


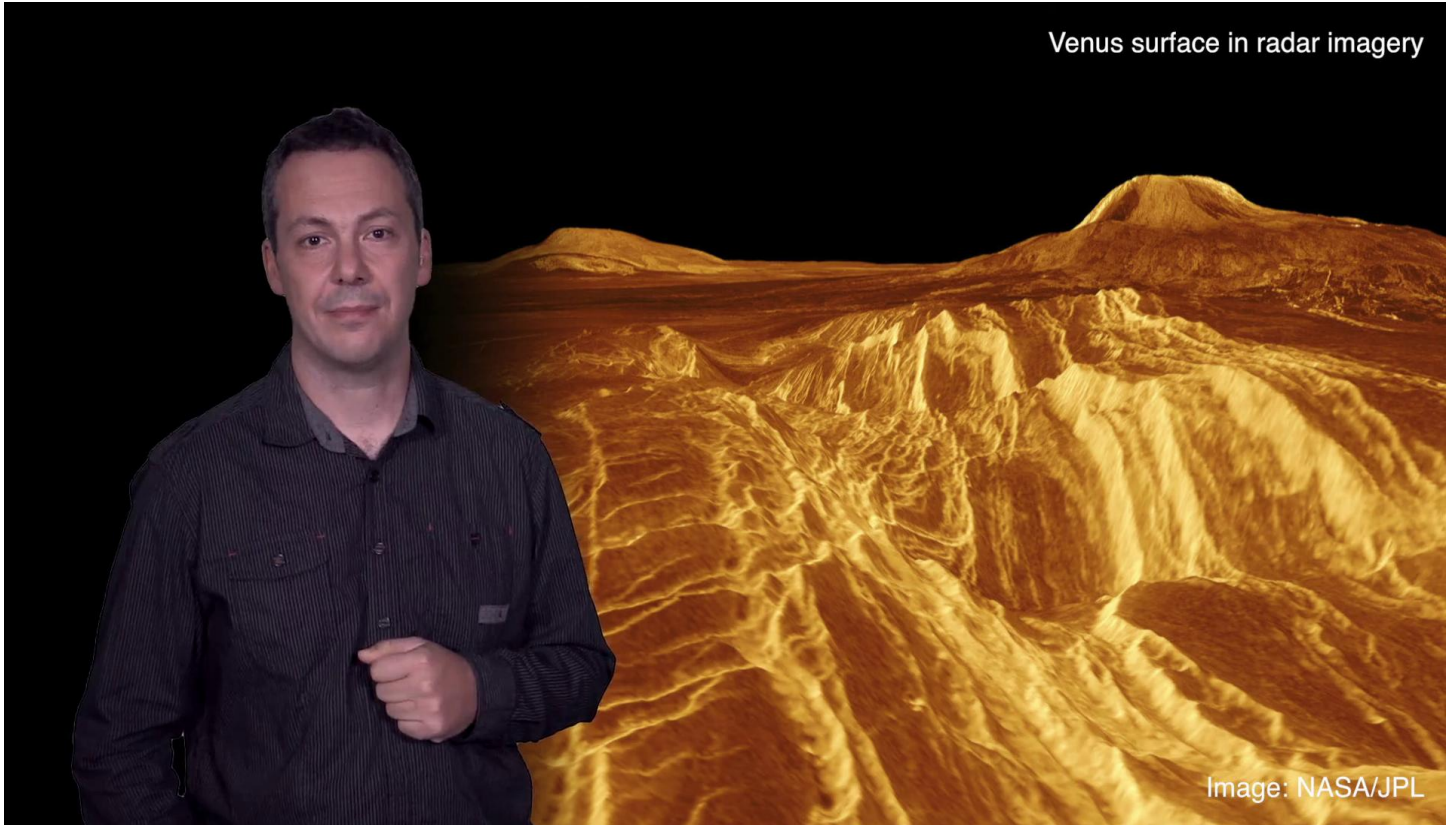
We will now talk about the planets and their atmospheres and in particular on their influence on the physical conditions on the surface of a planet. The Earth, Venus and Mars are for example three very similar planets yet their atmosphere are very different as well as the meteorological features on their surface. We will see in a simplified manner how the energy budget of a planet, namely the balance between received and emitted energy, completely determines the physical conditions on the surface and therefore maybe the development of life.

[illegible]

Summary







For example, on Venus the greenhouse effect is such that the surface temperature is completely determined by atmospheric physics and the atmosphere is so opaque to radiation that only radar imaging is able to unveil the surface of the planet, such as on this picture taken by NASA's Magellan probe.

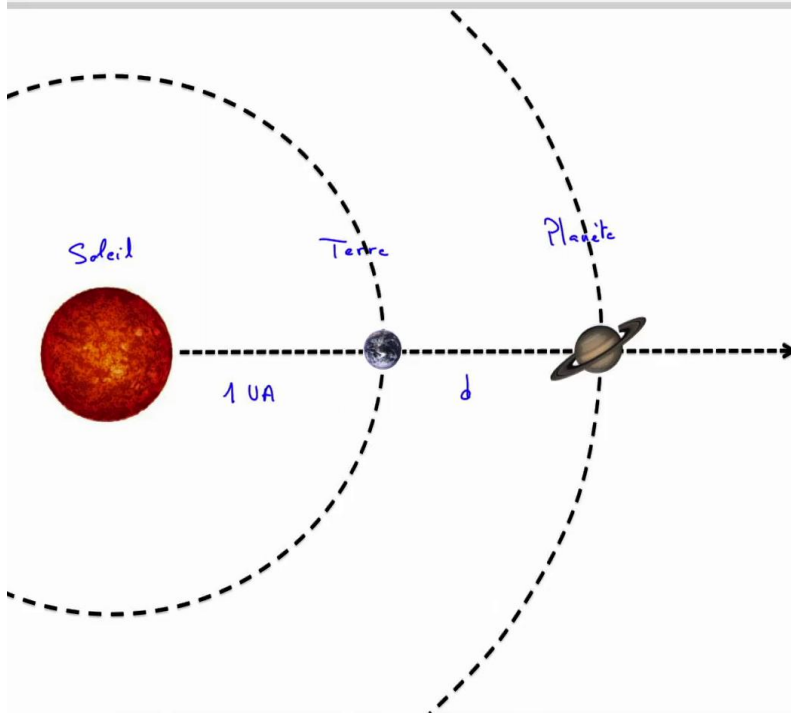
Notes

Summary

0m 38s



The Solar Constant



Energie reçue sur Terre
(hors atmosphère)

→ Constante Solaire

$$S = 1,37 \cdot 10^6 \text{ erg} \cdot \text{s}^{-1} \cdot \text{cm}^{-2}$$

A la distance d

$$S(d) = S \cdot \frac{4\pi d_{\oplus}^2}{4\pi d^2} \cdot 1$$

Introduction to Astrophysics

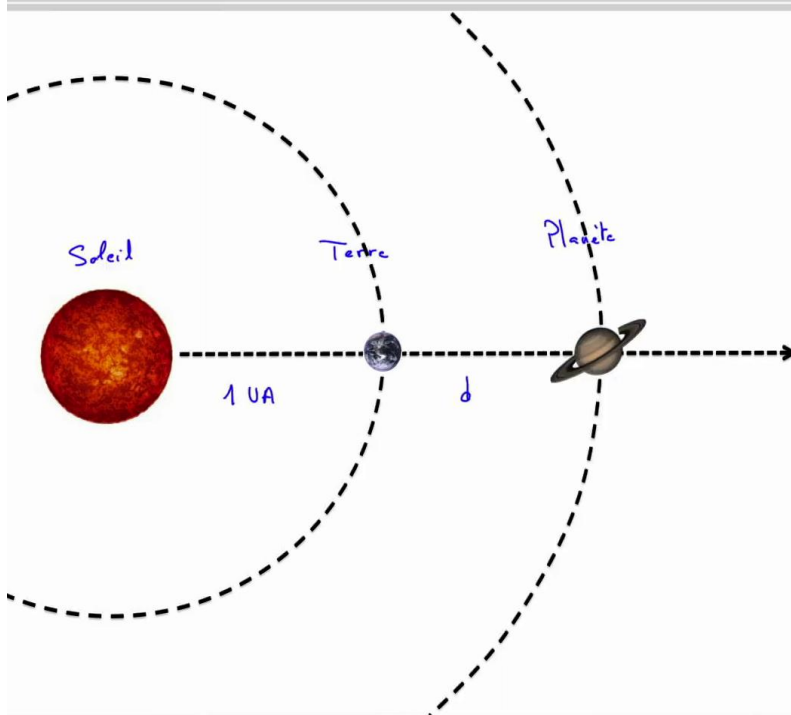
To understand the influence of planetary atmospheres on their planet, let us have a look at the energy budget of each planet, in particular the Earth. We have here a simplified representation of the solar system. The Sun is here, the Earth is here and here we have another planet, Saturn for example. The Earth is of course at one astronomical unit away from the Sun and Saturn, or any other planet, is at a distance d. We will now look at the energy budget, what is the energy received by planets and what is the energy emitted by planets. First the energy received on Earth. The energy received at the top of the atmosphere can be measured for example by satellites and is called the solar constant. The solar constant S is an energy flux, or more accurately a power flux, the numerical value of which is : $1.37 \cdot 10^6 \text{ erg} / \text{cm}^2 \text{ s}$ $1.37 \cdot 10^6 \text{ erg} / \text{cm}^2 \text{ s}$ since the solar energy is diluted, spread over a sphere with a surface of 4π times the square of one astronomical unit. At a distance d, namely the distance d here, S(d) is the solar energy, S integrated on a sphere with a surface of 4π times the square of one astronomical unit : $4\pi \cdot d(\text{Earth})$, so this is the square of one astronomical unit, and diluted on a sphere with a surface of $4\pi d^2$.

Notes

Summary



The Solar Constant



Energie reçue sur Terre
(hors atmosphère)

→ Constante Solaire

$$S = 1,37 \cdot 10^6 \text{ erg} \cdot \text{s}^{-1} \cdot \text{cm}^{-2}$$

A la distance d

$$S(d) = S \cdot 4\pi d_{\oplus}^2 \cdot \frac{1}{4\pi d^2}$$

$$S(d) = S \cdot \left(\frac{d_{\oplus}}{d}\right)^2$$

Introduction to Astrophysics

We have then here $1 / 4\pi d^2$. Finally $S(d)$ is simply a rescaling of S by a factor $(d(\text{Earth})/d)^2$ by a factor $(d(\text{Earth})/d)^2$ We have just seen the energy received by the Earth.

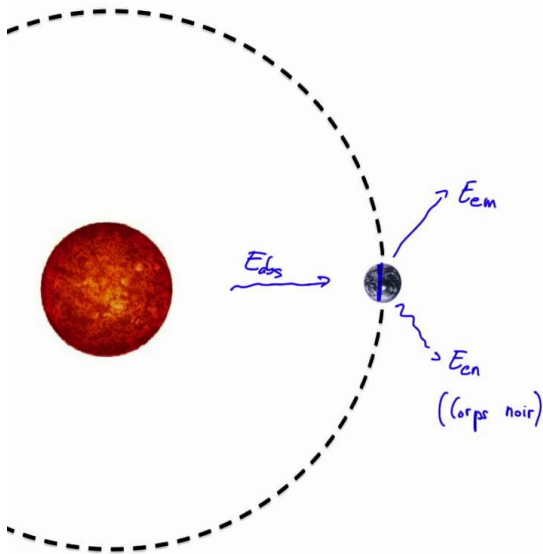
Notes

Summary



2m 59s

Energy Balance for the Earth



$$E_{abs} + E_{em} = E_{cn}$$

$$E_{abs} = S \cdot \pi R_{\oplus}^2 \cdot (1 - A)$$

A: albedo

A = 1 Tout est réfléchi

A = 0 Tout est absorbé

Pour la Terre A = 0.3

Introduction to Astrophysics

Now let us have a look at the full energy balance for the Earth. We have some energy here that is absorbed, which we just talked about. It is the energy flux coming from the Sun. We have some emitted energy which is the energy produced by the planet itself for example due to radioactivity in the mantle or the terrestrial crust. Finally there is some radiated energy. This radiated energy is due to the black body radiation. E_{cn} here is a black body radiation. If we observe the Earth from outside of the solar system and measure its spectrum, we will see a black body spectrum. What is now the energy balance? There is the solar flux which is absorbed energy and there is energy emitted directly by the Earth. Their sum must be equal to the black body energy, the one we observe from outside the solar system, the energy that an outside observer would receive. We rewrite the absorbed energy as a function of the solar constant. It is equal to the solar constant times the Earth's cross section. It is the energy received on Earth. The Earth's cross section is πR^2 . Obviously only a part of the light is absorbed and the rest is reflected. We express this with the factor $1-A$ where A is called the albedo. If $A = 1$ then all the radiation is reflected and if $A = 0$ all of it is absorbed. For the Earth, $A = 0.3$.

Notes

Summary



3m 22s

Energy Balance for the Earth

$$\begin{array}{ccccc}
 E_{abs} & + & E_{em} & = & E_{cn} \\
 \swarrow & & \downarrow & & \searrow \\
 \pi R_{\oplus}^2 \cdot S \cdot (1-A) & & 4\pi R_{\oplus}^2 \cdot Q & & \sigma T_{eff}^4 \cdot 4\pi R_{\oplus}^2 \\
 & & Q = 0.06 \text{ W} \cdot \text{m}^{-2} & & \\
 & & \text{au niveau du sol} & &
 \end{array}$$

Introduction to Astrophysics

So we have an absorbed radiation plus an emitted radiation, of which we're going to talk later, equal to the black body radiation. As we just wrote, the absorbed radiation is π times the radius of the Earth squared, namely the cross section, times the solar constant, times 1 minus the Albedo. The emitted radiation, which can for example be produced by the liquid magma under the terrestrial crust and its radioactivity, is the surface of the Earth, $4\pi \cdot R(\text{Earth})^2$ times Q the produced energy by this radioactivity, say at ground level. We can measure the value of Q and find 0.06 W/m^2 at ground level. We multiply Q by the factor $4\pi R^2$ to get the total energy emitted by Earth at ground level. Now what about the energy radiated as black body radiation. As we saw in the lecture on the black body, a black body emits an energy flux depending on its temperature : σT^4 . So we have σT^4 , T being the effective temperature of the black body. We have to multiply this by the total surface radiating this flux which is simply 4π times the Earth's radius squared. This gives the complete energy balance. Let us rewrite this equation in a slightly different manner.

Notes

Summary



5m 34s

Energy Balance for the Earth

$$E_{abs} + E_{em} = E_{en}$$

$$1 + \frac{4Q}{(1-A) \cdot S} = \frac{4\sigma T_{eff}^4}{(1-A) \cdot S}$$

Pour la Terre $A = 0.3$ (30% de lumière réfléchi)

$$Q = 0.06 \text{ W} \cdot \text{m}^{-2}$$

$$S = 1.37 \cdot 10^6 \text{ erg} \cdot \text{s}^{-1} \cdot \text{cm}^{-2}$$

$$\Rightarrow T_{eff} = 255 \text{ K}$$

Introduction to Astrophysics

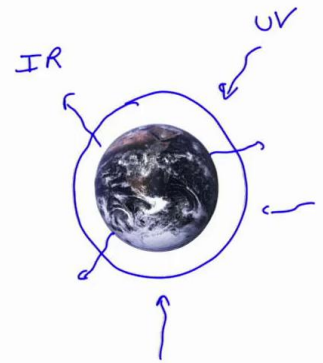
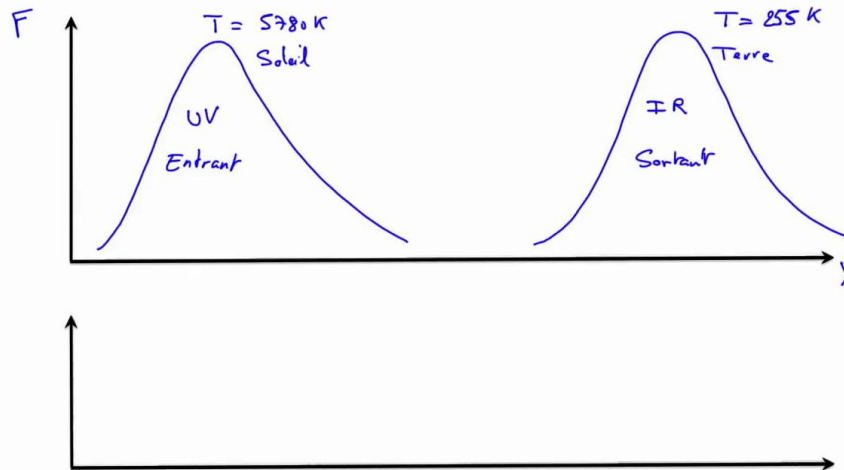
So we have : the absorbed energy plus the emitted energy is the black body energy. If we rearrange the different terms, we end-up with the following equation. So we have $4\sigma T^4$, with T the effective temperature which is actually the parameter we are interested in, over $(1 - A) \cdot S$. For the Earth, $A = 0.3$ which means that 30% of the light is reflected. We also had that $Q = 0.06 \text{ W/m}^2$. We also had that $Q = 0.06 \text{ W/m}^2$ at the Earth's surface. The solar constant S on the terrestrial orbit is $S = 1.37 \cdot 10^6 \text{ erg / cm}^2 \text{ s}$. If we plug all these numbers in this equation we get that the black body temperature of the Earth is 255 K. Note that this is the Earth's black body effective temperature and not the temperature at ground level which is completely dominated by the climatology, by Earth's atmosphere.

Notes

Summary



Energy Balance for the Earth



Introduction to Astrophysics

We just saw that the Earth behaves like a black body. We have the Earth with an atmosphere acting as a filter. We have on the one hand the incoming radiation from the Sun which is UV and visible light and on the other hand the outgoing radiation which is infrared light since we have a black body with a temperature of 255 K which peaks in the infrared domain. On one side we have UV radiation. If I draw here the emitted or received flux on Earth as a function of the wavelength, we have a black body curve. So this is a black body at a temperature of 5780 K, So this is a black body at a temperature of 5780 K, namely the Sun. This is some radiation with a peak in the UV/optical according to Wien's law and it is an incoming radiation. We have therefore an incoming UV/optical radiation which attempts to pass through the Earth's atmosphere acting itself as a filter. The Earth itself, as we just computed, emits black body radiation, with a curve of the same shape but this time with a black body temperature of 255 K. but this time with a black body temperature of 255 K. The Earth emits then in the infrared domain, and this is an outgoing radiation. What happens in the atmosphere ?

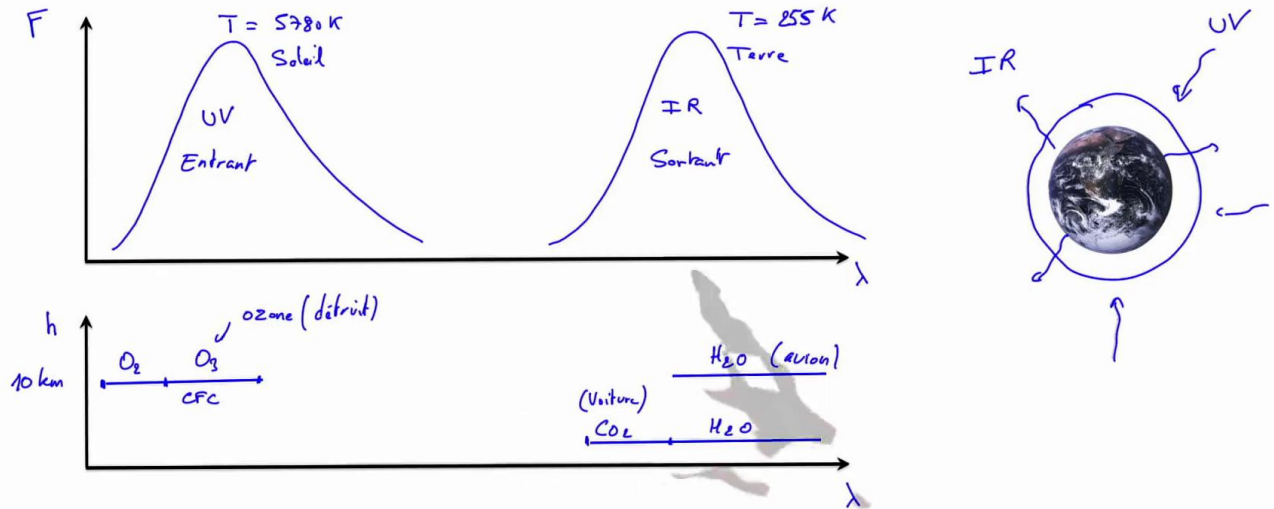
Notes

Summary



9m 03s

Energy Balance for the Earth



Introduction to Astrophysics

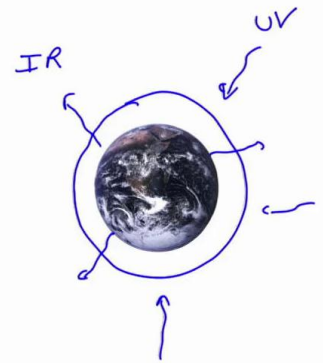
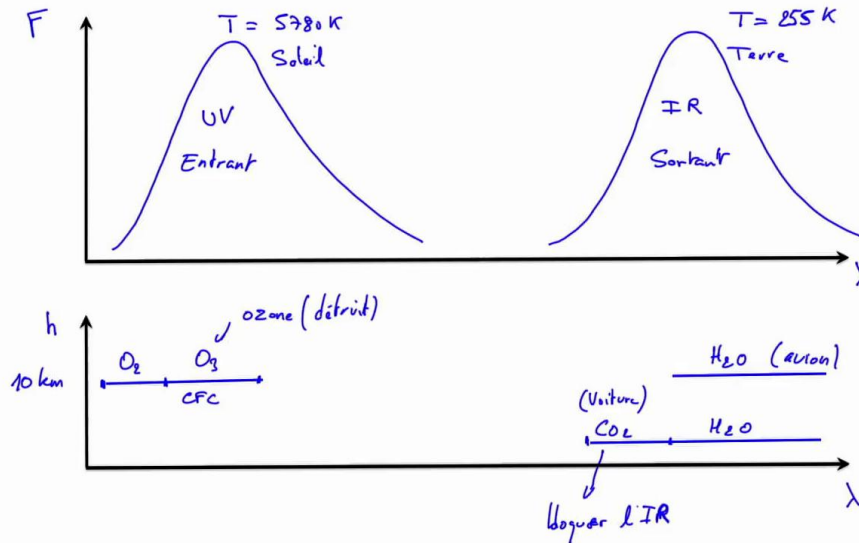
We show here as a function of the altitude and of the wavelength the different filters blocking the several kinds of radiation. First in the upper atmosphere, at an altitude of 10km, we have water molecules and ozone molecules. At ground level, up to a few hundred metres or a few kilometres high, we have CO₂ particles as well as of course some water. There is also water quite high in the atmosphere. There is also water quite high in the atmosphere. It can be water created by the burning of kerosene by the engines of airplanes. So here we have water produced by airplanes and water naturally present at ground level. On the ground, the CO₂ is partly caused by cars. There is here an ozone layer, that CFC can destroy. If we consider all of these together, we have : UV light that enters the atmosphere which would be blocked by the ozone layer but if the ozone has been destroyed it cannot filter this radiation. If the ozone has been destroyed, the UV radiation can penetrate all the way to the ground level because there are no more natural filters. UV light is blocked by ozone. If the ozone layer is destroyed, UV radiation can enter the atmosphere and thus contribute to warming the Earth.

Notes

Summary



Energy Balance for the Earth



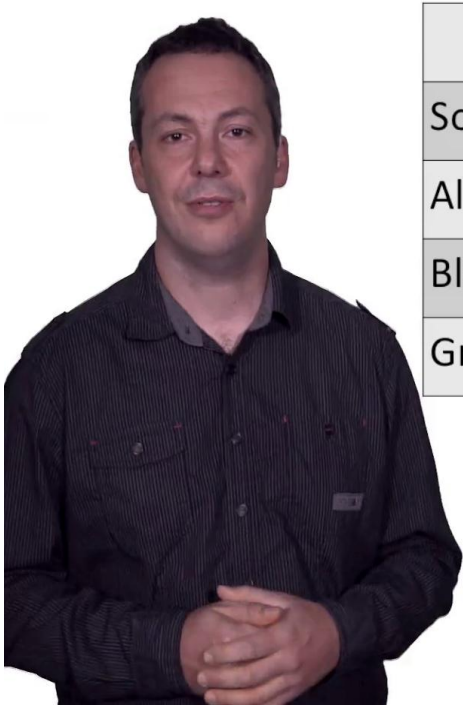
Introduction to Astrophysics

This obviously applies to any other planet which has incoming and outgoing radiation with several filters either at ground level or at high altitude. We have then UV light blocked by ozone, which is not blocked if the ozone layer has been destroyed, and we have an infrared outgoing radiation. This outgoing radiation could naturally escape if there was no filter such as CO_2 which indeed blocks infrared. As a result there is less outgoing radiation than there should and some energy is retained at ground level by this CO_2 , as well as by the water at high altitude, water also being an infrared filter. Water is naturally found at ground level but not at high altitude. Water ejected by the burning of kerosene by airplane motors acts like a filter blocking the outgoing infrared radiation. This shows that the climate we know on Earth and the greenhouse effect on Earth are due to the Sun's temperature, the Earth's black body radiation, and the chemical composition of the atmosphere, which is either natural or artificially altered by mankind and sets up a number of filters blocking incoming or outgoing radiation. There is a natural equilibrium unless any change is imposed by human activities. This equilibrium can be broken for example by adding filters here, water and CO_2 or by destroying filters protecting it from the incoming ultraviolet radiation.

Notes

Summary





	Venus	Earth	Mars
Solar Constant (kW.m^{-2})	2.6	1.4	0.6
Albedo	0.7	0.3	0.2
Black Body Temp. (K)	230	255	216
Ground Temp. (K)	735	288	210

Introduction to Astrophysics

Let us see a few numbers about the influences on the surface temperature of a planet. If we take Venus, the Earth and Mars as example, we see that the solar constant decreases with the distance but not the black body temperatures due to the quite different albedos of the planets and due to the small amount of intrinsic energy produced. However the surface temperature varies heavily due to the presence of an atmosphere regulating the energy fluxes between the planet and the rest of the Universe.

Notes

Summary

14m 29s

