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A model for the greenhouse effect

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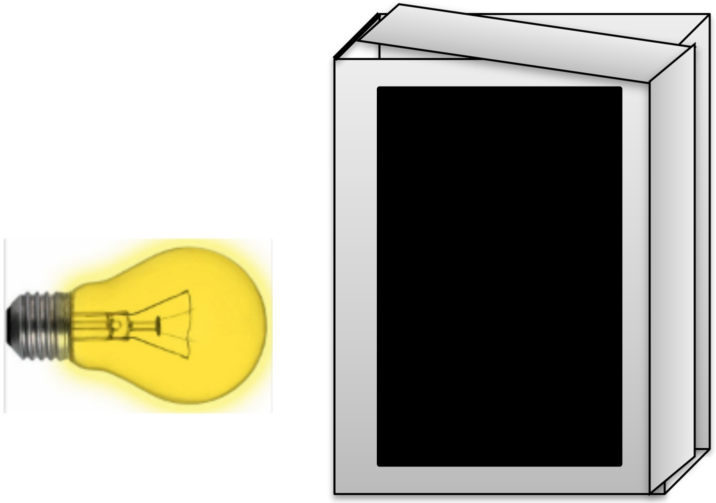
THE EXPERIMENT



EXPERIMENTAL MATERIAL:

- 1 bulb
- 1 'greenhouse' box: black aluminium plate, plastic lid
- 1 temperature sensor
- 1 graphical interface
- LP3 software

CHARACTERISTICS AND PHYSICAL ASSUMPTIONS UNDERLYING THE EXPERIMENT:

- The T sensor rests on the back of the aluminium plate (the assumption is made that the T is uniform throughout the plate);
- The black aluminium plate 'simulates' the earth's surface modelled as a black body;
- The plastic lid 'simulates' the atmosphere (making the assumption that it is a uniform layer).

EXPERIMENT in progress

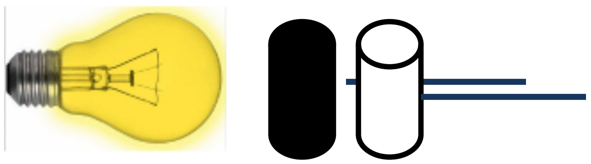
…

GROUP WORK!!!

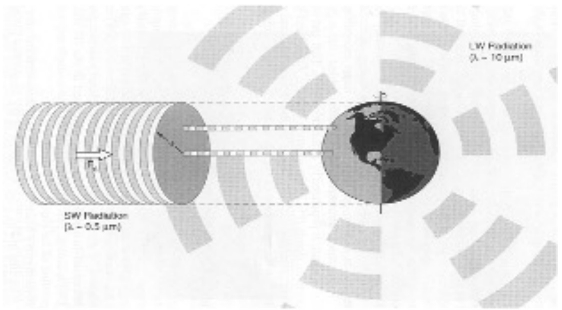
(20 minutes)

From EXPERIMENTS to MODEL

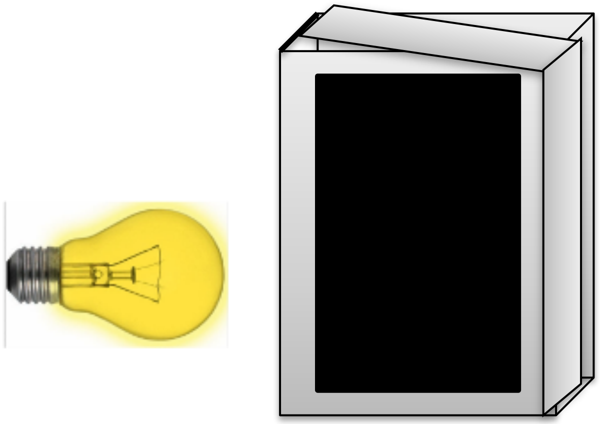
From the cylinders ...



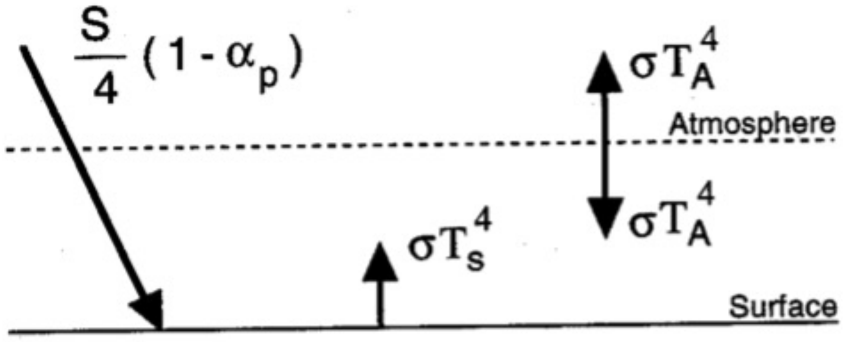
... to the planetary model



From the box ...



... to the Earth-Atmosphere system

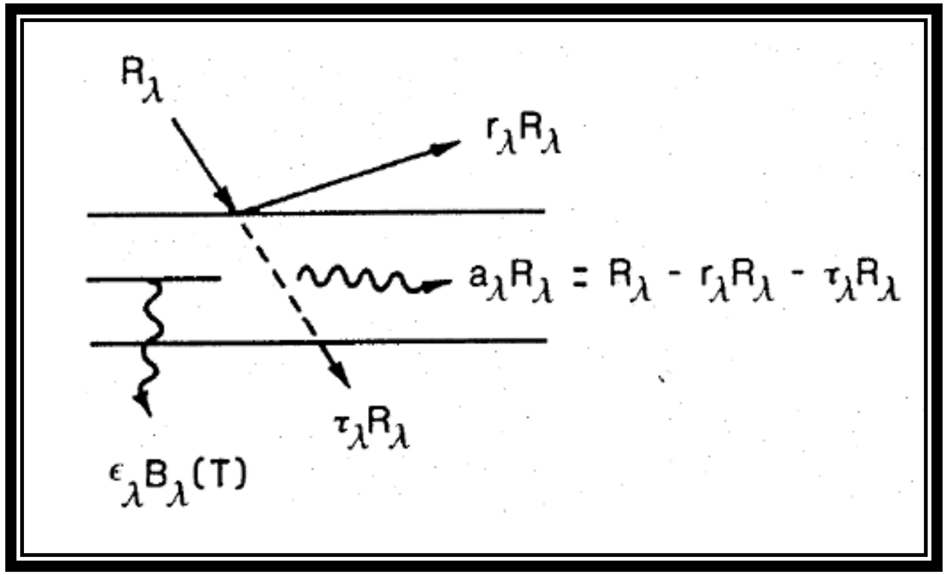


INTERACTION PROPERTIES

The Earth-Atmosphere System

To understand the role of the atmosphere, consider:

- the interaction properties between radiation and matter (**a**,**r**,**t**)
- the emissivity **ε**



Remember: a,r,t and ε vary with wavelength!!!

We will continue to adopt a simplified model and discuss **average** properties in the short-wave range (SW, 0.3-4 microns) and in the long-wave, or infrared range (LW, 4-50 microns).

This is a simplification!!!

Model 1: a planet without an atmosphere
Model 2: a planet with a homogeneous atmosphere (1 layer)

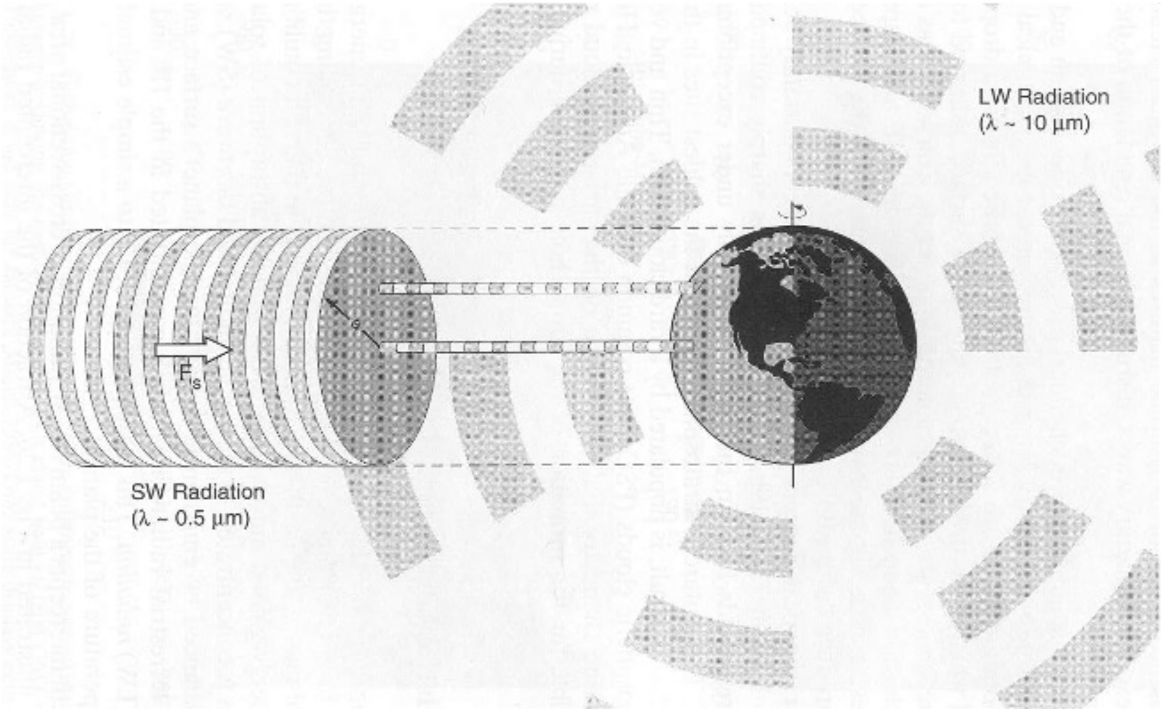
Model 1: planetary climate balance

Under equilibrium (steady-state) conditions, a relationship can be written between the average energy input (solar) and the average energy output.

$$\underbrace{(1-\alpha_p)S\pi r^2}_{\text{Absorbed radiation power}} = \underbrace{4\pi r^2\sigma T_e^4}_{\text{Emitted radiation power}}$$

- Planetary albedo
- Radiation from the sun
- Sunlit section

- Sphere surface (m²)



Model 1: planetary climate balance

$$\left(1-\alpha_p\right)S\pi r^2 = 4\pi r^2\sigma T_e^4$$

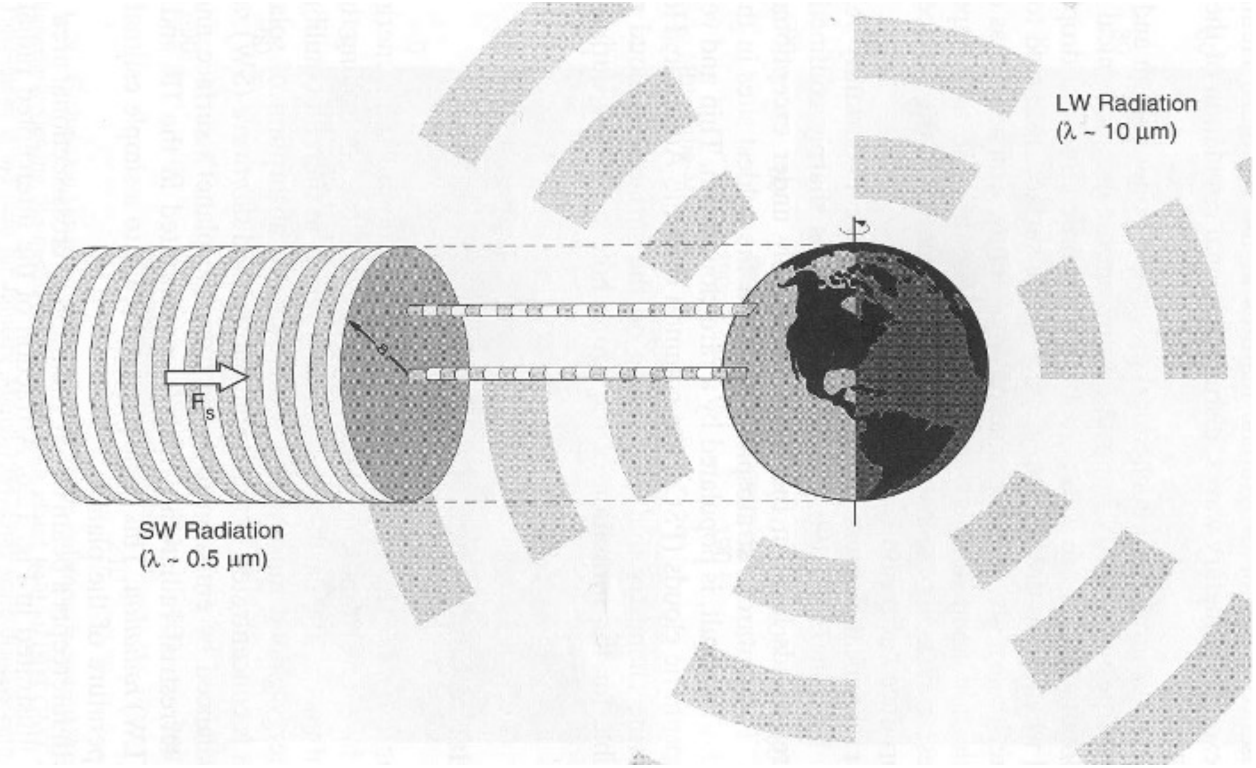
$$T_e = \left[\frac{(1-\alpha_p)S}{4\sigma}\right]^{1/4}$$

$\alpha_p = 0.3$ (*parte riflessa*)

$S \cong 1370\ W/m^2$

$\sigma = 5.67 \cdot 10^{-8}\ W/(m^2 \cdot K^4)$

$T_e = 255\ °K$



What are the assumptions/choices made in this MODEL?

1) We have put ourselves in a state of **equilibrium,** i.e. it is a planetary balance relationship and therefore identifies a stationary situation.
2) It can be applied to our planet to identify an **average** situation **over a long** period when compared to the period of the Earth's revolution (to eliminate seasonal variations and thus also daily variations).
3) We considered the **Earth** as:
   a) a perfectly spherical ball (assumption about its geometric properties);
   b) a black body (a hypothesis on its interaction properties with radiation)

What are the assumptions/choices made in this MODEL?

4) We considered the radiation of the body as if it were irradiated perpendicularly by a light ray with a cylindrical cross-section of radius equal to that of the Earth (geometric hypothesis)

5) We have made a **global average of the energy absorbed** by the body (*e.g.* being a spherical surface at the poles the net energy input is lower than at the equator) and also **a global average of the energy emitted**.

6) We put ourselves in the **absence of** atmosphere

Assumptions that we will 'unlock' in the next model!

Model 2: role of an atmosphere

The presence, around a planet, of an atmosphere that interacts with e.m. radiation. , **while not changing the balance between incoming and outgoing radiation,** substantially changes the average temperature of the layer and the surface.

Hypot hesis

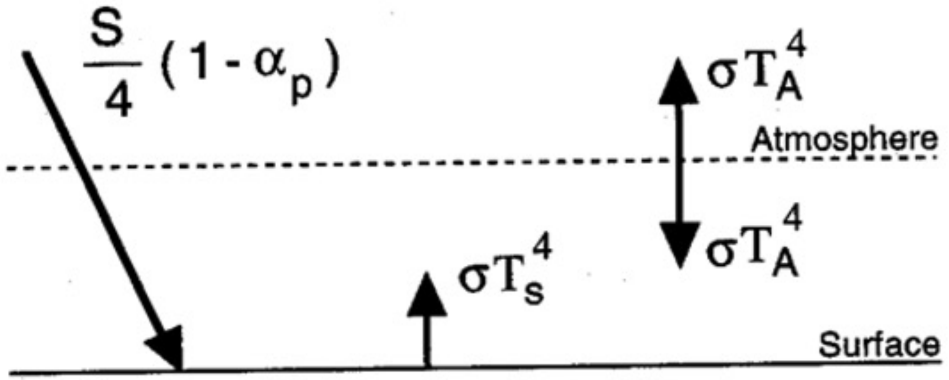
- SW incoming radiation does not change (assume solar constant)
- The outgoing radiation does not change because we are in equilibrium!

- **In the SW, the atmosphere is transparent**
- **In the LW it is completely absorbent**

(micron)	a (atm)	a (sup)	r
0.5 (SW)	0	1	0
10 (LW)	1	1	0

Model 2: role of an atmosphere (aatm=1)

The thermodynamic equilibrium hypothesis allows us to calculate the emissivity: **ε = a**



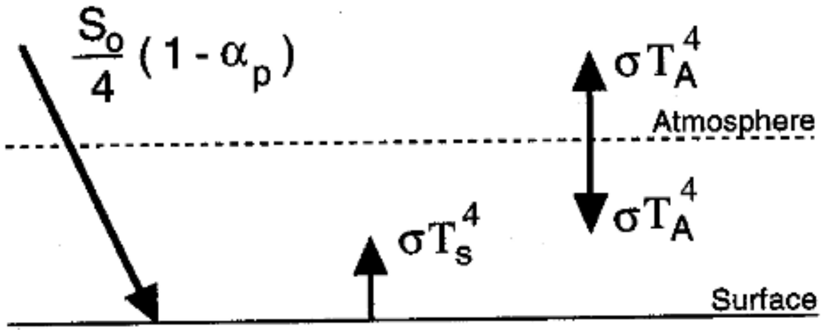
$$(1-\alpha_p)\frac{S}{4} = \sigma T_A{}^4 = \sigma T_e{}^4$$ → **System energy balance (sup+atm)**

$$(1-\alpha_p)\frac{S}{4} + \sigma T_A{}^4 = \sigma T_S{}^4$$ → **Surface energy balance**

$$T_S{}^4 = 2T_A{}^4 \quad \Rightarrow T_S = 303\ °K$$

Model 2: role of an atmosphere (aatm=a)

(micron)	a (atm)	a (sup)	r
0.5 (SW)	0	1	0
10 (LW)	a (*)	1	0



Thermodynamic equilibrium **ε = a**

(*) 0< *a*<1

$$(1-\alpha_p)\frac{S}{4} = \varepsilon\sigma T_A{}^4 + (1-a)\sigma T_S{}^4$$

→ **System energy balance (sup+atm)**

$$(1-\alpha_p)\frac{S}{4} + \varepsilon\sigma T_A{}^4 = \sigma T_S{}^4$$

→ **Surface energy balance**

$$\boxed{T_S{}^4 = \frac{2T_e^4}{2-a} \quad ; \quad T_A{}^4 = \frac{T_e^4}{2-a}}$$

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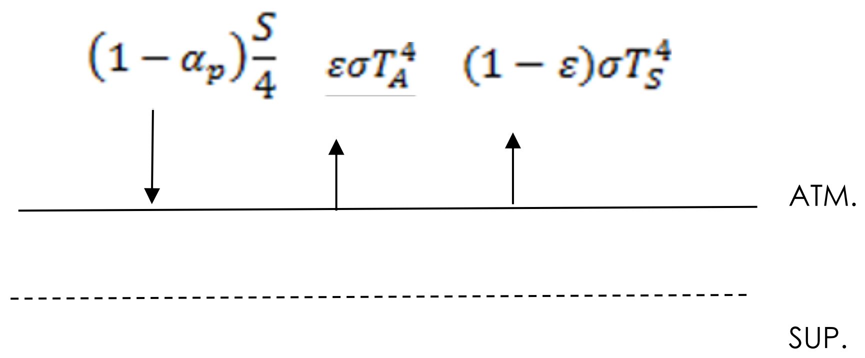
System balance (sup+atm)



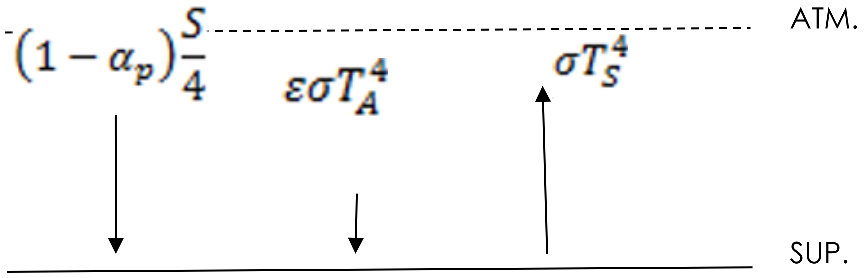
$$(1-\alpha_p)\frac{S}{4} = \varepsilon\sigma T_A{}^4 + (1-a)\sigma T_S{}^4$$

Solar radiation

Radiation emitted by the atmosphere

Radiation emitted from the Earth and transmitted from the atmosphere into space

Balance at the earth's surface



$$(1-\alpha_p)\frac{S}{4}+\varepsilon\sigma T_A{}^4=\sigma T_S{}^4$$

Radiation emitted by the Earth

Solar radiation

Radiation emitted by the atmosphere towards the Earth then absorbed by the Earth)

Model 2: role of an atmsphere (aatm=a)

$$T_S{}^4 = \frac{2T_e{}^4}{2-a} \quad ; \quad T_A{}^4 = \frac{T_e{}^4}{2-a}$$

a (atm for LW)	TA (°K)	TS (°K)
0	214.4	255.0
0.5	230.4	274.0
0.7	238.8	284.0
1	255.0	303.3

As '*a*' *increases, the* temperature of the atm and sup increase, in order to maintain the balance with incoming radiation.

In this case, it is only the Earth that contributes in sending radiation into space.

In this case, it is only the Atmosphere that contributes in sending the radiation into space.

Limitations of this model

- It is assumed that the atmosphere is homogeneous and has only one temperature.

- It does not include the fact that in a real atmosphere, gases have densities that vary with altitude and temperature also varies with altitude.

- Moreover, the atmosphere as a whole is NOT in thermodynamic equilibrium.

Assumptions/simplifications underlying the model

(consider that climate is not such a simple thing)

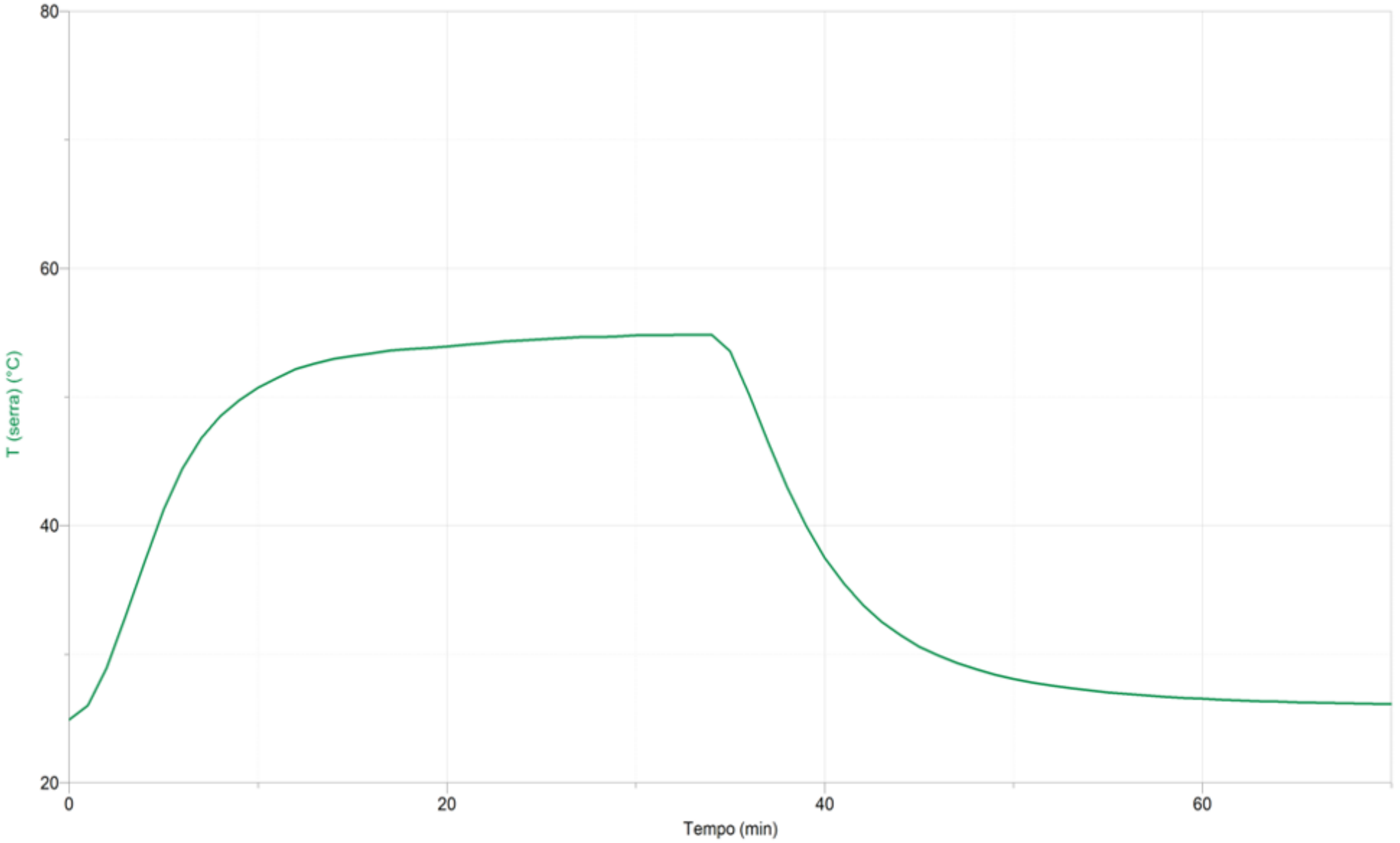
- our calculations predict a homogeneous planet
- we are making global average forecasts
- we are assuming that absorbance is averaged over only two intervals (short wave and long wave)

- carbon dioxide is assumed to be evenly distributed over the entire globe, but water vapour decreases as it moves towards the polar regions, so absorbance decreases

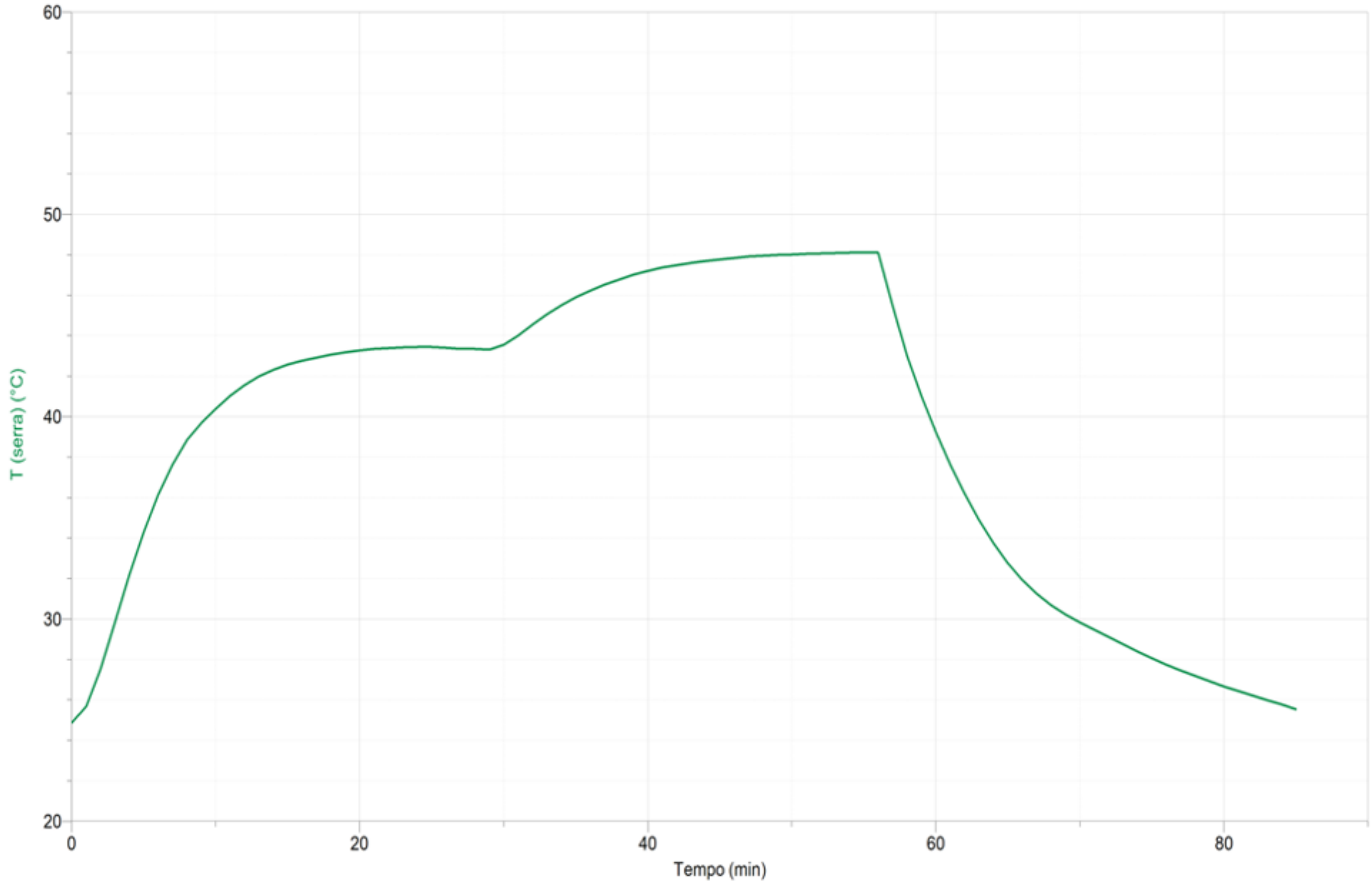
- **there are feedback effects** (melting ice decreases planetary albedo, so if albedo decreases, absorbance increases ... and this is positive feedback, i.e. it goes in the direction of increasing the effect)

GRAPHICS

Greenhouse WITHOUT lid

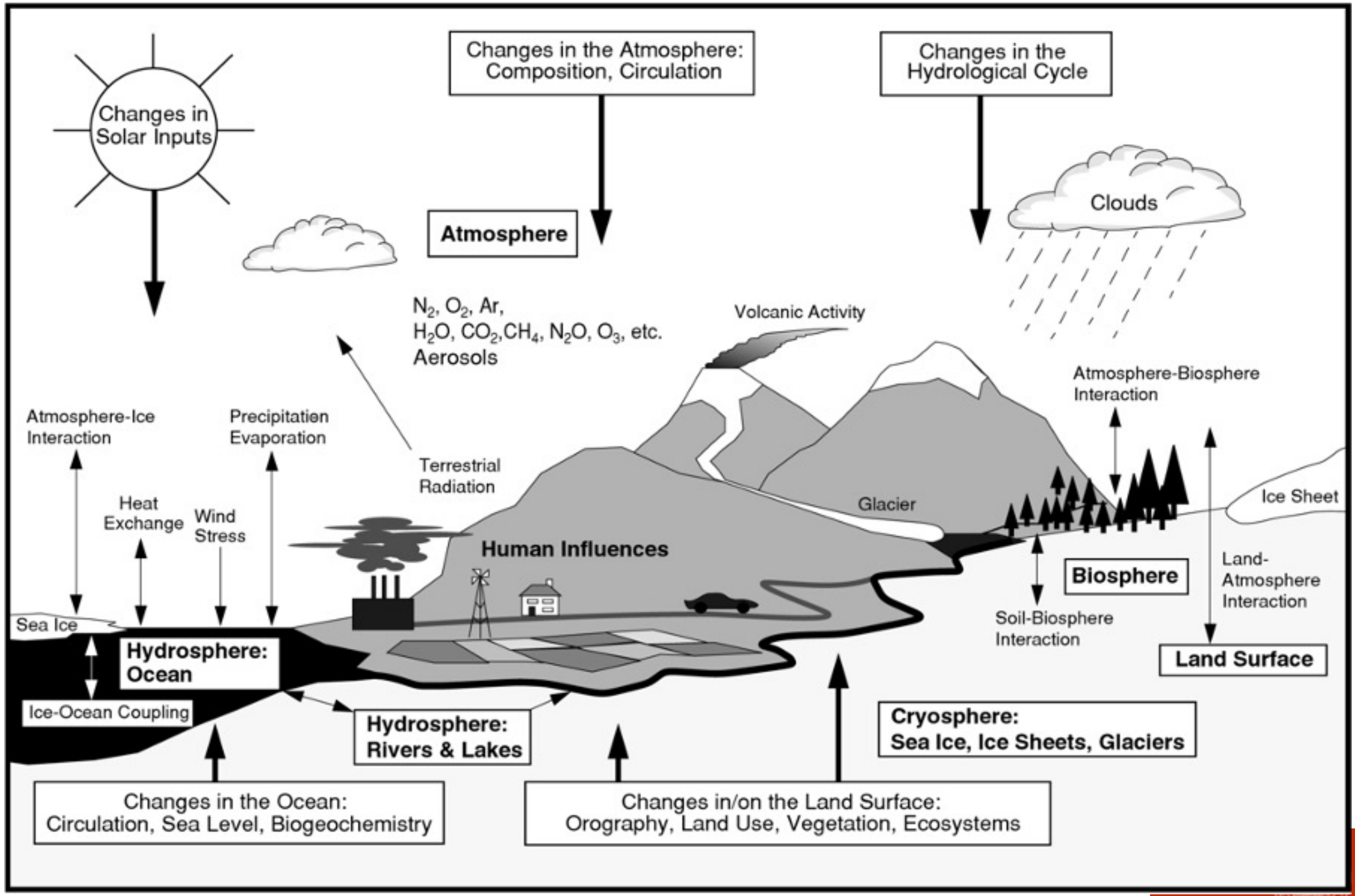


Greenhouse WITH lid



The 'climate' is a complex system!

It is the result of the interaction between the atmosphere and the Earth system, it is therefore composed of many (and different) sub-systems.



(taken from the 2001 WG1-IPCC report)

There are some important considerations to be made ...

The 'recomposition' of the parts does not return the total system in a linear manner, as the interaction between the parts produces feedback effects:

- ***Positive feedback:*** if it adds to the first cause
- ***Negative feedback:*** if it dampens the cause first

REFLECTION ...

- *What is the added value that the laboratory can provide in an educational course? But also what added value does having to think about experiments in dealing with complex, multi-disciplinary topics, such as climate change, provide to the laboratory?*
- *What are the different attitudes one can have when faced with a laboratory? And what is the relationship between experiment, reality, and modelling?*

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