Radiative-convective equilibrium in a grey atmosphere

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Complex systems in climate physics, 3 October 2023

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- A radiative-convective model is used to study a grey atmosphere.
- Comparison between numerical and analytical solutions is possible in radiative equilibrium.

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2. RTE describes radiative processes.
3. Fluid dynamics equations describe convective processes.

Hypotheses

- Thermodynamic energy equation in Local Thermodynamic Equilibrium (LTE):

$$\frac{\partial T}{\partial t} = -\frac{1}{\varrho c_P}\frac{\partial q}{\partial z} \quad . \tag{1}$$

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1. Thermodynamic energy equation describes average vertical temperature profile.
2. The study is conducted on an atmosphere in radiative-convective equilibrium.
3. Quantities do not depend on the frequency of electromagnetic radiation.

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- Hypotheses on total heat flux.
- Resulting thermodynamic energy equation:

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1. Diurnal cycle, constant irradiance, constant Bond albedo, surface emits blackbody radiation, constant gravitational acceleration.
2. Hydrostatic equilibrium, constant specific heat at constant pressure, scattering is neglected, absorption coefficient depends only on altitude, constant mass attenutation coefficient, ideal gas.
3. Heat flux determined only by radiative and convective processes, two-stream approximation, numerical correction for convection.

Vertical coordinates

- Relation between pressure and altitude:

$$P(z) = P_\mathrm{g} \exp\left(- \frac{z - z_\mathrm{g}}{z_0} \right) \quad . \tag{3}$$

- Relation between optical depth and pressure:

$$\delta(P) = \frac{\mu_\mathrm{m}}{g} (P - P_\mathrm{TOA}) \quad . \tag{4}$$

- Relation between optical depth and altitude:

$$\delta(z) = \frac{\mu_\mathrm{m}}{g} \left(P_\mathrm{g} \exp\left(- \frac{z - z_\mathrm{g}}{z_0} \right) - P_\mathrm{TOA} \right) \quad . \tag{5}$$

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1. Obtained from hydrostatic equilibrium and ideal gas law.
2. Obtained from definition of optical depth, hydrostatic equilibrium and hypotheses on attenutation coefficient.
3. Obtained by combining relations (3) and (4).

Analytical solution

- RTE for non-scattering medium in LTE:

$$\frac{1}{\mu}\frac{\partial L}{\partial z} = B_\nu - L \quad . \tag{6}$$

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Numerical solution

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└Radiative equilibrium
└Numerical solution

2023-10-02

Radiative-convective equilibrium

Radiative-convective equilibrium

Conclusion

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└─Conclusion

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