Radiativeconvective equilibrium in a grey atmospher

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Radiative-convective equilibrium in a grey atmosphere

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Complex systems in climate physics, 3 October 2023



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Radiative-convective equilibrium in a grey atmosphere

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Complex systems in climate physics, 3 October 2023

- 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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Introduction

• Average vertical temperature profile T(t, z) of atmosphere.

1. The analysed quantity is the atmospheric temperature profile averaged over all latitudes and longitudes.

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Average vertical temperature profile T(t, z) of atmosphere.

- Average vertical temperature profile T(t, z) of atmosphere.
- Radiative Transfer Equation (RTE).

- 1. The analysed quantity is the atmospheric temperature profile averaged over all latitudes and longitudes.
- 2. RTE describes radiative processes.

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Average vertical temperature profile T(t, z) of atmosphere.

- 1. The analysed quantity is the atmospheric temperature profile averaged over all latitudes and longitudes.
- 2. RTE describes radiative processes.
- 3. Fluid dynamics equations describe convective processes.

• Average vertical temperature profile T(t,z) of atmosphere.

• Radiative Transfer Equation (RTE).

Fluid dynamics equations.

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

$$\frac{\partial T}{\partial t} = -\frac{1}{\rho c_{P}} \frac{\partial q}{\partial z} \quad . \tag{1}$$

1. Thermodynamic energy equation describes average vertical temperature profile.

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└─Introduction

└─Hypotheses



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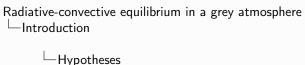
Conclusion

Hypotheses

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

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

• Radiative-convective equilibrium.





Radiative-convective equilibrium.

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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.



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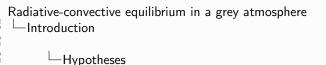
Conclusion

Hypotheses

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

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

- Radiative-convective equilibrium.
- Grey atmosphere.





- 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.

Additional hypotheses

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-Additional hypotheses

Hypotheses on the planet.

Additional hypotheses

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Hypotheses on the planet.

1. Diurnal cycle, constant irradiance, constant Bond albedo, surface emits blackbody radiation, constant gravitational acceleration.

Additional hypotheses

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Hypotheses on the planet.
 Hypotheses on the composition of atmosphere

Additional hypotheses

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- Hypotheses on the planet.
- Hypotheses on the composition of atmosphere.

- 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.

Additional hypotheses

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Additional hypotheses

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- Hypotheses on the planet.
- Hypotheses on the composition of atmosphere.
- Hypotheses on total heat flux.
- Resulting thermodynamic energy equation:

$$\frac{\partial T}{\partial t} = -\frac{1}{\varrho c_{P}} \frac{\partial}{\partial z} (E_{U} - E_{D}) \quad . \tag{2}$$

- 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.

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• Relation between pressure and altitude:

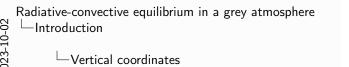
$$P(z) = P_{\rm g} \exp\left(-\frac{z - z_{\rm g}}{z_0}\right) \quad . \tag{3}$$

• Relation between optical depth and pressure:

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

• Relation between optical depth and altitude:

$$\delta(z) = \frac{\mu_{\rm m}}{g} \left(P_{\rm g} \exp\left(-\frac{z - z_{\rm g}}{z_{\rm 0}}\right) - P_{\rm TOA} \right) \quad . \tag{5}$$





- 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).

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Analytical solution

Analytical solution

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Radiative equilibrium

• RTE for non-scattering medium in LTE:

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

Numerical solution

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☐ Numerical solution

Numerical solution

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