \equiv \int_z^\infty \frac{dz}{l(z)} = \sigma \int_z^\infty n(z)dz = \Sigma \int_z^\infty N(z)dz \tag{6}$$

where $\Delta\nu \gg \alpha_i$ is the width of the band considered, S_i is intensity of i-th line and summation is over all lines in the band; $N(z) \equiv n(z)/N_A$ is molar concentration and $\Sigma \equiv \sigma N_A$ is the mean molar cross-section. The mean absorption cross-section $\sigma \equiv k_\mathrm{n}$ is independent of frequency and is not affected by pressure broadening of individual absorption lines, as far as line intensity S is invariant with respect to pressure broadening as well.

In our first reply we stated that Eq. (2.7) for τ is derived from the condition of hydrostatic equilibrium:

$$\frac{dp}{dz} = -N(z)Mg \tag{7}$$

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Here $M = 29$ g mole^{-1} is air molar mass. Expressing N from Eq. (7) and putting it into the above expression for τ we obtain:

$$\tau = \Sigma \int_z^\infty N(z)dz = -\frac{\Sigma}{Mg}\int_z^\infty \frac{dp}{dz}dz = \frac{\tau_s}{p_s}p \qquad (8)$$

Note that Eq. (8) and Eq. (2.7) are exact and independent of temperature changes in the atmosphere, while the above Eq. (4) for pressure broadening is approximate, valid in the approximation of constant atmospheric temperature.

In his second comment the referee stated that "different approaches should give the same answer" and attempted to derive (2.7) from pressure broadening. This statement is incorrect even for τ_ν, for which pressure broadening is essential. This is because hydrostatic equilibrium and pressure broadening are two completely unrelated physical phenomena. There can be

1) hydrostatic equilibrium without pressure broadening (in this case the equation for τ_ν will coincide with Eq. (2.7) for τ);

2) hydrostatic equilibrium and pressure broadening (Eq. (4) above);

3) pressure broadening without hydrostatic equilibrium;

4) no pressure broadening and no hydrostatic equilibrium.

In all the four cases the underlying physics and the resulting ratios between $\tau_\nu/(\tau_\nu)_s$ will be different.

Relationship (3.5) is not derived from observations, contrary to what the referee is saying in his second comment. The explicit derivation of Eq. (3.5) occupies pages 6711 and 6712 in the paper and is based on eqs. (3.1), (3.2), (3.3) and (3.4). We do not think it is necessary to re-write these formulas here once again. We believe that now as we have explained in detail that pressure broadening and the above Eq. (1) are

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unrelated to the physics considered in the paper, it will be possible for the referee to understand the derivation of Eq. (3.5). One misprint correction should be made in the text: in the third line on page 6712 one should read "with use of Eqs. (3.1) and (2.6)" instead of "with use of Eqs. (3.1) and (2.4)".

II. Other comments

Other statements made by the referee in his second comment largely re-iterate what was said in his first comment, to which we have already provided a reply. We would like to add the following:

The referee remarks that in the atmosphere the change of water vapor is dramatic with time and pressure, while the change of pressure is relatively very small. We have already noted that our formula

$$\frac{\tau_L}{\tau_{sL}} \approx \left(\frac{p}{p_s}\right)^{\beta_s}, \tag{9}$$

is written for the **mean** values of pressures, not for their variances. That the variance of water vapour pressure is high is a natural consequence of water vapor being far from hydrostatic equilibrium. This effect of vertical compression of the water vapour profile in the atmosphere, explicitly discussed in the paper, brings about intensive fluxes of water vapor and is responsible for large fluctuations of water vapor concentration in the atmosphere.

Without making any quantitative statements, the referee objects the results obtained by Raval and Ramanathan (1989) who, in agreement with the other authors and empirical observations, stated that surface temperature is the **major** determinant of atmospheric water content and, hence, τ_L. The referee writes that "surface temperature could affect the water vapor profile to some extent". According to the fundamental physical

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laws (not models!), this extent is the deciding one in the determination of the mean atmospheric water content.

The results of our paper pertain a lifeless planet with a liquid hydrosphere. The present-day Earth is not lifeless yet and its climatic system displays a different behaviour influenced by various ordered non-random processes in the biosphere. This behaviour is described by the ERBE data. A detailed comparison of the modern Earth and a lifeless Earth with exponentially decreasing OLR was given in our earlier paper (Gorshkov and Makarieva, 2002a). We show that the basic physics of a liquid hydrosphere greenhouse substance cannot be responsible for the observed long-term climate stability. The motivation for importance of such studies was explained by us in our previous reply to the referee, as well as in our earlier comments (Gorshkov and Makarieva, 2002b).

Finally, the conclusion about an exponential decrease of OLR with surface temperature is perceived by the referee as "too strong". The referee is presumably unaware of the fact that even on the present-day Earth a radical drop of OLR with surface temperature is an observable phenomenon for cloudy sky to which our statement about exponential OLR decrease pertains. Using the ERBE data, Stephens and Greenwald (1991) reported that for the cloudy sky the OLR drops approximately 1.5-fold with surface temperature rising from 299 to 301 K. This is an even more considerable drop than predicted from the Clausius-Clapeyron equation, which suggests a two-fold increase in τ (and, consequently, a two-fold drop in OLR) only for each ten degrees of temperature rise.

References

Goody, R. M. and Yung, Y. L.: Atmospheric radiation, theoretical basis, 2nd edn., Oxford Univ. Press, New York, 1989.

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, 2002a.

Gorshkov, V. G. and Makarieva, A. M.: Interactive comment on "Greenhouse effect dependence on atmospheric concentrations of greenhouse substances and the nature of climate stability on Earth" by V.G. Gorshkov and A.M. Makarieva, Atmos. Chem. Phys. Discuss., 2, S236–S239, 2002b.

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

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, 1991.

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