Geo Factsheet

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A Simple Guide to Energy Budgets

Importance of the energy budget

The sun is the Earth's primary source of energy, providing the planet with warmth and light, yet the temperature of the sun's radiating surface is more than 5500 °C. However only a minute proportion (0.002%) of this solar output actually reaches the Earth as the sun's energy is emitted in all directions. The fact that our planet is a relatively warm place indicates just how enormous the energy stores 'locked' in the sun actually are.

The sun's insolation (incoming solar radiation) is essential for maintaining the Earth's climate and life support systems (although some heat energy also comes from geothermal heating deep within the Earth). Through the process of photosynthesis, green plants convert insolation into consumable food energy, carbohydrate. In this way we obtain the majority of our food indirectly from the sun and, on combustion of organic matter (e.g. oil, coal, wood), can release usable energy. Energy can also be collected from the sun through the use of solar panels, which may be used to heat water, or to produce electricity directly (photo-voltaics). Wind and wave energy is also derived from solar radiation. These are sources of indirect solar energy as opposed to the direct energy of insolation.

Solar energy is probably the most environmentally sound renewable energy resource of all and it has many economic advantages. In particular, less developed tropical areas have great potential for harnessing solar energy especially at a local scale, although economic difficulties remain a barrier to exploitation.

Understanding the energy budget – some basics

The term 'budget' has the same meaning as with money – balancing income with outgoings. The Earth's climate system is constantly trying to maintain a balance between the energy that reaches the Earth from the sun and the energy that goes back from the Earth out to space. This is the idea of the radiation or energy budget. Its is sometimes more straightforward to use a systems approach when discussing the energy budget, and to think of the system in terms of its inputs and outputs.

Inputs

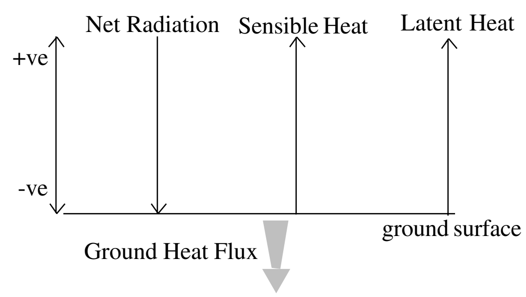
The only input into this system is energy derived from the sun often referred to as shortwave radiation since most of this energy is in the form of shorter wavelengths of electromagnetic radiation. Fig 1 The amount of energy and the wavelengths at which this energy is emitted is controlled by the high average temperature of the sun's radiating surface.

Outputs

Energy must also leave the Earth since if it did not the Earth would get hotter and hotter (remember that the system is 'balanced'). There are two main ways in which energy leaves the Earth:

- **Reflection.** Part of the shortwave energy that comes to Earth is simply reflected back into space. The fraction of solar energy which is reflected is termed albedo. Different surfaces have different albedo's (this is discussed later).
- **Emission.** This is electromagnetic radiation emitted directly from the Earth, in the form of longwave radiation. Sometimes it is possible to actually see this heat radiation, for example the shimmering of a tarmac surface on a hot sunny day. Emission is discussed in more detail in a later section.

Fig 2 Basic components of the surface energy balance



Net radiation (Rn) - mainly incoming shortwave radiation (- reflected component + small amount of longwave energy. Usually positive during the day when the sun heats the surface and negative at night as the surface cools.

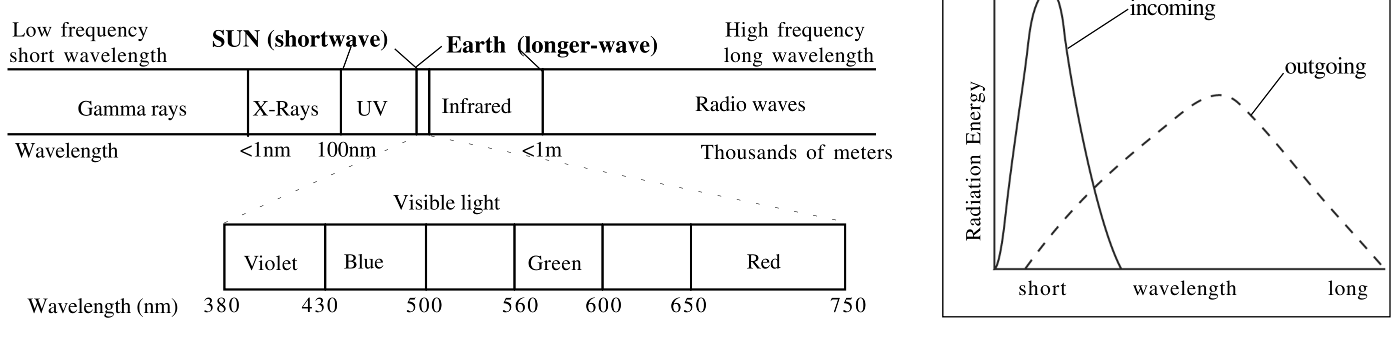
Latent heat (LE) is the energy that was used to evaporate the mass of water that the air now contains. (high water vapour = high latent heat, low water vapour/dry air = low latent heat.

Sensible heat (H) (mixture of air and water vapour containing heat) – this transferred from the surface during the day (positive), and negative at night (heat is moved towards the Earth's surface).

Ground heat flux (G) is the conduction of heat away from the surface through the soil or rock. Again, this is generally positive (away from the surface) during the day, and negative at night.

Fig 1. The electromagnetic spectrum

All electromagnetic waves transfer energy from place to place to place and can be: reflected, refracted and diffracted



Latent heat is an important process to recognise since it allows the transfer of heat to other parts of the Earth's surface. When water evaporates, heat must be supplied to convert the water from liquid to gaseous phase (the latent heat). The water vapour may then be transported by the atmosphere to a different region where the vapour may condense as cloud droplets and rain. During the condensation process, the same amount of latent heat is released. Hence, evaporation, transport of water vapour and then condensation causes a net transport of heat

Understanding emission

All bodies with a temperature above absolute zero emit longwave radiation. Consider the wall of a house with a southerly aspect after a bright spring day. In the evening you can feel the warmth radiating from the brick surface. The same wall will radiate even more heat after a hot summers day, long after sun-down. This demonstrates two important features of radiation:

1. Objects absorbing radiation will heat up
2. Hotter objects emit more radiation than cold objects

The wall example illustrates what is happening with the entire Earth. As the Earth warms up by absorbing sunlight, it increases the amount of infrared (longwave) radiation that it emits back to space – thus maintaining the balance of inputs and outputs.

Deconstructing the Energy Budget – Introducing the 'Players'

Fig 3 shows a typical illustration of the Earth's energy budget. In order to explain and understand this more fully, we need to examine the roles of certain 'players' within this structure - the atmosphere, clouds and land or sea surfaces.

1. The Atmosphere

Just like the skin surrounding an apple, the Earth's atmosphere protects the planet. The lower atmosphere, up to a altitude of about 80km, is mostly made up of nitrogen and oxygen, with a number of other trace gases.

Certain atmospheric gases absorb radiation at some wavelengths but allow radiation at other wavelengths to pass through unimpeded. The atmosphere is mostly transparent (little absorption) in the visible part of the spectrum (refer to Fig 1), but significant absorption of solar ultra-violet radiation by ozone, and terrestrial infra-red radiation by water vapour, carbon dioxide and other trace gases occurs.

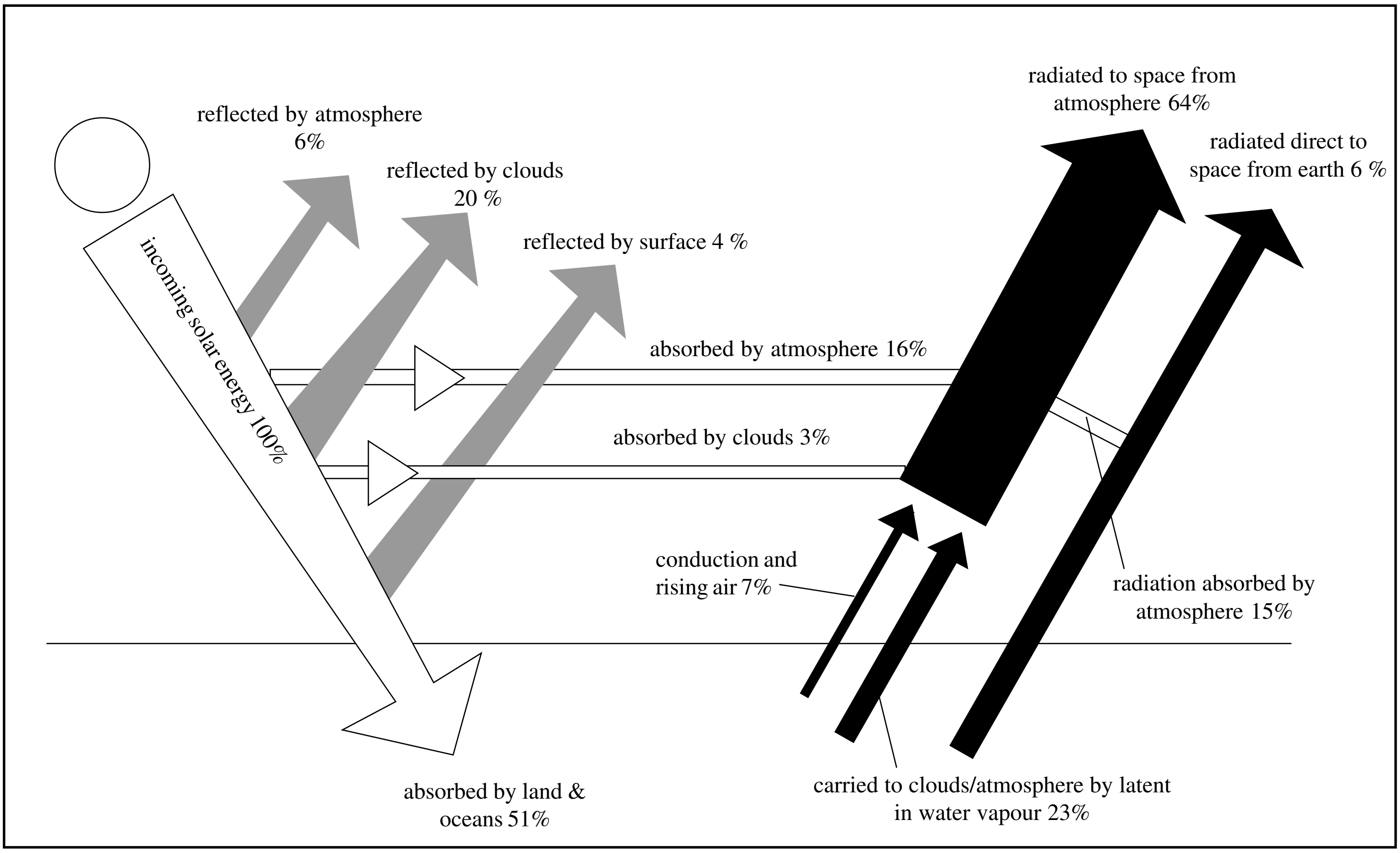
The absorption of terrestrial infra-red radiation is particularly important to the energy budget of the Earth's atmosphere. Such absorption by the trace gases heats up the atmosphere, and so the Earth stores more energy near its surface than it would if there was no absorption.

This process is popularly known as the greenhouse effect:

- Glass in a greenhouse is transparent to solar radiation, but opaque to terrestrial infra-red radiation (shortwave)
- The glass acts like some of the atmospheric gases and absorbs the outgoing energy (longwave)
- Much of this energy is then re-emitted back into the greenhouse causing the temperature inside to rise (good for plants!)

According to Fig 3, 16% of the incoming solar energy is absorbed by the atmosphere (this excludes 3% absorbed by clouds).

Fig 3. Earth's energy budget



2. Role of clouds

Clouds have two main functions in terms of the energy budget. They increase the Earth's albedo, but they also act as re-emitters of longwave radiation. In other words clouds reflect shortwave sunlight and trap infrared radiation. This idea is illustrated in Fig 4.

Fig 4. Simplified radiative effects of clouds

	High Clouds	Middle Clouds	Low Clouds	Totals
Approx proportions in atmosphere (%)	35	20	45	100
Reflectivity of shortwave radiation (Wm^{-2})	-15	-18	-22	-55
Outgoing longwave radiation (Wm^{-2})	12	10	5	27
Net effects	-3	-8	-17	-28

Clouds affect the temperature of the troposphere in several ways:

1. They reflect incoming shortwave radiation back out to space i.e. they help to keep the troposphere **cool**.
2. They also absorb outgoing longwave radiation and reradiate heat back towards the ground – thus helping to **warm** the troposphere

Which of the two processes dominates depends on factors such as cloud ice particle composition, cloud cover and cloud location and is the subject of much research by NASA.

However, in general: high altitude cirrus clouds reflect some incoming shortwave radiation back out to space but they let most through and this radiation is then able to reach the earth's surface. However, these clouds are very efficient at trapping in reradiated longwave radiation, so their **net** effect is to warm the troposphere. Remember that the temperature of the lower atmosphere is increasing anyway as a result of the concentration of greenhouse gases. Warm air near to the ground rises upwards, carrying water vapour with it and this reduces the amount of low-level cloud that forms. Eventually the water condenses at high altitude, forming more cirrus. Hence, cirrus cloud leads to greater warming which leads to more cirrus which leads to more warming – producing positive feedback.

Low level cumulus cloud reflects a lot of the incoming shortwave radiation back out to space and this cools the troposphere and the earth's surface. As the greenhouse gases warm the lower atmosphere, evaporation and transpiration increase, thus the humidity of the lower atmosphere increases. Condensation of this moisture at low level can produce thick layers of cumulus cloud. This cumulus cloud reflects more and more of the incoming radiation, thus acting against the effect of the greenhouse gases – negative feedback.

Remember *clouds also transport a significant amount of heat to the upper atmosphere in the form of latent heat. This energy is released again in the upper atmosphere when the water condenses as cloud droplets and ice crystals.*

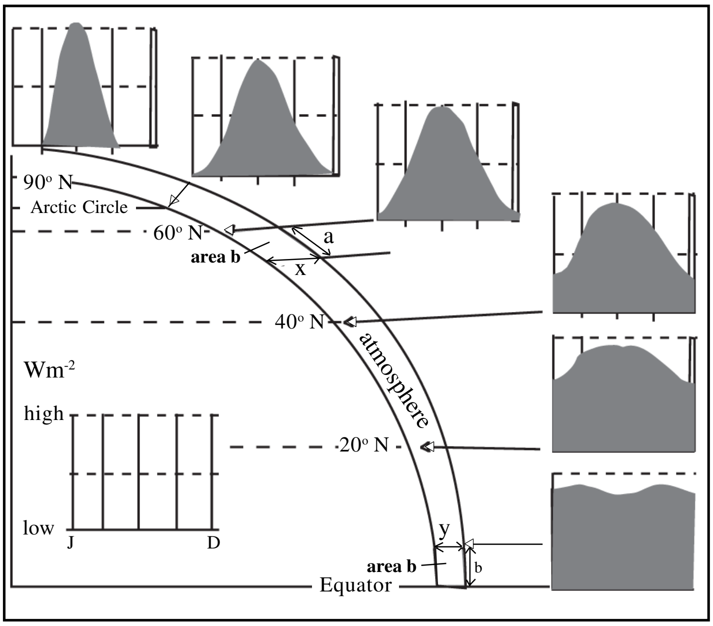
3. Land and sea surfaces: Albedo

Remember, albedo is a measure of the reflectivity of a surface. More precisely, it is the proportion of solar radiation that is reflected by a particular body or surface. Different surfaces have different brightness's or albedo's – the brighter the surface the higher the degree of reflectivity. For example ocean surfaces and rain forests have low albedo's which means they reflect only a small proportion of the sun's energy. Urban areas similarly have low albedo's – this is part of the reason for them experiencing hotter temperatures (particularly at night) compared to their surrounding rural hinterlands. Deserts and clouds, however, have higher albedo's; they reflect a high proportion of the sun's energy. Fig 3 shows that over the whole of the Earth, 30% of the incoming solar radiation is reflected back into space. This is made up of the 6% reflection by atmosphere, 20% reflected by clouds, and 4% reflected by the Earth's surface.

The effect of latitude

The amount of insolation received by the Earth's surface is dependent on a range of factors. Some of these may be described as local – examples include cloud cover, type and altitude, aspect and albedo. But the solar energy resource also varies on a much larger scale due to the effects of latitude. (Fig 5a).

Fig 5a Effect of lattitude on insulation



A key interpretation of this diagram is that the zone around the Equator (low latitudes) receives more insolation than the Poles (higher latitudes). This can be explained in two ways.

1. Incoming solar radiation has further to travel through the atmosphere at higher latitudes, i.e. distance x is longer than distance y, in comparison with lower latitudes in between the Tropics. Much of this energy is lost through absorption, reflection and scattering.

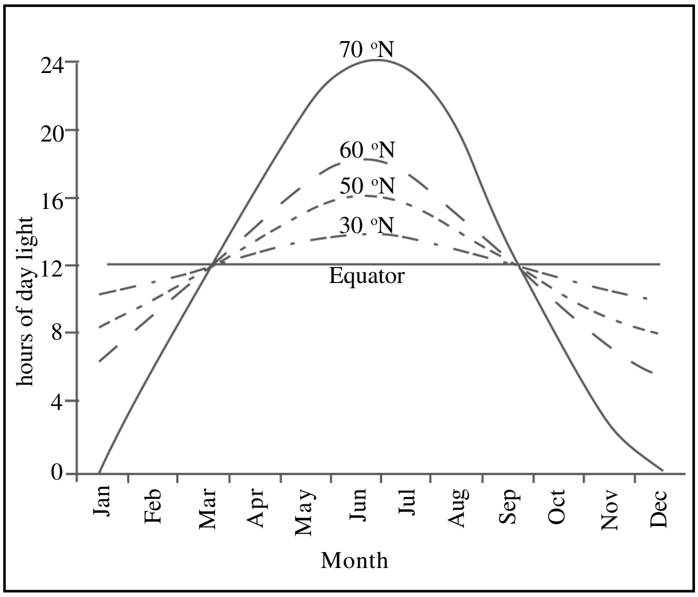
2. There is a larger area of atmosphere to heat up at the Poles in comparison with the equator, i.e. area a > area b

There are two common misconceptions associated with the effect of latitude. The first and most serious mistake is that the atmosphere is thicker at the Poles. This is **not** the case as the thickness does not vary with latitude (look at Fig 5a). Another misunderstanding is that the Poles are further away from the sun compared to Equatorial areas. Again this is not the case – remember that the Earth is tilted on its axis which causes seasonal changes in climate between the Northern and Southern Hemispheres.

Latitude, combined with the Earth's orbit around the sun, gives rise to annual variations in the insolation received at any particular place on the globe. This is usually measured in watts per square metre (Wm^{-2}) or megajoules per square metre (MJm^{-2}). Fig 5a shows that around the Equator there is very little seasonal variation in insolation, whereas towards the Polar region there is a gradual increase in seasonal variability.

An explanation for this can be linked to day-length –(Fig 5b).

Fig 5b Variations in day length



Between the Tropics there is little variation in day-length during the year, whereas at increasingly higher latitudes day-length varies.

At the Poles for instance, during the summer months (March – September) the amount of insolation is high corresponding with almost constant day-light around midsummer. During the winter months (October – February) there are extremely short days in terms of sunshine hours, hence the low levels of shortwave radiation received at high latitudes.

Final Concerns

Global environmental problems may have significant impact on the Earth's energy budget –

- The depletion of the ozone layer allows additional radiation to reach the surface while increases in the level of carbon dioxide in the atmosphere encourage retention of terrestrial radiation.
- Uncontrolled releases of nuclear material pose one of the greatest threats to the Earth's energy budget. It would destroy present patterns of energy flow in and out of the atmosphere, and create a 'nuclear winter' where global temperatures could fall by as much as 30°C in some parts of the world.

Example Questions

1) Explain how spatial variations in the amount of cloud cover may cause variation in the diurnal temperature range from day to day at any one place.
2) Briefly explain how on a global scale, heat is transferred in the atmosphere.

Answers

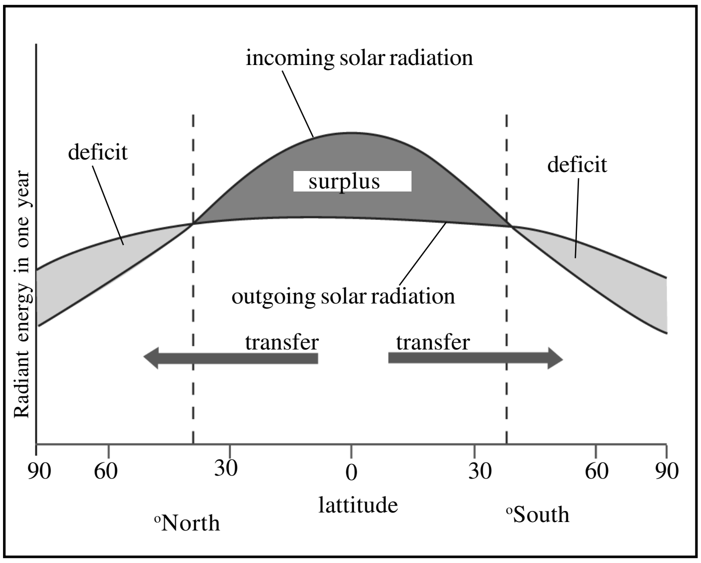
1) With clear skies insolation is high in daytime, so high temperatures; infrared radiation lost at night so lower temperatures. This causes a large diurnal temperature range. These type of conditions are experienced in deserts.

   Cloudy skies - clouds reflect insolation in the daytime resulting in a lower temperature but clouds also re-emit infrared (longwave) radiation back to Earth at night. This means that temperatures do not fall greatly, therefore there is a smaller diurnal temperature range. Such conditions are often associated with rainforest areas (between the Tropics).

2) The most obvious form of heat transport occurs when warm air is transported polewards and cold air is transported equatorwards. This direct transport of heat is called the sensible heat flux. However, a second and equally important type of heat transport occurs through latent heat flows.

Fig 6 provides a more detailed look at this mechanism.

Fig 6.



Within 37 degrees of the Equator more energy is received than lost (this is indicated by the surplus). In higher latitudes (polewards) there is an energy deficit. Regions in lower latitudes do not become progressively hotter, and higher latitude players (such as the UK) do not become progressively colder because the energy is transferred across the globe.

Additional Resources and Research

Many of the standard AS and A2 texts have some information about energy budgets, however there are some excellent web resources available at:

http://www.env.leeds.ac.uk/envi2150/ University of Leeds Climate change lecture notes. Very comprehensive resources, clear and well explained.

http://pao.gsfc.nasa.gov/gsfc/service/gallery/fact_sheets/fsheet.htm#earth NASA fact sheets. Again very comprehensive and readable resources

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