Radiativeconvective equilibrium in a grey atmospher

Marco Casari

Introductio

Radiative equilibrium

Radiativeconvective equilibrium

Conclusio

# Radiative-convective equilibrium in a grey atmosphere

Marco Casari

University of Turin

Complex systems in climate physics, 3 October 2023



#### Radiative-convective equilibrium in a grey atmosphere

Radiative-convective equilibrium in a grey atmosphere

Marco Casari

University of Turin

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.

2023-10-02

-Introduction

-Introduction

Marco Casari

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.

# Introduction

Radiative-convective equilibrium in a grey atmosphere 2023-10-02 -Introduction

-Introduction

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.

## Introduction



Radiative-convective equilibrium in a grey atmosphere -Introduction

2023-10-02

-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.
- 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.

└─Hypotheses

Marco Casari

Introduction

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

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

└─Hypotheses

#### Marco Casari

Introduction

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

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

• Radiative-convective equilibrium.

└─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. Quantities do not depend on the frequency of electromagnetic radiation.

# Additional hypotheses

—Additional hypotheses

Hypotheses on the planet.

Additional hypotheses

Marco Casari

Introduction

Radiative equilibrium

Radiativeconvective equilibrium

• Hypotheses on the planet.

Conclusion

2023-10-02

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

## Additional hypotheses

2023-10-02

-Introduction

Additional hypotheses

Marco Casari

Introduction

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

1. Diurnal cycle, constant irradiance, constant Bond albedo, blackbody

Radiative-convective equilibrium in a grey atmosphere

surface, constant gravitational acceleration.

-Additional hypotheses

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

Radiative-convective equilibrium in a grey atmosphere -Introduction

Additional hypotheses

Marco Casari

#### Introduction

Hypotheses on the planet.

Hypotheses on total heat flux.

• Hypotheses on the atmosphere composition.

2023-1 -Additional hypotheses

10-02

- 1. Diurnal cycle, constant irradiance, constant Bond albedo, blackbody surface, 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.

• Relation between pressure and altitude:

$$P(z) = P_{\rm g} \exp\left(-\frac{z - z_{\rm g}}{z_0}\right) \quad . \tag{2}$$



Vertical coordinates

• Relation between pressure and altitude:

$$P(z) = P_{\rm g} \exp\left(-\frac{z - z_{\rm g}}{z_{\rm 0}}\right) \quad . \tag{2}$$

• Relation between optical depth and pressure:

$$\delta(P) = \frac{\mu_{\rm m}}{g} (P - P_{\rm TOA}) \quad . \tag{3}$$

Radiative-convective equilibrium in a grey atmosphere └─Introduction

Vertical coordinates

└─Vertical coordinates



#### Vertical coordinates

Relation between pressure and altitude:

$$P(z) = P_{\rm g} \exp\left(-\frac{z - z_{\rm g}}{z_{\rm 0}}\right) \quad . \tag{2}$$

• Relation between optical depth and pressure:

$$\delta(P) = \frac{\mu_{\rm m}}{g} (P - P_{\rm TOA}) \quad . \tag{3}$$

• Relation between optical depth and altitude:

$$\delta(z) = \frac{\mu_{\rm m}}{g} \left( P_{\rm g} \exp\left(-\frac{z - z_{\rm g}}{z_{\rm 0}}\right) - P_{\rm TOA} \right) \quad . \tag{4}$$

Radiative-convective equilibrium in a grey atmosphere └─Introduction └─Vertical coordinates



# Analytical solution

Radiative-convective equilibrium in a grey atmosphere Radiative equilibrium

Analytical solution

2023-10-02

 $\sqsubseteq$ Analytical solution

Marco Casari

Introduction

Radiative equilibrium

Radiativeconvective equilibrium

Conclusio

#### Numerical solution

Radiative-convective equilibrium in a grey atmosphere Radiative equilibrium

2023-10-02

☐ Numerical solution

Numerical solution

Marco Casari

Introduction

Radiative equilibrium

Radiativeconvective equilibrium

Conclusio

Marco Casari

### Radiative-convective equilibrium

2

Radiative-convective equilibrium in a grey atmosphere
Radiative-convective equilibrium

Radiative-convective equilibrium

2023-10-02

-Radiative-convective equilibrium

equilibrium Conclusion

Radiative-

#### Conclusion

Radiative-convective equilibrium in a grey atmosphere —Conclusion

Conclusion

2023-10-02

-Conclusion

Marco Casari

Introduction

Radiative equilibrium

Radiativeconvective equilibrium

Conclusion