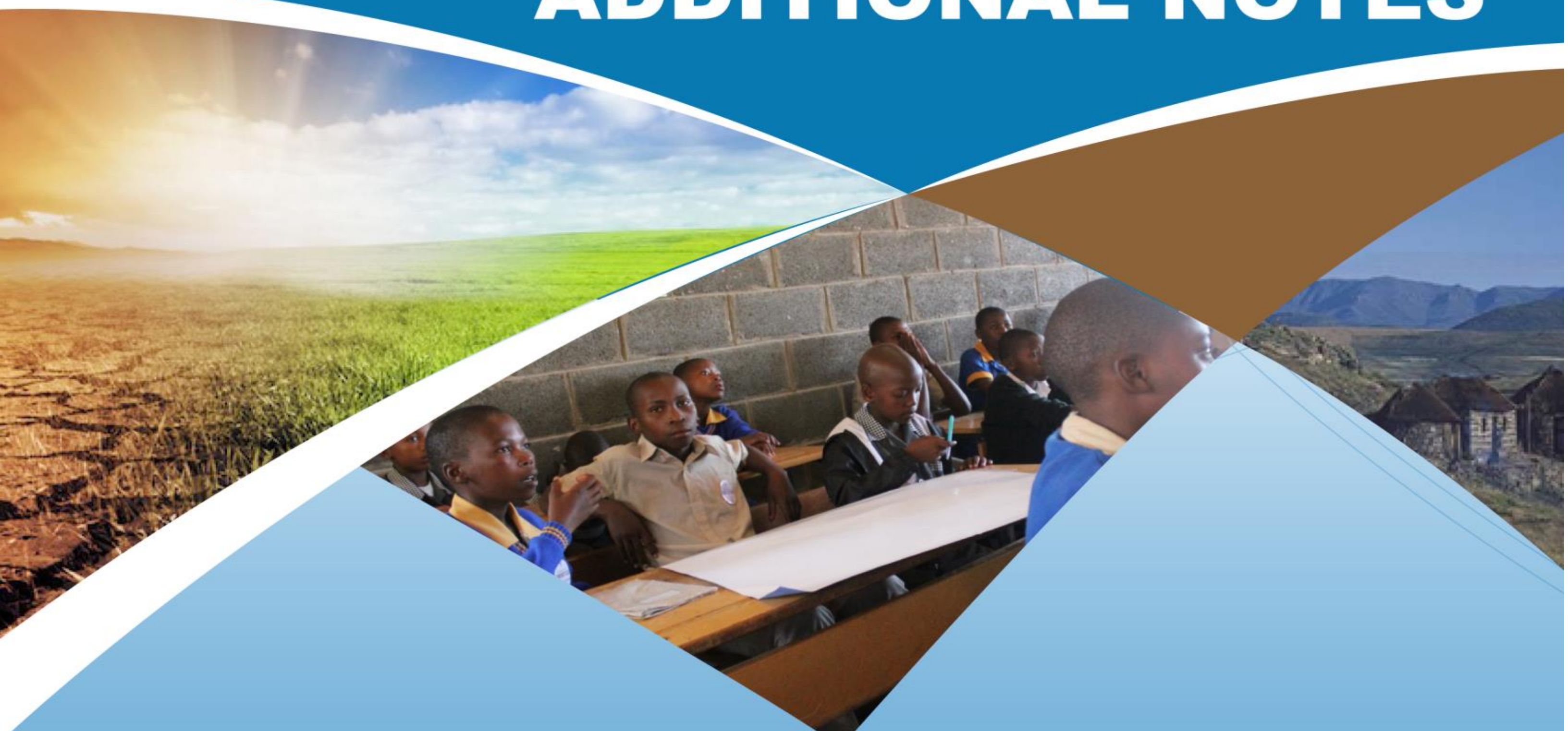
CLIMATE CHANGE TOOLKIT ADDITIONAL NOTES



LESOTHO METEOROLOGICAL SERVICES

MINISTRY OF ENERGY AND METEOROLOGY

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THIS DOCUMENT SERVES AS THE ADITIONAL NOTES TO THE CLIMATE CHANGE TOOLKIT

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Contents

Glossary

Absorb – uptake or taking in or reception by molecular or chemical action, as of gases or liquids.

Adaptation -reacting or changing to fit new circumstances.

Aerosols– fine solid particles and liquid droplets suspended in the air.

Agriculture –growing of crops and rearing of animals in order to get food and other useful products. Also includes storage, processing and marketing products.

Albedo -– is the fraction of solar energy (shortwave radiation) reflected from the Earth back into space.

Altitude –Height above sea level.

Anthropogenic emissions - Emissions of greenhouse gases, greenhouse gas precursors, and aerosols associated with human activities.

Atmosphere –a layer of gases surrounding a planet.

Atmospheric concentration of carbon dioxide –amount of carbon dioxide per unit volume in the atmosphere.

Atmospheric window - a region in the terrestrial range between 8 and 13 μm, where absorption of infrared wavelengths is weak and allows some of long waves to escape directly into space.

Biomass - In ecology: the amount of living matter in a given habitat, expressed either as the weight of organism per unit area or as the volume of organism per unit volume of habitat.

Carbon Sinks –is the natural or artificial reservoir that accumulates and stores carbon containing chemical compound for an indefinite period. E.g. forests, oceans, soil and atmosphere.

Carbon source –is anything that release more carbon than they absorb.

Carbonaceous aerosols -

Chlorofluorocarbons (CFCs) -

Climate change education –educating people about climate change.

Climate change –fluctuations in the pattern of climate over a long period .

Climate –weather averaged over a long period of time.

Conduction - the transfer of heat through matter by molecular activity, meaning energy is transferred through contact between individual molecules.

Conservation Agriculture –a concept for resource-saving agricultural crop production that strives to achieve acceptable profits together with high and sustained production levels while concurrently conserving the environment.

Convection - the transfer of heat by bulk movement or circulation within a fluid.

Conventional Tillage –tillage operations considered standard for a specific location and crop and that turn to bury the crop residues usually considered as a base for determining the cost effectiveness of soil erosion practices.

Decomposition –breakdown of plant and animal matter by microbes

Deforestation –cutting down of forests

Ecosystem –a community of living organisms such as plants, animals and microbes in a given area interacting with each other and also with their non-living environments such as weather, earth, sun, soil, climate and atmosphere.

Electro-magnetic radiation - a form of energy transfer that travels through vacuum, propagating as a wave.

Emissions –are substances that are discharged to the atmosphere.

Energy –ability to do work.

Equator –a line that divides the earth into two equal spheres.

Force - physical power or strength possessed by an object or exerted to object.

Fossil fuels –are fuels formed by natural processes such as anaerobic decomposition of buried dead organisms, e.g. crude oil, coal, natural gas.

Frequency - the number of cycles or completed alternations per unit time of a wave or oscillation.

Global energy budget - quantified estimates of the globally averaged energy budget for the whole Earth-atmosphere system, and its component parts.

Global warming –an increase of temperature over the earth surface.

Global warming potential

Greenhouse effect- surface warming attributed to the back radiation from the atmosphere.

Greenhouse gases –are gases in the atmosphere that absorb and emit radiation within the thermal infrared range.

Halo carbons –a compound such as fluorocarbons that consists of carbon combined with one or more halogens.

Halogens- the group of gases that contain fluorine, chlorine, bromine, iodine and astaines used as fire extinguishers.

Heat –foam of energy emitted from hot bodies.

Hemisphere –half of the sphere.

Herbicides –are chemicals used to manipulate or control undesirable vegetation.

Hydro Power –power derived from energy of falling water and running water which may be harnessed for useful purposes.

Hydrochloroflourocarbons- group of gases found in refrigeration and air-conditioning systems, which contain fluorine, chlorine and carbon compounds.

Infrared (ir) radiation- an electromagnetic radiation with a wavelength from 700nm to 1mm.

Latent heat of vaporization - amount of heat needed to convert 1 kg of liquid water to water vapour at the same temperature.

Light –a form of energy.

Mitigation –action that limit, stop or reverse the magnitude or rate of long term climate change.

Nuclear Power –use of nuclear reactors to release nuclear energy and thereby generate electricity.

Organic matter- plant matter especially that can be converted to fuel and is therefore regarded as a potential energy source.

Organism – any living thing.

Ozonelayer –transparent layer of the atmosphere surrounding the earth that filters harmful sun's rays to reach earth's surface.

Pesticides –are substances meant for attracting, seducing and destroying or mitigating any pests.

Pests –are animals or insects that cause problems for people by damaging crops.

Planetary albedo- incident solar radiation that is reflected by the whole Earth.

Precipitation –forms of water deposited on the earth surface.

Radiation –transfer of heat energy without any medium.

Radioactive forcing- the perturbation (disturbance) to the energy balance of the whole Earth-atmosphere system.

Reflection –bouncing of light from a body.

Revolution –movement of a body on its orbit once a year.

Rotation –spinning of a body.

Runoff –water that flows on the surface.

Solar energy –energy emitted by the sun.

Stratosphere –a layer of atmosphere as divided into stratas.

Styrofoam - the trade name of a polystyrene foam product used for housing insulation.

System - combination or an assemblage of things or parts forming a complex unit.

Temperature –measure of heat.

Terrestrial radiation - the radiation emitted by the planet.

Thermal expansion - the increase in volume of matter due to increase in temperature.

Tillage –is the agricultural preparation of soil by mechanical agitation of various types such as digging, stirring and overturning.

Troposphere –the lower layer of the atmosphere.

Ultraviolet radiation - an electromagnetic radiation with a wavelength from 400nm to 10nm.

Variable –changing.

Vegetation –different plant species covering the earth surface.

Volcanic aerosols –gas fumes and solid particles emitted into the atmosphere by volcanism.

Wave - is an oscillation accompanied by a transfer of energy that travels through space or mass.

Wavelength –distance between two successive waves.

Weather –set of all phenomena in a given atmosphere at a given time (hours or days).

Weed –a plant considered undesirable in a particular situation (a plant in the wrong place).

Wetlands –large swampy areas of water supply.

1 Introduction

The changes in the climate are already causing significant harm to both physical and biological systems. Scientists examine ice core data as well as other physical datasets to understand the implications of climate change on the physical world. Similarly, they look at datasets of biological systems and think about the adaptations that humans need to make to adjust to the changing climate. However, scientists may still have doubts about the reality of climate change and the process of scientific consensus that makes us know that climate change is unequivocal and that there is overwhelming evidence that human activities are the main causes. Climate change requires global action and local solutions.

Global climate change and its impacts on people and resources pose serious societal challenges. The actions we take today will influence future greenhouse gas emissions and the magnitude of warming; they will also affect our ability to respond and adapt to changes, and to reduce the vulnerability of people and places to harm. Educating future generations about the causes and effects of global climate change is imperative since implementing solutions depends on an informed public, for both societal and individual level actions. The Intergovernmental Panel on Climate Change (IPCC) proclaims that:

Education policies and curricula need to promote strategies to address climate change, in terms of **adaptation and mitigation,** by increasing knowledge and understanding of the causes and impacts. Additionally, it should enhance knowledge, skills, values and attitudes for effective mitigation using appropriate action oriented pedagogies. (UNESCO/UNEP, 2011, p. 55).

This toolkit is intended to build teachers' capacity for effective integration of climate change into their respective teaching subjects. While the toolkit is not subject-specific, teachers can adapt it to address specific learning outcomes in their subject areas. It is appropriate for use from primary school level up to the secondary level (both junior and senior secondary).

The specific purposes of this toolkit are to:

- Help teachers to deliver accurate information (knowledge and facts) about causes and impacts of climate change;
- Help teachers to appropriately use the local context when teaching relevant concepts and issues of climate change;

- Build teachers competences to encourage development of action-competence skills relating to climate change adaptation and mitigation.

Thus the toolkit has rich content dealing with basic science of climate change, its mechanisms, adaptation and mitigation. It also has a variety of learners' activities that can be adapted to suit specific contexts of schools and classrooms. Another important feature of this toolkit is that it has short assessment tasks that could help the teachers to assess students' learning.

a. What does integration of climate change mean?

The international framework on mainstreaming climate change education, as part of education for sustainable development (ESD), recognizes that climate change is cross-curricula and multi-disciplinary in nature (UNESCO-UNEP, 2011). This suggests that the successful implementation of climate change in formal education requires an integrated approach to curriculum organization. The notion of curriculum integration can be traced back to the era of the Progressive Education Movement of the 1960s and 1970s, which emerged out of the dissatisfaction with traditional education that emphasized disciplinary knowledge as opposed to real life problems and challenges. It is associated with American education philosophers, notably John Dewey, who viewed schools as democratic spheres, where individuals can be empowered to effectively deal with practical life challenges (Dewey as cited in Jackson, 1992). The idea behind curriculum integration is to link what is taught in schools with real life problems and issues, which are of personal and social significance (Beane, 1997).

In this toolkit, 'integration of climate change' means emphasizing climate and climate change facts, concepts and issues in related subject content areas. The toolkit draws on existing literature on environmental education (see for example, van Ransburg and Papaditrio as cited in Mokuku et al, 2005, p. 167) to make a distinction between integration and infusion. Unlike **infusion** which means making minor inclusions of climate related content, **integration** requires making climate change a major topic for learners, but without diluting the content of the subject. It also requires linking subject knowledge with local context and daily life experiences of the learners. Teachers need to encourage their learners to use critical thinking, problem-solving and decision-making skills to analyze complex environmental, social and economic issues associated with climate change. While such a deep learning may not be easy to achieve in certain school subjects which are rather peripheral to climate change, it is important that teachers of such subjects make an attempt to identify relevant themes where basic knowledge of climate change can be promoted. Thus climate change can be integrated in physical and social science subjects (Biology, Chemistry, Geography, agriculture and Development Studies), and be infused in languages and Mathematics.

b. More about this toolkit

This toolkit can be adapted for use from primary up to tertiary levels of the Lesotho Education system. It is intended to guide teachers to lead students through a progression of understanding. It introduces students to weather and climate, and the local and global impacts of climate change. This is to hook the students to the subject matter and get them to think about their own connection to climate change.

This toolkit anticipates a curriculum which integrates concepts from the earth, life, and physical sciences as well as the most current data on climate systems to help students understand concept of climate change, the justification for these concept, and why these concepts are both scientifically and socially important. The following goals frame this toolkit guide:

1. Students will be able to (SWBAT) explain the elements of climate and analyze the earth's energy balance that affects climate change. (What is climate change?)
2. SWBAT identify the proximate and ultimate causes of climate and climate change as well as the evidence for these causes. (What is responsible for climate change and how do we know?)
3. SWBAT analyze the impact of climate change on physical and biological systems. (Why does climate change matter?)
4. SWBAT compare and contrast climate change mitigation strategies (macro and micro) and adaptation strategies in light of environmental, economic, political, and ethical impact. (What can we do?)
5. Students will use data and evidence to justify claims relating to climate, climate change, adaptation and mitigation.

To pursue these goals, the toolkit has been divided into six objectives, which are stated later in the document. The guide provides a variety of both teacher-centered and student-centered activities ranging from lectures guided by content-based material, teacher-led demonstrations, student-led investigations, and group analysis of data. Underlying these activities is a philosophy of learning by inquiry as well as justifying claims with evidence. To measure the achievement of the above goals, formative assessments are embedded throughout the toolkit as well as sets of questions applicable to particular topics/concepts. For example, students begin a concept map in the first objective that is continually developed with more terms and more interactions. Summative assessments are also included.

These forms of assessment measure student achievement in a variety of ways and provide a more valid picture of student understanding. The first summative assessment, a traditional test, includes 10 multiple choice items on the major concepts of climate change science. It also includes open-ended questions that push students to interpret data and apply their knowledge of the climate system to new, but related situations. Perhaps the keystone of the entire toolkit – combines group and individual work that forces students to use their understanding of climate science and mitigation options to make decisions about how society should cut carbon emissions and how it can also adapt to the unavoidable consequences of climate change.

The toolkit is comprehensive in that it includes the activities, assessments, and materials to guide an entire curriculum on climate change. However, the curriculum is not intended to be prescriptive as teachers should feel free to exercise their professional judgment about modifying activities and creating lesson plans to suit their needs in attempting to integrate climate change issues in various components of the curriculum.

Concept maps serve a rich purpose in helping students articulate their understandings of how concepts are related and help tell a coherent story about climate systems and climate change. Right from inception students are asked to begin their individual concept map and continue adding words throughout the lessons. It may be useful, however, to create a 'word wall' for the entire class in which new or difficult terms are defined for students to reference. We also suggest development of a class list of connector phrases.

Students should be encouraged to add terms that may not appear in the lesson plans and to use these concept maps on activities throughout the objectives. It might be helpful to provide students with a legal sized piece of paper (8.5 x 14) or bigger (11 x 17) so that students will have enough room for all of the concepts and connections.

c. Concept Map Instructions

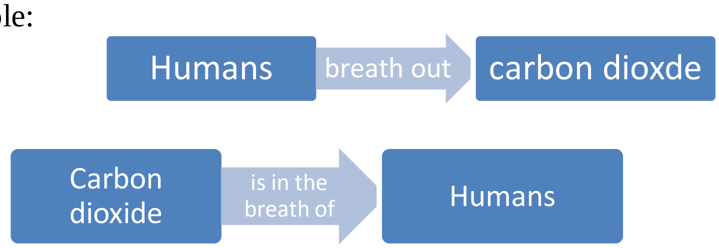
You are going to create a concept map over the next 3 weeks. A concept is a general idea or notion formed about a particular thing. A concept map is a visual representation of your understanding of the different parts that make up a concept. This concept map will focus on climate change. Every few days you will get a few new concepts to add to your map.

Key parts to a concept map:

- concepts
- linking lines with arrows
- linking phrases

The concepts are words that represent a thing or idea. You will be linking concepts with a line which has an arrow. On top of the line you will write a linking phrase that completes a sentence. For example, if you were given the words 'trees' and 'birds', you might write a linking statement 'Birds build nests in trees" with the arrow pointing to trees or a statement "trees are homes to birds" with the arrow pointing towards birds.

Example:



Start your concept map in the center of your paper and make the font small, but legible. You will be adding 25 more concepts during the course. **Please use pencil**.

First Words for your Concept Map:

Climate System
Weather
Atmosphere
Also add to your concept map: Two factors that you think affect the climate

Access to curriculum and instruction relies greatly on the language demands of the tasks and interactions. The role of language demands in the science classroom is of great importance as evidenced. This curriculum was created with language goals for students that can be found on the lessons. The activities and resources were also created in a way that recognizes the language demands and provides access, with proper scaffolding and assistance from the teacher, for all students.

The Scientist's Mantra

We Are Climatologists!

The climate is changing all over the Earth,
It makes us question what it's all worth.
The hot gets hotter and the wet gets wetter,
The sea is rising and we don't breathe better.
Greenhouse gases are trapping the heat,
We need to do something; we can't sit on our seat.
Public transportation is the way to go.
It's one of the ways to keep emissions low.
Energy from the sun, wind, & plants won't run out,
They can power our world without any doubt.

A Teacher's Guide for Integration of Climate Change: Basic and Secondary Education

d. Understanding Weather and Climate

In the 1980s, scientific evidence linking greenhouse gas emission from human activities with global climate change started to arouse public concern. There were calls in the international community to take immediate steps to address the problem.

i. What is Weather?

Weather" is the set of all phenomena in a given atmosphere at a given time. The term usually refers to the activity of these phenomena over short periods (hours or days), as opposed to the term climate, which refers to the average atmospheric conditions over longer periods of time. When used without qualification, "weather" is understood to be the weather of Earth. On Earth, common weather phenomena include such things as wind, cloud, rain, snow, fog and dust storms. Less common events include natural disasters such as cyclones and ice storms. Almost all familiar weather phenomena occur in the troposphere (the lower part of the atmosphere - see fig.1). Weather does occur in the stratosphere and can affect weather lower down in the troposphere, but the exact mechanisms are poorly understood.

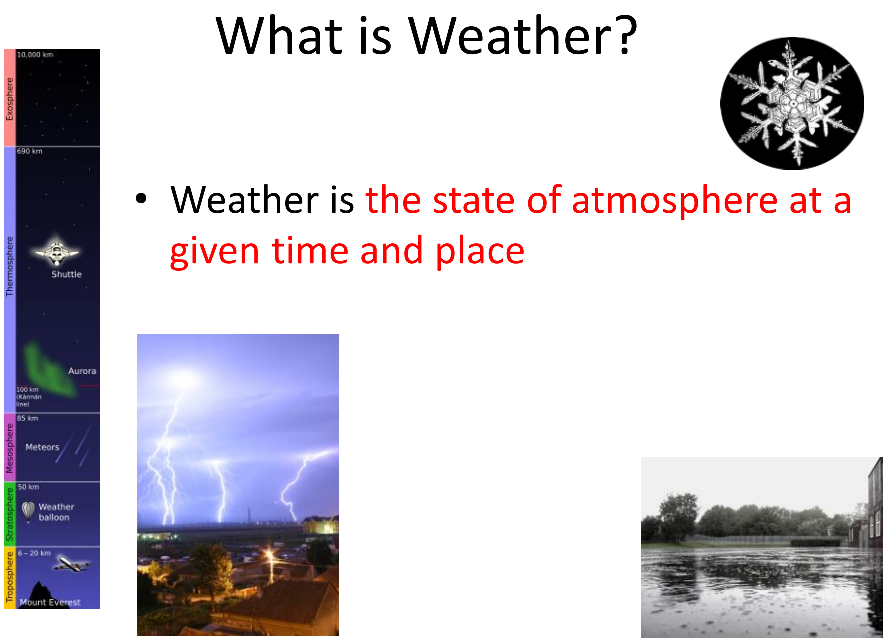


Fig.1.1 Weather events

ii. What is climate?

Climate is defined as the weather averaged over a long period of time. The standard averaging period is 30 years but other periods may be used depending on the purpose. Climate also includes statistics other than the average, such as the magnitudes of day-to-day or year-to-year variations. Therefore, climate is “the average and variations of weather over long periods of time”. Different “Climate Zones” such as tropical, temperate or polar can be defined using parameters such as temperature and rainfall.

Climate in your place on the globe is called regional climate. It is the average weather pattern in a place over more than thirty years, including the variations in seasons. To describe the regional climate of a place people often describe what the temperatures are like, how windy it is, and how much rain or snow falls. The climate of a region depends on many factors including the amount of sunlight it receives, its altitude, topography, and how close it is to oceans. Since the equatorial regions receive more sunlight than the poles, climate varies with latitude.

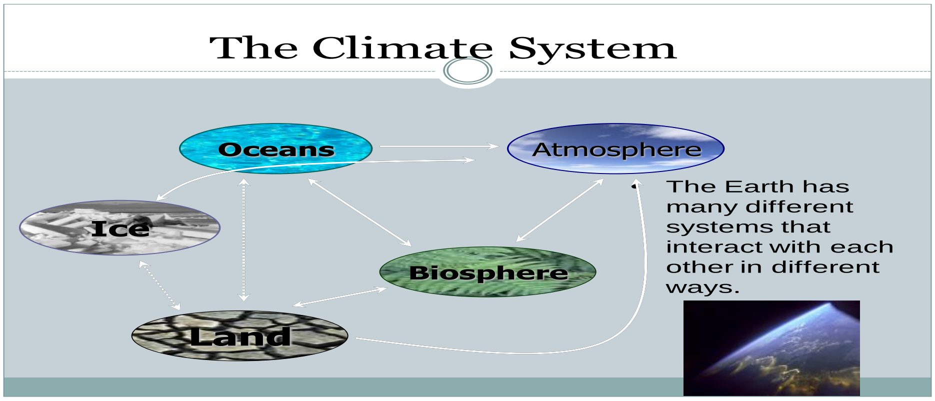


Fig.1.2 The climate system

The climate includes interaction between all areas on the surface of the Earth and in the atmosphere. For example, water evaporates from the ocean to form water vapor clouds in the atmosphere. The wind can then carry these clouds over the land where the water falls as rain or snow. Eventually the water may return to the ocean via rivers etc. Also, the biosphere the living plants and animals, live in and utilize the land, sea and sky - so you can see how everything is connected.

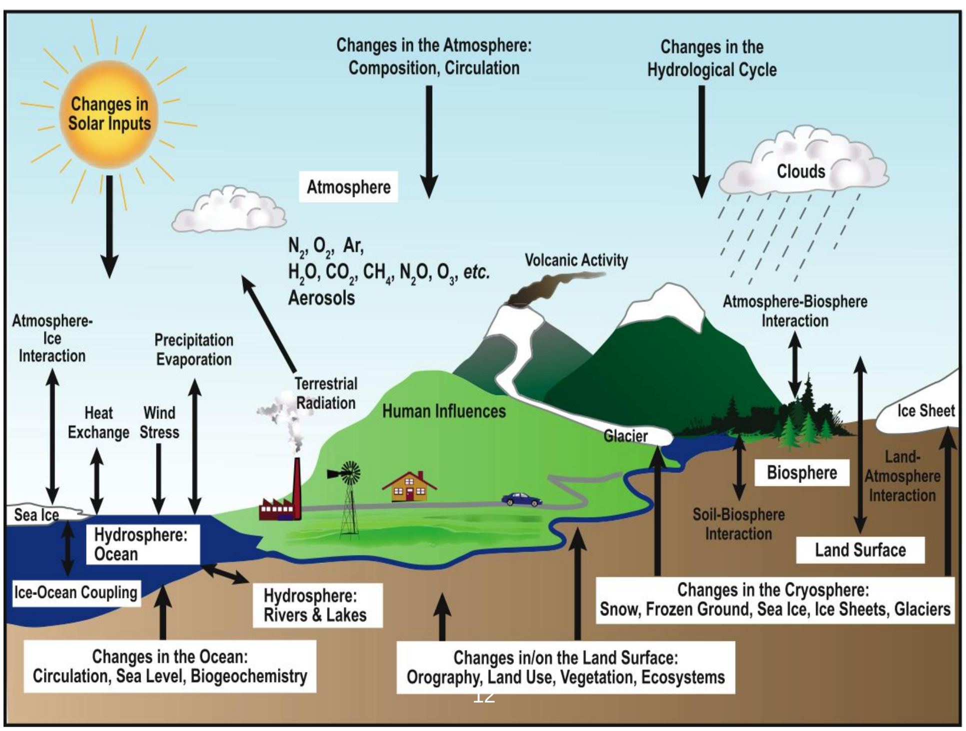


Fig.1.3 Comprehensive climate system

However, we can also look at climate at the scale of an entire planet. **Global climate** is a description of the climate of a planet as a whole, with all the regional variations averaged. Overall global climate depends on the amount of energy received by the sun and the amount of energy that is held in the system. These amounts are different for different planets. Scientists who study Earth's climate and climate change study the factors that affect the climate of our whole planet.

While the weather can change in just a few hours, **climate changes** over longer timeframes. Today, climates are changing. Our Earth is warming more quickly than it has in the past according to the research of scientists. Hot summer days may be quite typical of climates in many regions of the world, but global warming is causing Earth's average global temperature to increase.

The earth's global climate is a dynamic system driven by such variables that include the amount of solar radiation, chemistry of the atmosphere, amount and types of clouds, and the rest of the components of the climate system. A change in the temperature can cause changes in other parameters that affect climate such as weather elements like clouds or precipitation.

The heat that enters into the Earth system comes from the Sunlight traveling through Earth's atmosphere, heating up the land and oceans. The Sun affects climate when the amount of solar energy let into the system is altered. Changes in Earth's orbit over thousands of years and changes in the Sun's intensity affect the amount of solar energy that reaches the Earth. Climate will change if the factors that influence it fluctuate. The global climate is highly affected by the amount of radiation draped in the lower atmosphere by the greenhouse gases. The more the greenhouse gases in the atmosphere, the greater the amount of radiation draped and more warming of the lower atmosphere.

Heat exits the Earth system when the planet surface radiates it away after being warmed by solar energy. Greenhouse gases in our atmosphere, allow the lower atmosphere to absorb heat that is radiated from the Earth's surface, trapping heat within the Earth system. Without any greenhouse gases, Earth would be a frozen world. However, the amount of greenhouse gases in our atmosphere is on the rise, causing temperature to rise.

2 Unit 1: The Science of Climate Change

At the beginning of the 21st century, terms such as the ‘greenhouse effect’, ‘greenhouse gases’ and ‘global warming’ were making headline news globally both in print and news media. Climate change is a key issue on today’s social and political agenda. This Unit is designed to consolidate the teachers understanding of the basic science behind these terms, and then to review what is known about the human impact on the composition of the atmosphere since the beginning of industrialisation. We shall explore two objectives;

1. the basic science that underpins climate change and global warming and
2. the relationships with greenhouse gases and the consequent greenhouse effect.

Having studied this unit, the teacher should be able to:

- Understand the physical basis of the natural greenhouse effect, including the meaning of the term “radiative forcing”;
- Know the way various human activities are increasing emissions of natural greenhouse gases, and are also contributing to sulphate aerosols in the atmosphere;
- Be aware of the difficulties involved in the detection of any unusual global warming signature above the background noise of natural variability in the earth climate and attributing (in whole or in part) any such signal to human activity;
- Understand that although a growing scientific consensus has become established through the IPCC, the complexities and uncertainties of science provide opportunity for climate skeptics to challenge the Panel’s findings.

2.1 Objective 1: understanding the pre-requisite science relevant to teaching of greenhouse effects in global warming.

2.1.1 The Visible Spectrum of the Solar Radiation

A balance between incoming solar radiation and outgoing radiation from the much cooler terrestrial surface establishes the earth’s global mean temperature. To understand this fundamental observation we need to review the electromagnetic spectrum. Electromagnetic radiation is the only form of energy transfer that travels through the vacuum of space, propagating as a wave. By convention, the full spectrum of electromagnetic radiation is carved up into regions, each characterized by a particular range of wavelengths **(Fig.2.1).** The **wavelength** (symbol λ) is just the distance between successive crests or troughs of a wave (**Fig.2.1A**).

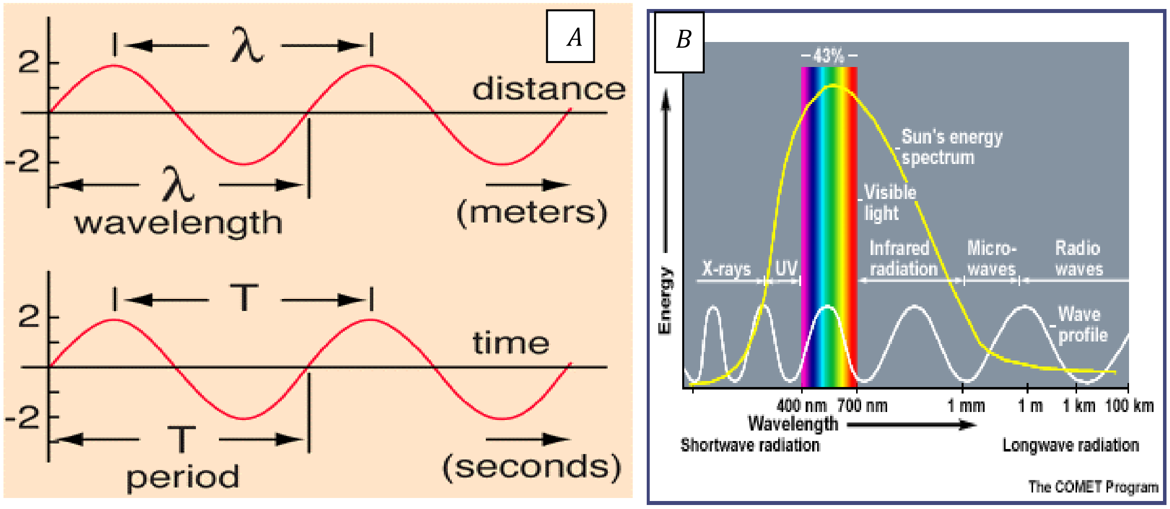


Fig. 2.1 A) Wave length given in Nanometers, B) Wavelength is given in nanometers

Our eyes are sensitive to **visible radiation**, which corresponds to the wavelength range from about 400nm (violet light) to 700 μm (red light) (**Fig. 2.1B**). When all wavelengths in this range are present, we perceive this as 'white light'. To either side of the visible band lie the ranges known as **ultraviolet (uv) radiation** (with wavelengths below that of violet light) and **infrared (ir) radiation** (with wavelengths above that of red light). As with any propagating waves, the shorter the wavelength, the higher the frequency (f) i.e. the higher the number of waves passing a point in a given time. For electromagnetic radiation, the two multiplied together give the speed of light (c): $c = f\lambda$.

The Sun is the ultimate source of energy for the earth's climate. Thus, it is appropriate to begin with a review of this global balancing act which determines the global mean surface temperature (GMST). The heart of the matter is that the energy flows to and from space are in the form of radiation – or to be more precise, **electromagnetic radiation** (**Fig.2.1B**).

2.1.2 Heating and ***cooling*** the Earth: the overall radiation balance

The Sun emits electromagnetic radiation with a range of wavelengths, but its peak emission is in the visible band – the sunlight that allows us to see. The wavelength of radiation has important climatic implications, as we shall see shortly. For now, we are mainly interested in the overall rate at which energy in the form of solar radiation reaches the Earth.

Test 2.1

Question: *What is the SI unit for the rate of energy transfer, or 'power'?*

Answer: *The watt (W), defined as 1 W=1 J s^{-1} (joule per second).*

Radiation streams out of the Sun at the rate of 3.85×10^{26} W and beaming it to planet Earth approximately 150×10^6 km away. However, the Earth intercepts only a tiny fraction of this radiant flux – an amount equivalent to the solar radiation falling on the flat, circular disc depicted in **Fig.2.2**.

Note that we imagine the disc to be just outside the Earth's atmosphere and aligned at right angles to the Sun's rays: the solar input per unit area (a square metre, say) of this disc is called the solar constant. Measurements from satellite-borne radiation sensors give the solar constant an average value over recent years of 1368 W m^{-2}. Of course, the Earth is a rotating sphere, not a flat disc. As explained in the paragraph below Figure 2, when averaged over the surface of the whole globe, the solar input per unit area at the top of the atmosphere comes down by a factor of four, to 342 W m^{-2}. For simplicity, we shall refer to this globally averaged value as '100 units', though you should remember that these are units of 'energy per unit time per unit area'.

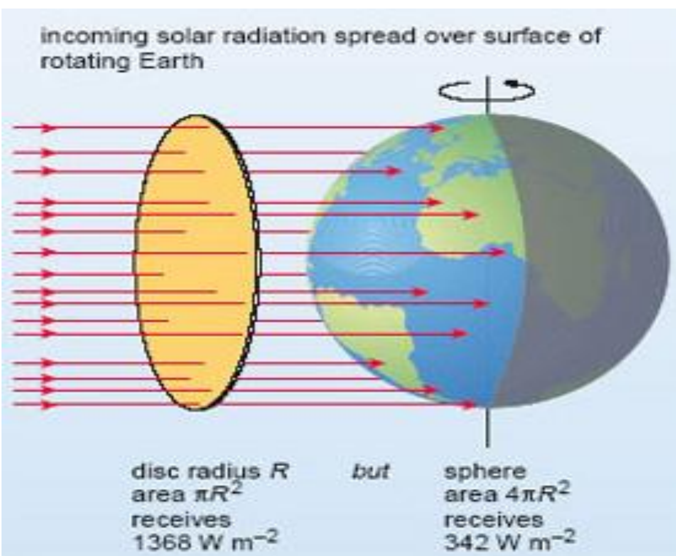


Fig. 2.2: Incoming solar radiation spread over the surface

The Earth intercepts an amount of solar radiation equivalent to that falling on a disc with the same radius (R) as the Earth, facing the Sun: this comes to ($1368 \times \pi R^2$) W, where πR^2 is the area of the disc (in m^2). However, the Earth is spherical , so the area presented to the incoming solar radiation by the rotating Earth (over a period of 24 hours or more) is $4\pi R^2$; i.e. four times as great. Thus, the solar input per unit area averaged over the surface area of the whole Earth is a quarter of the solar constant; i.e. 1368 Wm^{-2}=4 x 342 Wm^{-2}.

Not all of the incoming solar radiation is available to heat the Earth: some of it is reflected directly back to space (**Fig.2.3**). The proportion of incident solar radiation that is reflected by a given surface is called the albedo .

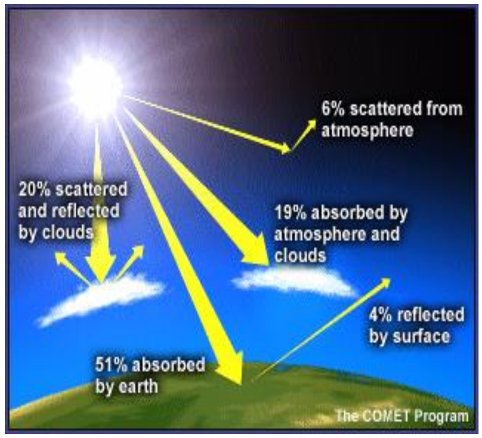


Fig. 2.3: Left: The Earth viewed from space on visible spectrum; Right: Reflective properties of different components of the climate system

Fig.2.3 shows an image of the Earth from space formed from reflected sunlight (solar radiation at visible wavelengths). Clouds and the ice-covered mass of Antarctica (at the bottom of the image) appear bright because they reflect strongly; i.e. they have a high albedo – up to 90% in the case of fresh snow and sea-ice. By contrast, the oceans have a low albedo (typically less than 5%) and appear dark in this image. In general, most land surfaces have moderate albedo, with values ranging from 10–20% for forests to around 35% for grasslands and deserts. Evidently, the albedo can vary markedly around the world, depending on the cloud cover and surface characteristics. The **planetary albedo** is the combined figure for the Earth as a whole: on average, it has a measured value of 31% (31 units). The remainder (69 units) is absorbed by the atmosphere and materials at the Earth's surface (the oceans, soils, vegetation and so on).

Test 2:

Question: *What is the rate per unit area at which solar energy is absorbed by the Earth's atmosphere and surface?*

Answer: *69 units is 69% of 342 W m*$^{-2}$ *or (342 W m*$^{-2}$*)* $\times$ *(69/100) = 236 W m*$^{-2}$.

Suppose now that the Earth's atmosphere is stripped away, but the planetary albedo is unchanged. (This may strike you as a curious proposition, but it will help to expose just how important the atmosphere really is.) The energy flows at the surface of this 'airless' world are shown in Fig.2.4. To the left of the figure, a nominal 100 units of solar radiation reach the planet; 31 units are reflected away and all of the remaining 69 units are absorbed by the surface.

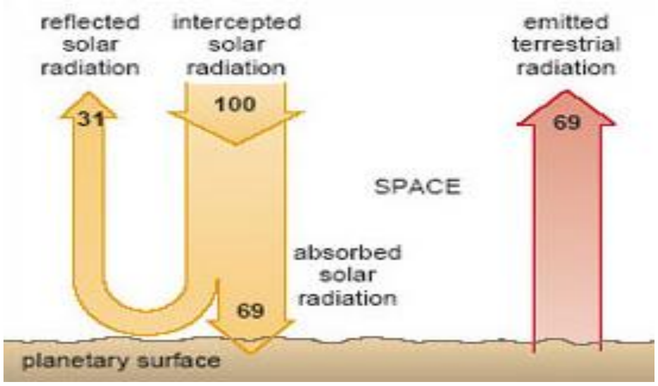


Fig. 2.4: The steady-state balance between incoming and reflected solar radiation

Test 3:

Question: *By itself, what would be the effect of this continual input of solar energy?*

Answer: *The surface would warm up; indeed, it would get progressively hotter and hotter*

Fortunately, there is a compensating cooling effect. Like the Sun, all objects (you and I included) emit electromagnetic radiation. Further, they do so at a rate that depends on the temperature of the object: the hotter an object becomes the higher its radiative power – the rate at which it emits radiation. For our planet, a steady or equilibrium temperature is maintained by a dynamic balance: the rate at which solar energy is absorbed (the 69 units to the left in **Fig.2.4**) must be balanced by the rate at which the planet loses energy to space as emitted radiation (the 69 units to the right in **Fig.2.4**). Note that this emitted radiation originates with the 'jostling about' of atoms within the surface; it is not the same thing as the reflected solar radiation, which merely 'bounces off' the surface. To emphasize the distinction, we shall refer to the radiation emitted by the planet as **terrestrial radiation**.

Expressed in quantitative terms, the relationship between temperature and radiative power is the basis for a well-established law of physics. The appropriate calculations tell us that, for an Earth-like planet to emit radiation to space at a steady rate of 236 W m^{-2} (the 69 units depicted in Fig.1.4), it should have an equilibrium temperature of -19 °C. This equilibrium temperature is known as the **effective radiating temperature** and, were it not for the atmosphere, this would also be the Earth's global mean surface temperature. Conditions would certainly be inimical to life as we know it. But how does the atmosphere perform the vital trick of keeping the GMST at a more temperate 15 °C? The answer is bound up with an important difference between 'solar' and 'terrestrial' radiation – one that again depends on the temperature of the source.

Test 4

Question:

When a metal poker is heated in an ordinary fire it glows 'red-hot'; if heated to a higher temperature (in an oxy-acetylene flame, say), it would glow 'white-hot'. Generalizing from this example, does the average wavelength of emitted radiation increase or decrease as the temperature of the emitting body rises? Include your reasoning.

Answer:

*White light contains all visible wavelengths (Box 2.1.P 24 -25), whereas red light is at the long wavelength end of the visible band (**Fig.2.1**). 'White-hot' objects therefore emit light of shorter average wavelength than cooler 'red-hot' ones. Generalizing, as the temperature of an object rises, so the average wavelength of the radiation it emits will decrease*

The trend you identified in **Fig. 2.1** is evident in **Fig.2.5**. Here, the curves record the distribution, or spectrum, of wavelengths emitted by the Sun (with an average surface temperature of 5500 °C) and the Earth (with a GMST of 15 °C). The plots are schematic, in the sense that the vertical scale is not defined, but each shows how the radiative power is apportioned among the range of wavelengths emitted.

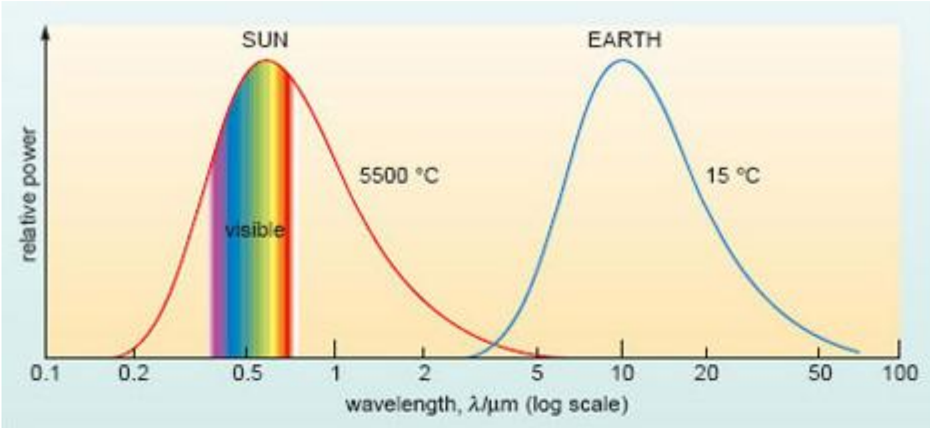


Fig. 2.5: Wavelength spectrum of solar radiation (red) and terrestrial radiation (blue)

The solar spectrum has been simplified and is for the solar radiation intercepted by the Earth (as in **Fig.2.2),** not the total power emitted by the Sun. Note that the wavelength scale is logarithmic.

Test 5

Question:	*With reference to **Fig.2. 5**, is it reasonable to use 'shortwave' and 'longwave' as a shorthand for incoming solar radiation and outgoing terrestrial radiation, respectively?*
Answer:	*Yes. The two curves in **Fig. 2. 5** barely overlap: solar radiation peaks in the visible band, although there are contributions at both shorter wavelengths (in the ultraviolet, UV) and longer wavelengths (in a region often called the 'near' infrared). By contrast, radiation emitted at cooler terrestrial temperatures lies entirely at longer infrared (ir) wavelengths.*

This pattern is important because the atmosphere is relatively transparent to incoming shortwave radiation, but not to outgoing long wave radiation. This has a profound effect on the actual energy balance at the Earth's surface.

When this radiative balance is perturbed, for example by a change in solar radiation, atmospheric composition or surface reflectivity, Earth's surface temperature responds by seeking a new equilibrium. This response, which is in the range of 0.3 –1°C per W m^{-2} of forcing (IPCC 2001) alters climate. Significant climate change can accompany even modest changes in global temperature. For example, during the last ice age 20 000 years ago, globally averaged temperatures were 5°C cooler than at present; a response to a forcing of 6.5 W m^{-2} (Hansen, 2004).

The visible light is absorbed by land, oceans and vegetation at the surface and is transformed into heat and re-radiates in the form of invisible long wave infrared radiation. This, however, is an over simplified statement. If it was so, then during the day the earth would heat up and at night, all the accumulated energy would be radiated back into space and the planet temperature would fall far below zero very rapidly. However, greenhouse gases in the atmosphere absorb the heat and re-radiate it in all directions reducing the amount radiated out to space. The greenhouse gases hold heat in like the glass walls of a greenhouse and are responsible for the fact that the earth enjoys a temperature range suitable for our active and complex biosphere.

2.2 Objective 2: To understand and teach scientific content relevant to explaining and understanding the fundamental mechanism of climate change

2.2.1 Bringing in the atmosphere: the natural greenhouse effect

- The earth's surface absorbs (mostly visible) sunlight /solar radiation and subsequently emits infrared light /radiation.
- Greenhouse gases selectively absorb and retain (because these molecules can become asymmetrical) infrared radiation in the process release heat energy.
- Heat energy leaves more slowly warming the earth.
- The foregoing leads to global warming.

As a dam built across a river causes a local deepening of the stream, so our atmosphere, thrown as a barrier across the terrestrial rays, produces a local heightening of the temperature at the Earth's surface. (Tyndall, 1862, quoted in Weart, 2004)

Thus, writing in 1862, John Tyndall described the key to our modern understanding of why the Earth's surface is so much warmer than the effective radiating temperature. Tyndall's careful experimental work had established what others only suspected: expressed in modern scientific terms, certain atmospheric gases absorb infrared radiation with wavelengths in the range spanned by outgoing terrestrial radiation (about 4 to 100 μm; Fig.1. 5; NB. 1 μm = 10^{-6}m).

These are the **greenhouse gases**. Tyndall identified water vapour and CO_2, but the list of natural greenhouse gases (naturally present in the atmosphere long before human activities began to make their mark) also includes methane (CH_4), nitrous oxide (N_2O) and ozone (O_3). The main mechanism by which these gases absorb infrared radiation is through the vibrations of their molecules. We shall not pursue the scientific principles that underlie this mechanism in any detail, but the key points we shall need are summarized in Box 2.

Box 2.1 'Exciting' molecular vibrations

- *The chemical bonds that hold a molecule together are like springs. Therefore, they can stretch and flex, making the molecule vibrate. Molecular vibrations always have a characteristic frequency. If a molecule absorbs radiation of a matching frequency – and hence with a characteristic wavelength (Fig.2.1) – the energy it gains makes it vibrate more vigorously. The frequencies of molecular vibrations invariably correspond to wavelengths in the infrared part of the spectrum.*
- *To be 'infrared active' (i.e. to absorb infrared radiation through changes in the way it vibrates), a molecule must contain more than two atoms or, if there are just two atoms, these are of different elements. More complex molecules, such as the greenhouse gases, can vibrate in several ways, each with its own characteristic frequency. So they can absorb a range of wavelengths in the infrared.*
- *Once 'excited' by absorbing infrared radiation, a greenhouse gas molecule can lose energy again by re-emitting radiation of the same wavelength. Alternatively, it can pass energy on to other molecules in the air by bumping into them: the net effect is to increase the total 'energy content' of the air, warming it up.*

Molecular structures of some of the greenhouse gases are depictured below;

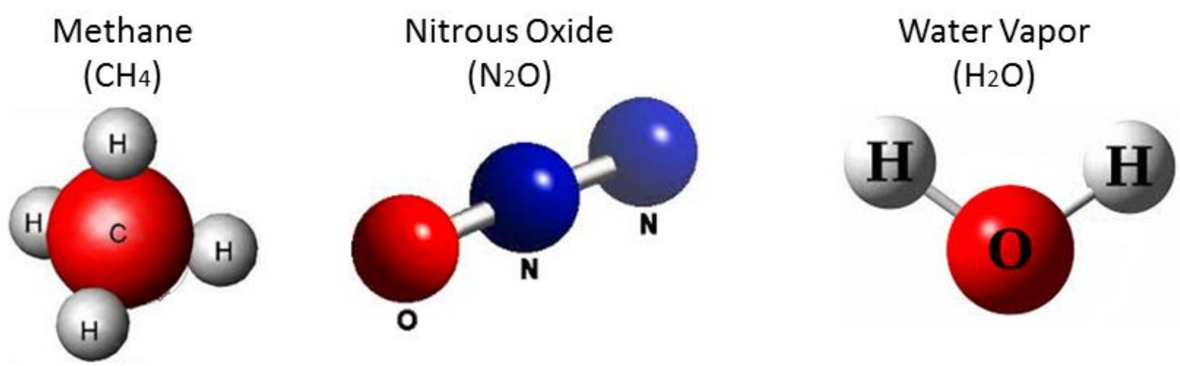


Fig. 2.6: Molecular structures of methane, nitrous oxide and water vapor

Taken together, the natural greenhouse gases absorb infrared wavelengths throughout most of the terrestrial range; there is only one region, between 8 and 13 µm, where absorption is weak. Known as the 'atmospheric window', this allows some of the long wave radiation from the surface to escape directly to space, but most of it is intercepted by the atmosphere. That changes the simple picture in Fig.1.4 substantially. A better representation is shown in Fig.1.7.

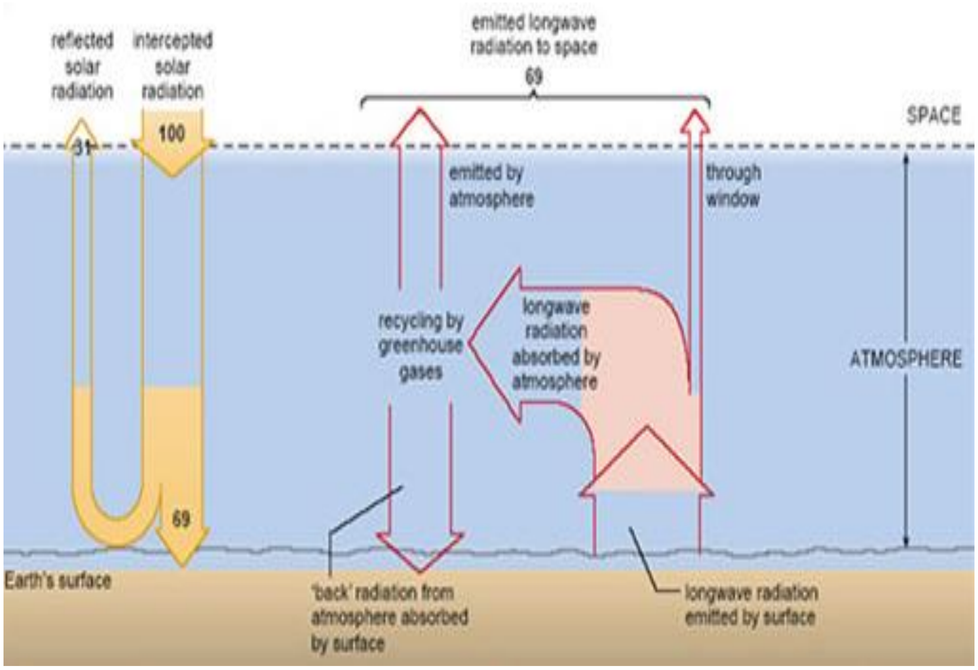


Fig. 2.7: Schematic representation of globally averaged radiation balance

Now most of the long wave radiation from the surface is effectively 'trapped' and recycled by the atmosphere, being repeatedly absorbed and re-emitted in all directions by the greenhouse gases. This warms the atmosphere. Some of the re-emitted radiation ultimately goes out to space, maintaining an overall radiation balance at the top of the atmosphere (Fig.2.8).

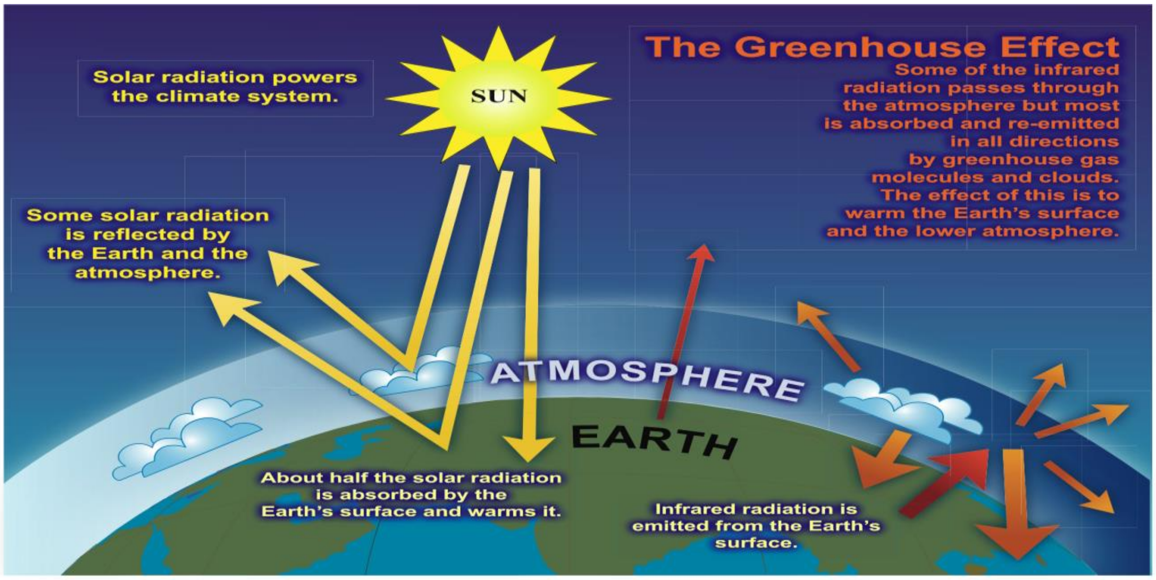


Fig. 2.8: Radiation balance between the sun, the atmosphere and the earth

This prevents the whole Earth-atmosphere system from heating up without limit. The crucial difference is that much of the re-emitted radiation goes back down and is absorbed by the surface. It is this additional energy input – over and above the absorbed solar radiation – that keeps the Earth's GMST over 30 °C warmer than it otherwise would be. As in **Fig.2.4**, **Fig.2.6** shows that 69 units of solar radiation are absorbed by the planet and 69 units of long wave radiation go back out to space. However, this overall radiation balance is now at the top of the atmosphere, not at the surface, which receives an extra input of energy through the 'back radiation' from the atmosphere. The surface warming attributed to the back radiation from the atmosphere is called the **greenhouse effect**. The gases which cause greenhouse effect are normally referred to as greenhouse gasses (GHGs). As is the case with other gases in the atmosphere, GHGs are mostly found in the lower atmosphere (troposphere). The contribution that each greenhouse gas makes to the total effect depends on two main factors:

- how efficient it is at absorbing outgoing long wave radiation, and
- its atmospheric concentration.

The striking thing is that most of these gases are only minor atmospheric constituents, as shown by the information collected in **Table 2.1**.

Table 2.1: average mixing ratios of some gases in the dry air troposphere

3 **Recent (1998) average mixing ratios of some of the gases in (absolutely) dry air in the troposphere ≈ 10 km above the surface of the earth).**		
4 **Gas**	5 **Formula**	6 **Mixing Ratio**
7 **Nitrogen**	8 **N_2**	9 **0.78**
10 **Oxygen**	11 **O_2**	12 **0.21**
13 **Argon**	14 **Ar**	15 **0.0093**
16 **Trace Gases**		
17 **Carbon Dioxide**	18 **CO_2**	19 **3.68×10^{-4}**
20 **Methane**	21 **CH_4**	22 **1.745×10^{-6}**
23 **Nitrous Oxide**	24 **N_2O**	25 **3.14×10^{-7}**
26 **Ozone**	27 **O_3**	28 **$10\text{-}100 \times 10^{-9}$**

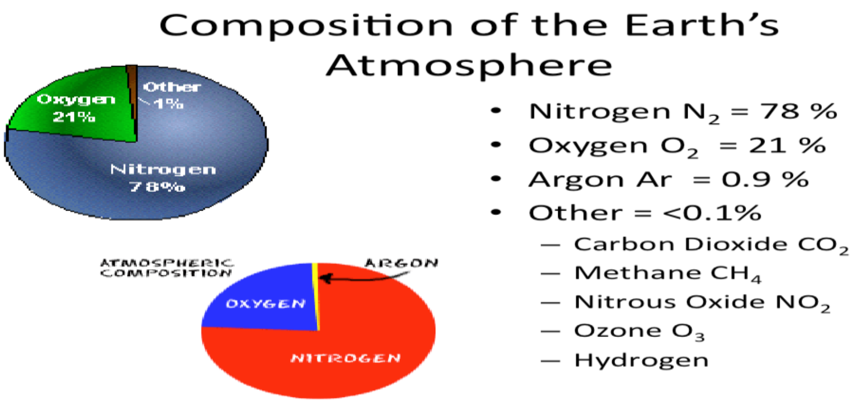


Fig. 2.9: atmospheric composition of gases

Here, concentrations are given as 'mixing ratios' – the measure of atmospheric composition that has become familiar to policy makers and other stakeholders in the climate change debate. The term is explained in Box 2.1

Box 2.2 Mixing ratios

Strictly, the mixing ratio (by volume) tells us about the 'fractional abundance' or proportion of a given atmospheric gas, although you will often find it referred to as the 'atmospheric concentration'. Taking oxygen (O_2) as an example, the formal definition is as follows:

$$Mixing - Ratio = \frac{N(O_2)}{N_{Total}}$$

*Where N_{total} is the total number of molecules in a given volume of air (e.g. m^3) and $N(O_2)$ is the number of molecules of oxygen in the same volume of air. Expressing the fraction in decimal form or as a percentage (by multiplying by 100) is fine for the major atmospheric constituents (see the entries in Table 1), but it becomes unwieldy for minor constituents like the greenhouse gases. In this case, values are usually recorded as **ppm (parts per million, 10^6)** or as **ppb (parts per billion, 10^9)** – or even as **ppt (parts per trillion, 10^{12})** for the least abundant species.*

Test 6

Question: *In **Table 2.1**, the mixing ratio of CO2 is given as 368 ppm. Express this value as a number (in scientific notation), and then as a percentage.*

Answer: *A value of 368 ppm means that in every million molecules of air, 368 will, on average, be molecules of CO2. So 368 ppm is equivalent to* $368/10^6 = 368 \times 10^{-6} = 3.68 \times 10^{-4}$ *(in scientific notation). Multiplying by 100, this becomes* 3.68×10^{-2}*% or 0.0368%.*

Question: *Now express the mixing ratio of* CO_2 *in ppb.*

Answer: *If there are 368 molecules of CO2 per million in total, there would be 368 000 per billion, so the answer is 368 000 ppb. Thus, 1 ppm=*10^3 *ppb, and similarly 1 ppb=*10^3 *ppt.*

Question: *Given the information in **Table 2.1**, how would you describe the bulk composition of the lower atmosphere?*

Answer: *99% is nitrogen and oxygen (roughly in a 4: 1 ratio), and most of the rest (0.93%) is argon.*

Question: *Is any one of these major components a greenhouse gas?*

Answer: *No. The chemically inert noble gas argon exists as individual atoms; nitrogen and oxygen molecules each consist of two atoms of the same element. None of them fulfils the criterion for being infrared-active (**Box 2.2**).*

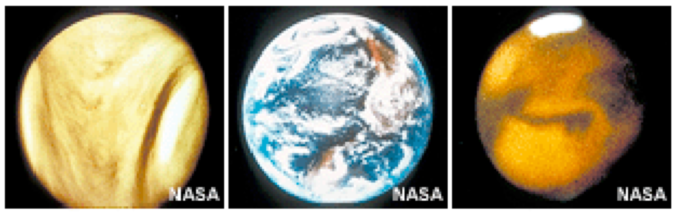
Note that the mixing ratios in **Table 2.1** are for dry air. The contribution from water vapour is not included because the amount in the air is highly variable – from practically none at all up to about 4% (by volume). Part of the explanation is that air can 'hold' only a certain amount of water vapour: it has a 'saturation' limit, which depends mainly on temperature. The variable humidity of the air (a measure of its water vapour content) is part of our everyday experience: it affects the ability of sweat to evaporate, for example, and the drying of clothes on the line.

Averaged over time and around the globe, water vapour represents about 0.5% of the total atmospheric gas. This relatively high abundance makes water vapour the single most important natural greenhouse gas: it contributes about 60% of the surface warming attributed to the natural greenhouse effect. Carbon dioxide, the second most abundant, contributes a further 25% or so;

most of the rest is due to the other three trace gases in Table 2.1, which have much lower atmospheric concentrations.

The fact that the Earth is neither a frozen lifeless rock like Mars nor a hot lifeless one like Venus shows that the natural greenhouse effect is not a ‘bad thing'; indeed, it is a ‘good thing'!

The “Goldilocks” Principle



	Venus	Earth	Mars
Surface pressure relative to Earth (bars)	90	1	0.007
Major greenhouse gases (GHG)	CO_2	H_2O, CO_2	CO_2
Temperature if no GHG (°C)	-46	-18	-57
Actual temperature (°C)	477	15	-47
Temperature change due to GHG	+523	+33	+10

Mars is too cold, Venus is too hot, but the Earth is just right!

7

Fig. 2.10: Comparison of properties of Mars, Earth and Venus

Instead it is the extra warming produced by an enhanced or amplified greenhouse effect, due to an increase in the atmospheric concentration of CO_2 (and indeed other greenhouse gases), that lies at the heart of current concerns. We shall sometimes refer to this as an increase in the atmospheric ‘burden’ of CO_2 (or of greenhouse gases in general), since an increase in concentration necessarily implies an increase in the total amount (or number of molecules) of the gas in the atmosphere.

Box 2.3

☐ ***What would happen if the Earth did not have greenhouse gases?***

- *Main greenhouse gases (GHGs: CO_2 and H_2O)*
- *The Earth's temperature without GHGs: -5^{0}C (268.15K)*
- *Actual average Temperature: 15^{0}C (288.15K)*
- *Temperature change due to GHGs: 20^{0}C*

BOX 2.4

☐ ***This is an example of why we want to have greenhouse gases***

- *They make our planet habitable and bring the temperature up to a level humans can live*
- *It does not mean that the temperature everywhere is on a daily basis equal to 15^{o}C, but just that the global average temperature is 15^{o}C.*
- *We know this because we can look at other planets e.g. Mars and Venus and compare their temperatures and atmosphere to ours (See Goldilocks Principle).*

Test 7

Question: *Analogies are a useful aid to understanding, and can be a powerful means of communicating scientific ideas to a lay audience. However, they can be misleading. Look back at the quote from John Tyndall at the beginning of Section 2.2.1. In what way is the analogy used there a misleading one? Explain your reservations, making reference to the mechanism that actually creates the Earth's greenhouse effect.*

Answer: *The basic problem is the notion of a 'barrier across the terrestrial rays'. This could suggest that the atmosphere somehow 'reflects' back outgoing radiation (an error that sometimes appears in newspaper accounts to this day) and/or that none of it ever goes out to space – in which case the planet would simply heat up without limit! In reality, some of the longwave radiation from the surface escapes directly to space (at wavelengths in the 'atmospheric window'). The rest is absorbed and re-emitted (up and down) by greenhouse gases in the atmosphere. Back radiation from the atmosphere keeps the surface warmer than it otherwise would be (the natural greenhouse effect). But some of the re-emitted radiation ultimately goes out to space, maintaining an overall radiation balance at the top of the atmosphere.*

2.2.2 Energy flows within the Earth-atmosphere system

Before we focus on the enhanced greenhouse effect, we need to refine the schematic representation in Fig. 6 and draw in some of the other processes that influence the Earth's temperature – not only at the surface, but also at different levels within the atmosphere.

2.2.3 The vertical 'structure' of the atmosphere

The atmosphere is not a simple, uniform slab of absorbing material. On the contrary, it gets progressively 'thinner' or less dense with increasing altitude (height above mean sea level); i.e. the total number of molecules in a given volume of air is lower, and so is the pressure. About 80% of the total mass of the atmosphere is within some 10 km of the surface; 99.9% lies below 50 km.

The important corollary is that the key greenhouse gas molecules (H_2O and CO_2) are also more abundant close to ground level, and increasingly scarce at higher altitudes. So a better picture of radiation trapping in the real atmosphere is to imagine it happening in a series of stages. Outgoing longwave radiation is repeatedly absorbed and re-emitted as it 'works up' through the atmosphere; it is re-radiated to space only from levels high enough (i.e. thin enough) for absorption to have become weak. This suggests that the atmosphere should be warmer at ground level – close to the source of the outgoing radiation, and where the absorbing molecules are more abundant. Everyday experience confirms this expectation; it generally gets colder as you walk up a mountain, for example.

The vertical temperature profile of the atmosphere can be categorised as follows:

Troposphere

This is the layer where all weather related activities occur, at an altitude of about 10 km from the earth's surface. In this area the temperature decreases with height until tropopause. The tropopause separates the troposphere and above layer stratosphere.

Stratosphere

In the stratosphere the temperature profile increases with height immediately after the tropopause until at an altitude of about 50km, the stratopause level.

Mesosphere

Above the stratopause, temperature decreases strongly with height in the mesosphere, until the mesopause is reached at an altitude of about 80 km.

Thermosphere

Above the mesopause, temperature increases with height in the thermosphere and above until to the sun.

The vertical gradients above 10 km are strongly influenced by the absorption of solar radiation by different atmospheric constituents and by chemical reactions driven by the incoming light. In particular, the warming in the stratosphere at heights of about 30-50 km is mostly due to the absorption of ultraviolet radiation by stratospheric ozone, which protects life on Earth from this dangerous radiation.

Table 2.2 The structure of the atmosphere

29 Atmospheric layer	30 Temperature range	31 Vertical distance	32 Chemical composition
33 Troposphere	34 Decreases (18 to -60)	35 0 to 10Km	36 Oxygen, nitrogen, trace gases
37 Stratosphere	38 Increases (-60 to -10)	39 10 to 48km	40 stratospheric ozone
41 Mesosphere	42 Decreases (0 to -80)	43 48 - 84km	
Thermosphere	Increases (-80 to above)	84km and above	Helium, hydrogen

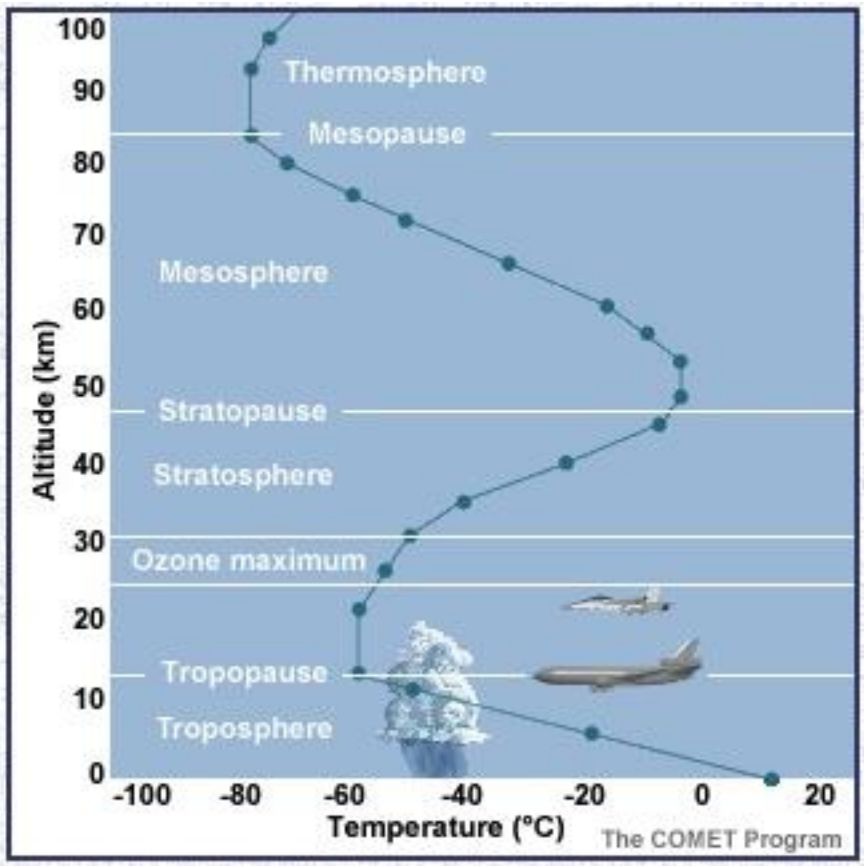


Fig. 2.11: The characteristic temperature profile

The atmosphere produces a vertical structure like a series of concentric shells. The successive regions or 'spheres' are separated by 'pauses' where the change in temperature with altitude switches from decreasing to increasing, or vice versa. The outer more-rarefied reaches of the atmosphere (which extends up to 100 km or so) are not included.

2.2.4 The fate of incoming solar radiation

Test 8	
***Question**:*	*Look back at Fig.1.7. In this schematic representation, what is the fate of incoming solar radiation?*
Answer:	*It is either reflected back to space (31 units) or absorbed by the surface (69 units).*

Some solar radiation is, in fact, absorbed as it travels down through the atmosphere. Mostly, this is radiation at wavelengths in the two 'tails' of the solar spectrum (Fig2.12) – the ultraviolet and the near infrared.

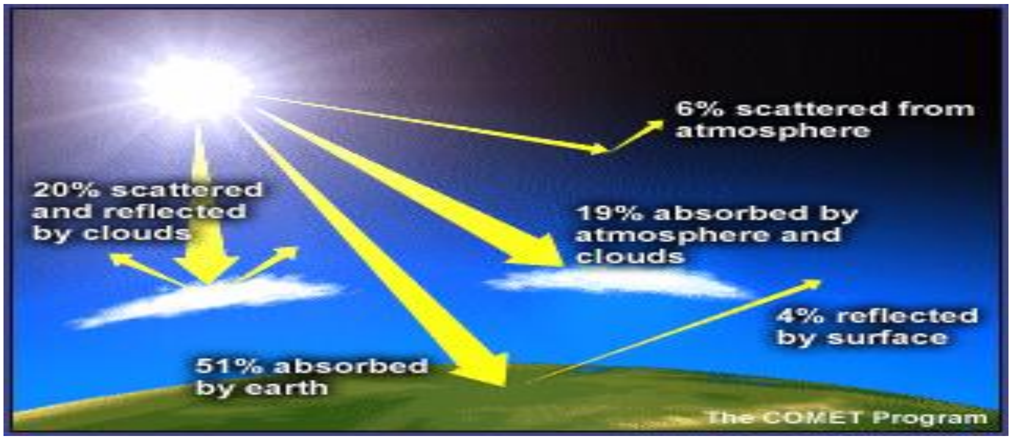


Fig. 2.12 Absorption of solar radiation by various matters

Like water vapour and CO_2, the ozone in the troposphere acts as a greenhouse gas. Unlike those two gases, however, very little of the Earth's ozone is, in fact, in the lower atmosphere; the bulk of it (some 90%) is in the stratosphere, where it forms the **ozone layer**. In this more-rarefied region, ozone plays a different role because it also absorbs the shorter ultraviolet wavelengths in the solar spectrum – radiation that is lethal to many micro-organisms and can damage important biological molecules, leading to conditions such as skin cancer in humans.

Fortunately for life on Earth, most of this radiation is absorbed by the ozone layer, preventing it from penetrating deeper into the atmosphere. More pertinent here, the absorption of incoming solar energy by stratospheric ozone heats this region of the atmosphere directly. In effect, the stratosphere is heated from above, whereas the troposphere is heated from below. This is why the highest temperatures are found at the top of the stratosphere, and at the bottom of the troposphere (as shown in Fig.2.11).

About half of the incoming near-infrared radiation is also absorbed, mainly by water vapour lower down in the troposphere. In addition, the atmosphere contains a huge assortment of **aerosols** – fine solid particles and liquid droplets suspended in the air. Except in the aftermath of a major volcanic eruption (discussed later), aerosols are also most abundant in the lower atmosphere; natural sources include desert dust wafted into the air by wind, smoke and soot from wildfires, salt from sea-spray, and so on. Depending on their make-up, aerosols can absorb solar radiation – or (and this is usually more important) scatter some of it back to space. Globally, aerosols make a significant contribution to the Earth's albedo (included in the figure of 31% quoted earlier). They also play another important role. Many aerosols act as **cloud condensation nuclei**, providing surfaces that promote the condensation of water vapour to form the liquid droplets (or ice crystals, at higher and colder altitudes) suspended in clouds – a process that occurs less readily in ‘clean’ (i.e. aerosol-free) air.

2.2.5 The role of clouds

We have already identified one role that clouds play in the Earth's climate: they are highly reflective. At any given time, about half of our planet is covered by clouds; the sunlight they reflect back to space accounts for about 55% of the total planetary albedo. However, clouds also absorb and re-emit outgoing longwave radiation; i.e. they contribute to the back radiation from the atmosphere, and hence to the natural greenhouse effect. This is why temperatures tend to be lower under clear night skies than on nights with extensive cloud cover.

Thus, clouds present something of a paradox: they both warm and cool the Earth. The balance between these two opposing effects is a delicate one – dependent on factors such as the type and thickness of the clouds, their altitude, whether they consist of water droplets or ice crystals, and so on (Fig.2.13). Averaged over time and around the world, satellite data indicate that the net effect of clouds in our current climate is a slight cooling of the surface. As you will see, predicting how the balance between warming and cooling might shift in a warmer world remains one of the biggest headaches for climate scientists.

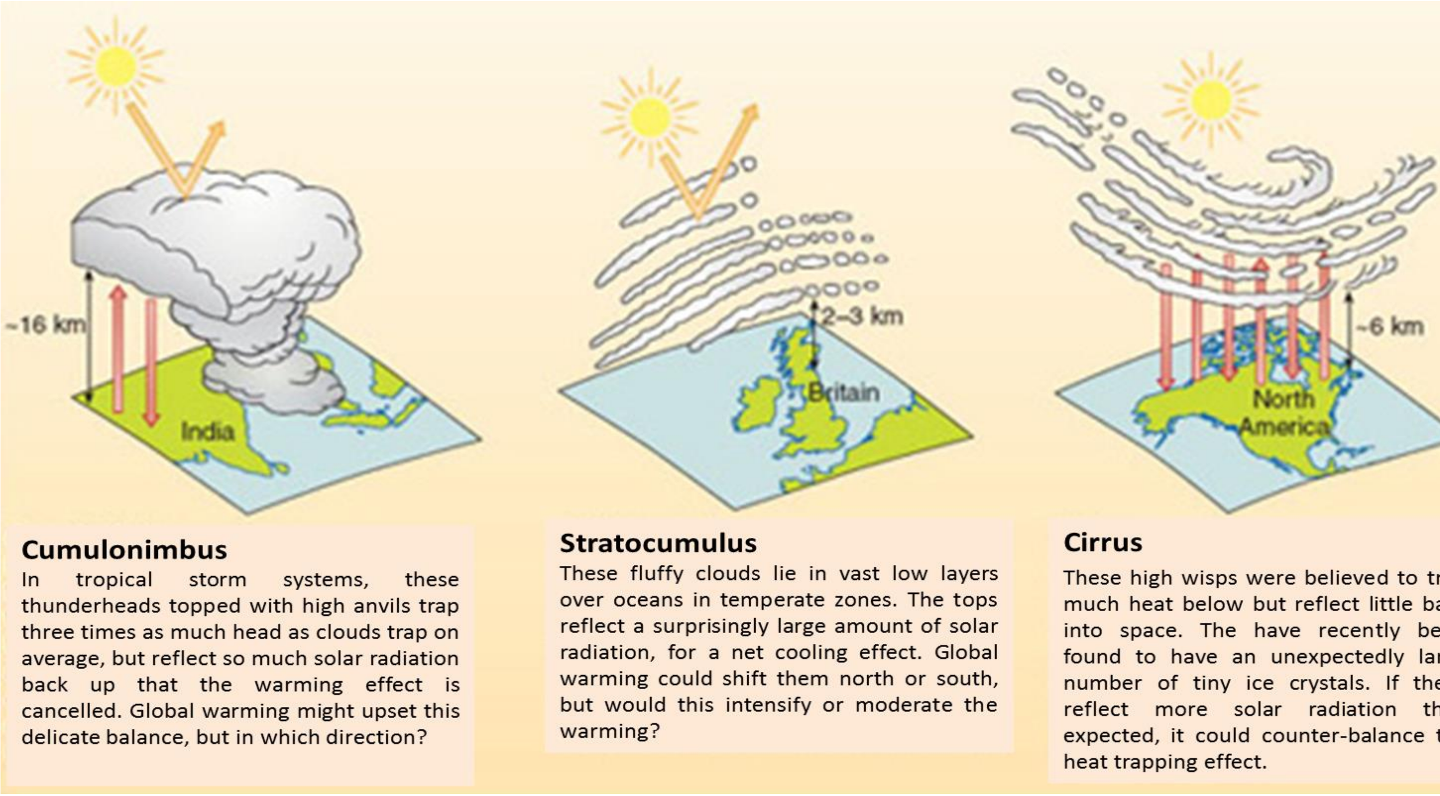


Fig. 2.13 types of clouds

Fig.2.13. Researchers are only beginning to understand the complex role clouds play in modulating the planet's temperature. The figure summarises some key points, stressing how different types of clouds affect the Earth's radiation balance differently. How these variations fit together to produce a global cooling effect, and how that might change in a warmer world, remains uncertain.

2.2.6 The role of convection in the atmosphere

We now come to our final refinement to the simple picture in **Fig.2.11**. Recall that the troposphere is heated from below, with temperature then falling with increasing altitude. This situation sets the scene for the onset of convection – the bulk flow or circulation of a fluid driven by differences in temperature. Convection in the atmosphere plays a vital role in two further mechanisms – quite apart from the emission of longwave radiation – whereby energy is transferred from the Earth's surface to the atmosphere. The first is the transfer of 'thermal' energy (often referred to rather loosely as 'heat') by a combination of conduction and convection. This is essentially the same mechanism that heats a saucepan of water on the stove (**Box 2.5**).

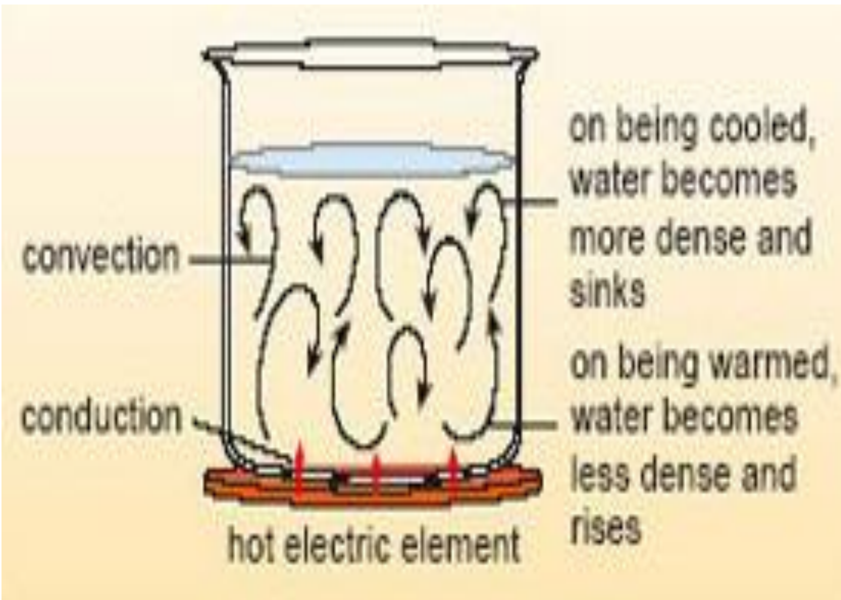


Fig. 2.14 Heat transferes during the heating process of water

Box 2.5

☐ ***Heating water by conduction and convection***

Anyone who tries to pick up a metal spoon left in contact with a hot pan quickly learns that metals are good conductors of heat. ***Conduction*** *is the transfer of heat through matter by molecular activity; i.e. the energy is transferred through contact between individual molecules. By contrast,* ***convection*** *is the transfer of heat by bulk movement or circulation within a fluid (a liquid like water or a gas like the air).*

In ***Fig. 2.14****, heat is transmitted from the electric element, through the pan to the water in contact with the base of the pan by conduction. As water in this layer warms up, it expands – this is called* ***thermal expansion*** *– and so becomes less dense than the water above. Because of this new buoyancy, the warm water begins to rise, to be replaced by cooler, denser water from above which is heated in its turn. On reaching the surface, the warmed water begins to lose heat to the air; it cools, becomes denser and sinks, then is heated again and rises, and so on. As long as the water is heated unequally (i.e. from the bottom up), the water will continue to 'turn over' in a convective circulation so that eventually all of it becomes warm.*

The second form of energy transfer is indirect, but even more important on a global scale. It involves the evaporation of water – mainly from the oceans, but also from lakes and rivers, soils, rocks and vegetation on land. Evaporation requires energy, known as the **latent heat of vaporization**, which is extracted from the surface involved. This is why the evaporation of sweat acts to cool the body. The latent heat of vaporization of water, i.e. the amount of heat needed to convert 1 kg of liquid water to water vapour at the same temperature (and the amount of heat released to the surrounding environment when 1 kg of water vapour condenses) is 2.25×10^6 J kg^{-1} – higher than the value for any other substance.

Test 9

Question: *How does convection in the overlying air help to promote the evaporation of water?*

Answer: *Convection carries air containing water vapour upwards, so the air just above the surface does not become 'saturated' enabling more water to evaporate.*

As we noted earlier, the saturation limit of air depends on temperature: cool air can carry less water vapour than warm air. As moisture-laden air is carried upwards, it cools and may become saturated. Continued rise and further cooling then results in the condensation of water vapour onto aerosols in the air: clouds form and latent heat is released to the atmosphere. Clouds, the turbulence of atmospheric convection and the winds that redistribute heat around the world are largely confined to the troposphere (tropos is Greek for 'turning').

Test 10

Question: *Look back at Fig. 2.11. It is often said that the tropopause acts like a lid, preventing convection in the lower atmosphere from reaching any higher. Can you suggest why?*

Answer: *With (less dense) warm air lying above (more dense) cooler air, conditions in the stratosphere are not conducive to convection. (Stratos is Latin for 'layered'.)*

Rapidly rising air can (and does) overshoot the tropopause, mostly in the up draught of violent storms over the tropics. There are return routes as well, mainly at middle latitudes. In general, though, the circulation of air in the stratosphere does not interact strongly with the wind systems in the lower atmosphere. It is within the troposphere that the full drama of the Earth's weather occurs.

2.2.7 An overview of the global energy budget

Fig. 2.15 incorporates the additional factors considered earlier including the non-radiative energy transfers across the surface-air boundary (green arrow). Essentially a more detailed version of Fig. 7, this figure gives quantified estimates of the globally averaged energy budget for the whole Earth-atmosphere system, and its component parts. Test 10 (below) should help you to find your way around Fig. 2.15, and to draw together many of the key points developed so far in this chapter. Make sure to try answering it before moving on.

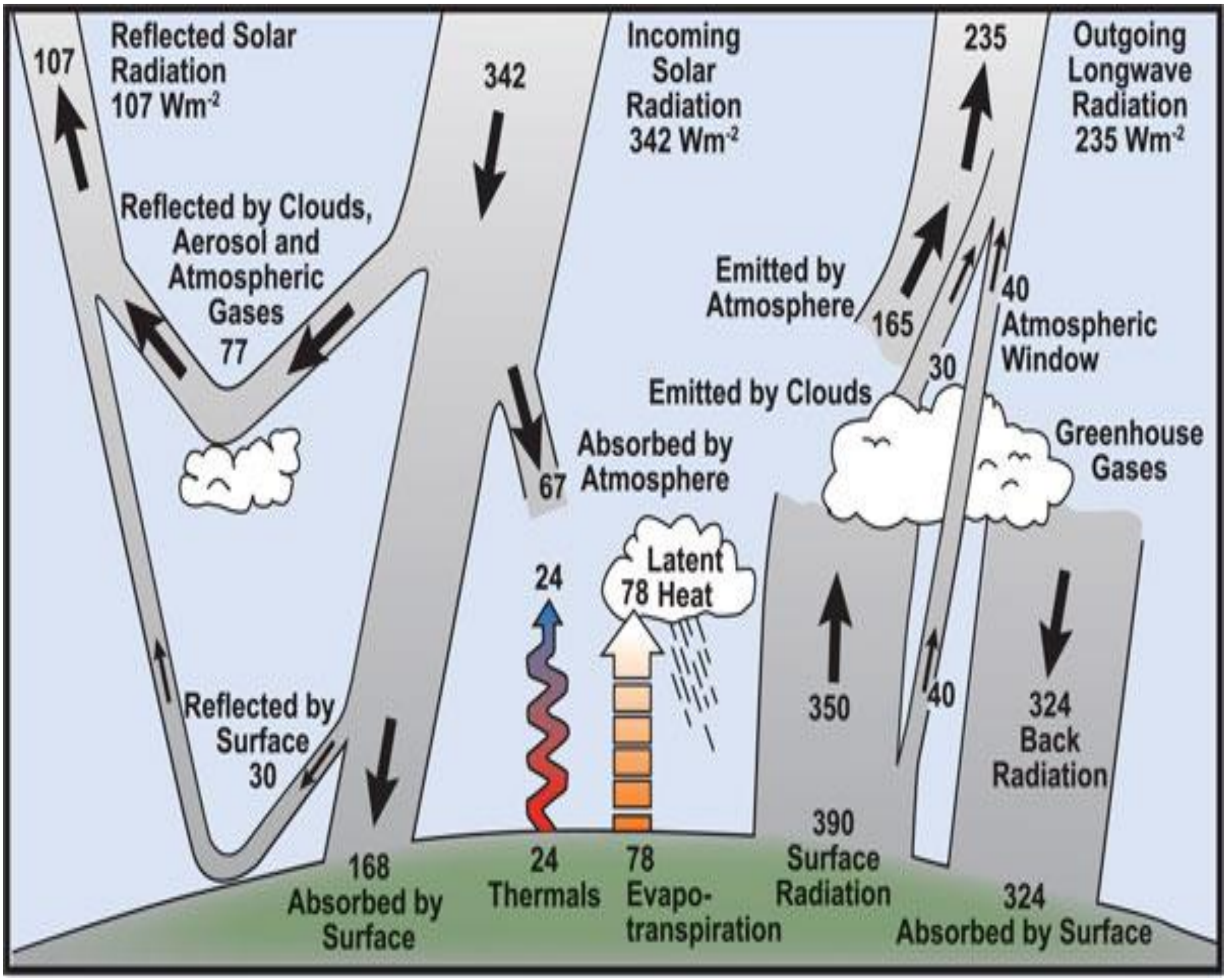


Fig. 2.15 Schematic overall energy budget for the Earth and its atmosphere.

Test 10: *With reference to **Fig 2.15***

10.1 What proportion (as a percentage) of the Earth's planetary albedo is due to solar radiation reflected by the surface? Which regions of the world are likely to be mainly responsible for this contribution?

10.2 Calculate the difference between the rate of energy gain and the rate of loss for: (i) the Earth's surface; (ii) the atmosphere; and (iii) the whole Earth-atmosphere system (i.e. at the top of the atmosphere). What do you conclude about the Earth's GMST?

10.3 What proportion (as a percentage) of the longwave radiation emitted by the surface is absorbed by the atmosphere?

10.4 Translate the 114 units of longwave radiation emitted by the surface into a rate of energy transfer (in W m^{-2}). Explain why your answer is consistent with the fact that the Earth's GMST is higher than its effective radiating temperature (−19 °C).

Answer

10.1 The planetary albedo is the proportion of incoming solar radiation reflected or (scattered) directly back to space – 31 units according to Figure 12. Surface reflection contributes 9 units or (9/31) × 100% = 29%. Snow- or ice-covered surfaces (predominantly at high latitudes) are likely to be mainly responsible, given their high albedo.

10.2 (i) The total rate of energy gain by the Earth's surface is the sum of the appropriate downward-pointing arrows in Figure 2.12; i.e. (49 + 95) units = 144 units. The total loss rate is the sum of the upward-pointing arrows that originate at the Earth's surface: (30 + 114) units = 144 units. The difference is zero, so the surface is in a steady state; the GMST is not changing.

(ii) Proceeding as in (i), the total rate of energy gain by the atmosphere is: (20 + 30 + 102) units = 152 units. The total rate of loss is: (95 + 57) units = 152 units. The difference is again zero.

(iii) For the whole Earth–atmosphere system, the total rate of energy gain (solar radiation intercepted) is 100 units, and the total rate of loss is (31 + 57 + 12) units = 100 units, confirming that the whole system is also in a steady state.

10.3 The proportion is (102/114) × 100% = 89% (to 2 significant figures).

*10.4 100 units is equivalent to 342 W m^{-2}, so 114 units is equivalent to (342 W m^{-2}/100) × 114 = 390 W m^{-2}. This is significantly higher than the rate of emission (236 W m^{-2}; **Section 2.2.1**) from a body with an effective radiating temperature of −19°C. Since the rate of emission increases with increasing temperature, this implies that the Earth's GMST is higher than −19 °C.*

To sum up: in **Fig.2.15**, the whole Earth–atmosphere system is in a dynamic **steady state** or equilibrium. Most (89%) of the outgoing long wave radiation is absorbed and recycled by the atmosphere, and ultimately re-emitted to space from higher, colder levels (**Fig.2.11**). As a result, energy circulates within the system at a higher rate than the rate of input or output at the top of the atmosphere: this is why the Earth's surface is warmer than it otherwise would be. But in a balanced state, there is no net accumulation of energy in any part of the system, and no net loss. In short, **Fig.2.16** depicts a world where the GMST is not changing. So what might cause the Earth's GMST to change?

2.2.8 'Radiative forcing' as an agent of climate change

Since its first major report in 1990, the IPCC has used the concept of 'radiative forcing' as a simple measure of the importance of a potential climate change mechanism. The basic idea is straightforward. Any factor that disturbs the radiation balance at the top of the atmosphere has the potential to 'force' the global climate to change: it will either warm up or cool down until a balance is restored. The perturbation to the energy balance of the whole Earth-atmosphere system is called **radiative forcing**, and is given in the units $W\ m^{-2}$.

Test 11	
Question:	*Look back at **Fig.2.15**. What three factors could disturb the radiation balance at the top of the atmosphere?*
Answer:	*A change in the Sun's output, and hence in the solar constant; a change in the Earth's albedo; and a change in the long wave emission to space.*

Among the more enduring hypotheses to account for climate change are those based on the idea that the Sun is a variable star and that its output of energy varies through time. Indeed, this idea underlies the sceptical view that recent global warming has little to do with human activities; rather, the argument goes, solar variability is the main culprit. We shall come back to that issue later. For now, we use the possibility of solar variability to put some flesh on the notion of radiative forcing.

To that end, **Fig.2.15** illustrates the effect of a 1% change (up or down) in the solar constant, and hence in the globally averaged solar radiation intercepted by the Earth (the 100 units in (**Fig. 2.16a**). Assuming that the planetary albedo is unchanged (at 31%), an increase in the solar constant (**Fig.2.16b**) produces a **positive radiative forcing**: the rate at which the Earth-atmosphere system absorbs solar radiation (69.69 units) is now greater than the rate at which it emits long wave radiation to space (69 units). This has a warming effect. Conversely, a reduction in the solar constant (**Fig 2.16c**) produces a **negative radiative forcing**, which has a cooling effect.

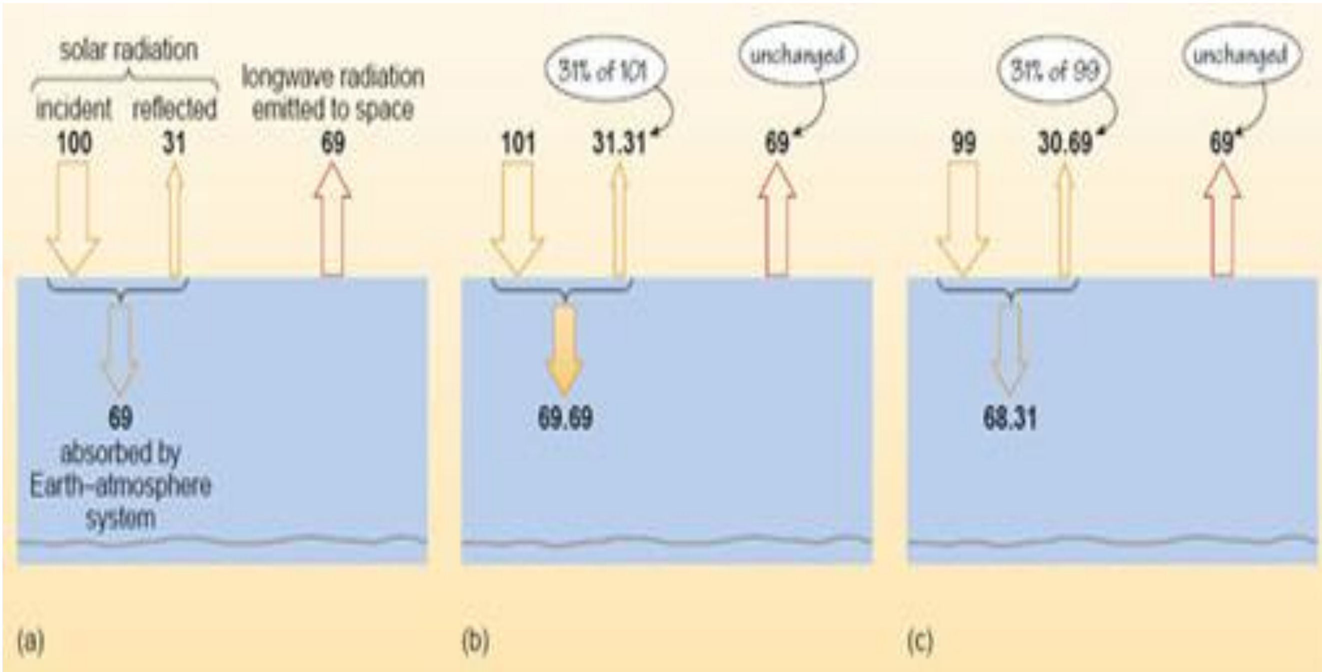


Fig. 2.16(a) The globally averaged radiation balance at the top of the atmosphere from Fig.2.16 (i.e. 100 units is equivalent to 342 W m^{-2}). (b) and (c) The imbalance induced by a 1% increase or decrease, respectively, in the solar constant, assuming no change in the planetary albedo.

Explosive volcanic eruptions spew vast quantities of gases and fine-grained debris (volcanic ash) into the atmosphere. The greatest eruptions are sufficiently powerful to inject material high into the stratosphere, where it gradually spreads around the world. The result can be a significant and widespread cooling effect on climate (see **Box 2.6**).

Test 12

Question 4: *According to **Fig.2.16**, what is the radiative forcing, in W m^{-2}, associated with a ±1% change in the solar constant?*

Answer: *The radiative forcing is the difference between the rate at which the Earth–atmosphere system absorbs solar radiation and the rate at which it emits long wave radiation to space. From parts (b) and (c) of **Fig. 2.16**, the magnitude of the radiative forcing is (69.69 − 69) units or (69 − 68.31) units = 0.69 units, which is equivalent to (342 W m^{-2}/100) × 0.69 = 2.4 W m^{-2} (to 2 significant figures). The forcing is positive for a 1% increase in the solar constant (**Fig. 2.16b**) and negative for a 1% decrease (**Fig. 2.16c**).*

Box 2.6

☐ 1816: the 'year without a summer'

The bright sun was extinguished, and the stars
Did wander darkling in the eternal space,
Rayless, and pathless, and the icy earth
Swung blind and blackening in the moonless air;
Morn came and went – and came, and brought no day,
And men forgot their passions in the dread
Of this their desolation.

(Lord Byron, Darkness, 1816)

The largest volcanic event of modern times was the eruption of Mount Tambora in Indonesia in

April 1815. Where records exist, they reveal a period of abnormally cold weather that prevailed during the spring and summer of 1816 in many parts of the Northern Hemisphere. The effects were especially severe in the northeastern United States, with average temperatures in New England up to 3.5 °C below normal in June, for instance, and unseasonal frosts and snowfalls. Europe was also badly affected, leading to crop failures and famine in England, France and Germany. The below-average temperatures lasted for about two years.

In the summer of 1816, there were also widespread reports of a dim Sun, or persistent haze that was not dispersed by surface wind or rain (since it was actually up in the stratosphere) – though few captured its effects as powerfully as Byron's poem.

Test 13

Question: *Why might a major volcanic eruption be expected to have a cooling effect on climate at the Earth's surface?*

Answer: *It increases the load of aerosols in the stratosphere, potentially increasing the absorption of incoming solar radiation in this region and/or scattering more of it back to space (Section 1.3). Both effects cause a cooling at the surface.*

Although one of the more dramatic features of a major eruption (Fig.2.17), volcanic ash has little enduring impact on climate because it settles out of the stratosphere within a few months. Far more important is the amount of sulfur dioxide (SO2), one of the volcanic gases, emitted during the eruption. Chemical reactions rapidly convert the gas to droplets of sulfuric acid, and these sulfate aerosols can remain in the stratosphere for several years (the persistent haze of Box 539).

Their main effect is to increase the back-scattering of solar radiation. The aerosols travelled around the world and lowered the average surface temperature in the Northern Hemisphere by about 0.5 °C.

Fig. 2.17 The explosive eruption of Mount Pinatubo in the Philippines in June 1991 devastated the surrounding area and sent about 25 × 10^9 kg of SO_2 into the stratosphere. Over the following year, the haze of sulfate

Test 14

Question: *With this in mind, how would you describe the climatic effects of a major volcanic eruption in terms of radiative forcing?*

Answer: *The extra load of stratospheric aerosols effectively increases the planetary albedo (the second of the three factors identified at the beginning of this section), and this constitutes a negative radiative forcing. (The effect is analogous to a reduction in the solar input.)*

The resulting cooling effect can be significant (as noted in connection with the Pinatubo eruption in **Fig.2.17**), but only on a relatively short-term basis – typically, 1–3 years at most. Air movements gradually carry the sulfate aerosols down into the troposphere, where they are usually washed out by rain within a few weeks.

But how does an increase in the atmospheric burden of greenhouse gases lead to a radiative forcing of climate? Again we use an illustrative example. Suppose the atmospheric concentration of CO_2 is doubled instantaneously (known as a **CO_2-doubling)**, but everything else (the solar input, planetary albedo, concentrations of other greenhouse gases, etc.) remains the same. What would be the immediate effect? With more molecules of CO_2 in the atmosphere, a higher proportion of the outgoing long wave radiation would be absorbed, reducing the net emission to space. Complicated, but well-understood, calculations give a reduction by about 4 W m^{-2} (from 236 W m^{-2} to 232 W m^{-2}) for a CO_2-doubling.

Test 15

Question: *Does this change represent a positive or negative radiative forcing?*

Answer: *The forcing is positive. The effect is analogous to an increase in the solar constant (by rather more than 1%, according to Question 4).*

There is no dispute about this central conclusion. Increasing the atmospheric concentration of CO_2, or any other greenhouse gas, will force the global climate to warm up; we shall often refer to this as '**greenhouse forcing**'. However, the weighty tomes issued by the IPCC bear witness to the fact that 'the devil is in the detail'! In particular, there is still major uncertainty about what is perhaps the most fundamental question in the whole climate change debate: how much will the Earth's GMST rise in response to a given amount of greenhouse forcing? We shall revisit this question many times as the topic unfolds. Here, we focus next on what is known about the amount of greenhouse forcing to date.

3 Unit 2: Human Induced (anthropogenic) Climate Change

3.1 Objective 3: To understand the science of human induced climate change

3.1.1 The human influence on the atmosphere: the coming of the industrial age

The Industrial Revolution in the 19th century saw the large-scale use of fossil fuels for industrial activities. These industries created jobs and over the years, people moved from rural areas to the cities. This trend is continuing even today. More and more land that was covered with vegetation has been cleared to make way for houses. Natural resources are being used extensively for construction, industries, transport, and consumption. Consumerism (our increasing want for material things) has increased by leaps and bounds, creating mountains of waste. Also, our population has increased to an incredible extent.

In addition, there are many other ways in which humans affect the various components of the climate system. **Agriculture, deforestation, urbanization** and **other forms of land cover change** alter the proportion of incoming solar radiation reaching the ground surface that is reflected back to space, thus affecting the energy balance and hence the temperature and dynamics of the climate system. **Land use change** also affects the carbon cycle, which in turn affects the state of the climate system. These human activities increase the atmospheric concentration of greenhouse gases.

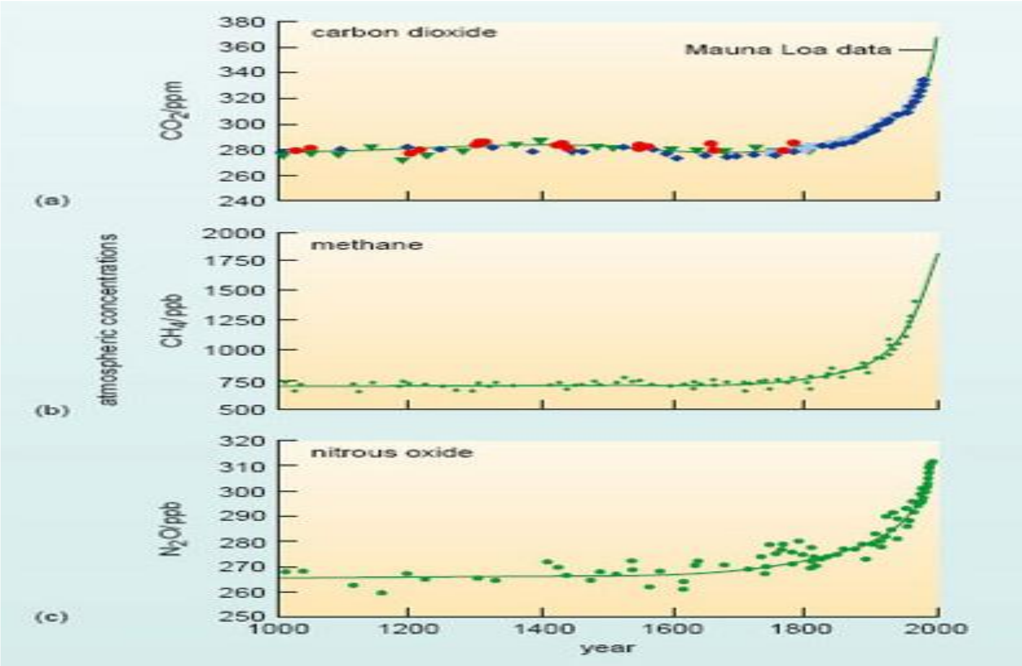


Fig. 3.1 The change in atmospheric concentration of greenhouse gases with time

Fig. 3.1 (a) above charts a continuing rise in CO_2 concentration since measurements began in 1958, when the level was 315 ppm; the value had reached about 370 ppm by the end of the 20th century. Important as changes in atmospheric CO_2 undoubtedly are, we need to be aware that this is not the whole story of human-induced greenhouse forcing. In particular, monitoring programs established during the 1980s reveal an upward trend in the levels of two other natural greenhouse gases as well – methane (CH_4) and nitrous oxide (N_2O) Fig. 3.1 (b) and (c).

The increased concentration of GHGs allow radiation from the sun to pass through the atmosphere to the earth's surface where it is reemitted as long-wave radiation and gets trapped by the GHGs and reemitted back to the surface. This continuous emission and reflection of solar radiation results in warming of the lower atmosphere, referred to as greenhouse effect. Fig.3.2 below indicates that the atmospheric greenhouse effect.

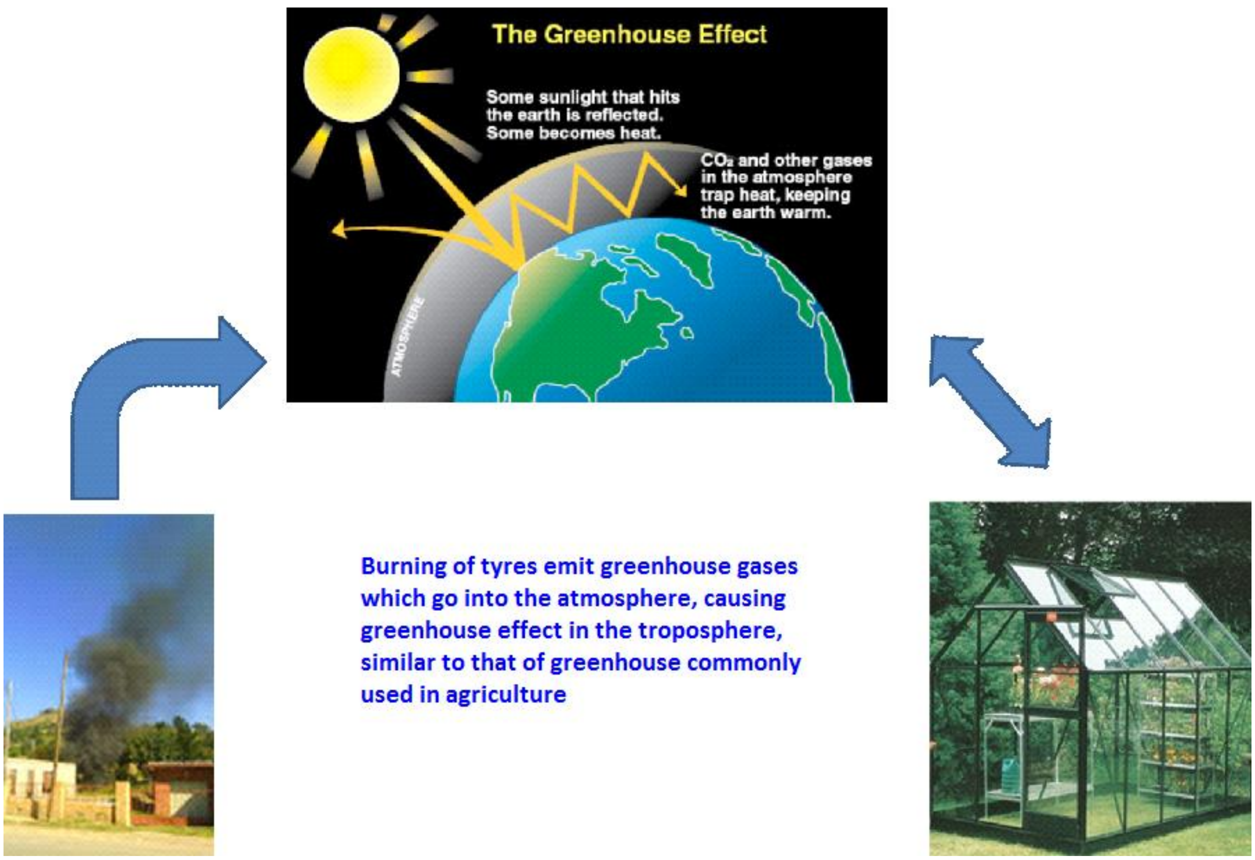


Fig. 3.2 Burning of tyres result into greenhouse effect

The question is: how do we know that the buildup of all three gases over recent decades is due to human intervention?

Referring to Fig. 3.1 (a) above, it is evident that the CO_2 concentration in the atmosphere was almost constant before industrialization. A significant increase was observed in the years when industrialization began. Similar patterns are evident for both methane Fig.3.1 (b) and nitrous oxide Fig.3.1 (c). For each gas, the average level over the first 750 years of these ice-core records (i.e. up to 1750) is taken as a measure of its 'pre-industrial' concentration; these values are collected in Table 2, along with some other pertinent information we shall come on to shortly.

Test 3.1

Question: *With this longer-term perspective in mind, what does Fig. 3.1 (a) suggest about the change in atmospheric CO_2 during the period covered by the Mauna Loa record?*

Answer: *It continues a rising trend that seems to have started towards the end of the 18th century. For some 800 years before that, the CO_2 level fluctuated little about a mean value close to 280 ppm.*

Table 3.1. Information on 'well-mixed' greenhouse gases influenced by human activities. (Source: IPCC, 2001a.)

Concentration

Gas	**Pre-industrial**	**1998**	**Atmospheric lifetime/years**	**Global Warming Potential**
natural greenhouse gases				
CO_2	280 ppm	368 ppm	~100	1
CH_4	700 ppb	1745 ppb	12	23
N_2O	270 ppb	314 ppb	114	296
synthetic halocarbons				
CFC-11($CFCl_3$)	**0**	268 ppt	45	4600
CFC-12 (CF_2Cl_2)	**0**	533 ppt	100	101600
HCFC-22 (CHF_2Cl)	**0**	132 ppt	12	1700

Test 3.2

Question: *Using the information in Table 3.1, calculate the percentage change in the atmospheric concentrations of (i) CO_2; (ii) CH_4; and (iii) N_2O since the pre-industrial period 1750 up to 1998.*

Answer: *There has been an increase by (i) 31%; (ii) 149%; and (iii) 16%. For CO_2, for example, the concentration has increased by (368–280) ppm=88 ppm, so the percentage increase has been (88/280) ×*

There is one further point to note about the plots in Fig. 3.1. The increase in the atmospheric burden of these gases since pre-industrial times is not linear; rather it appears to be accelerating. For example, it took over 200 years for the level of CO_2 to rise from 280 to 330 ppm (1750 to around 1975); it has taken just 30 years for it to increase by the same amount, i.e. a further 50 ppm.

As indicated in the heading to Table 3.1, these three natural greenhouse gases are described as being 'well-mixed', which means that they are distributed fairly uniformly throughout the troposphere. This is because they persist in the atmosphere long enough to be moved around the world by large-scale air movements and 'mixed up' with other atmospheric constituents, so their concentrations do not vary much from place to place. Current estimates of the **atmospheric lifetimes** of CO_2, CH_4 and N_2O are also given in Table 3.1 – along with comparable information for some of the infrared-absorbing **halocarbons** that do not occur naturally, but are now found in trace amounts in the atmosphere (albeit at the level of only a few tens to hundreds of parts per trillion , ppt) as a result of their manufacture and use for various purposes. As a group of compounds, halocarbons can be thought of as derived from hydrocarbons (methane, for the examples in Table 3.1), but with some or all of the hydrogen atoms in the molecule replaced by halogen atoms – usually some combination of fluorine (F) and chlorine (Cl), as in the **chlorofluorocarbons (CFCs)** and hydrochlorofluorocarbons (HCFCs).

Indicted for their role in stratospheric ozone loss, the use of all CFCs is now been phased out under the evolving provisions of the Montreal Protocol on Substances that Deplete the Ozone Layer (first agreed in 1987). The two main CFCs are included in Table 3.1 for two reasons. First, these compounds are eventually destroyed by chemical reactions within the atmosphere, but this is a slow process – whence their long atmospheric lifetimes. It will take many decades to remove all trace of these compounds from the atmosphere. Secondly, CFCs are also potent greenhouse gases – and so, unfortunately, are many of the other halocarbons (typified by HCFC-22 in Table 3.1) that have come on stream as CFC-substitutes in some key areas (e.g. refrigeration), and are now building up in the atmosphere. Basically, this can be traced back to the fact that halocarbons tend to absorb strongly at infrared wavelengths within the 'atmospheric window', where absorption by the natural greenhouse gases is weak.

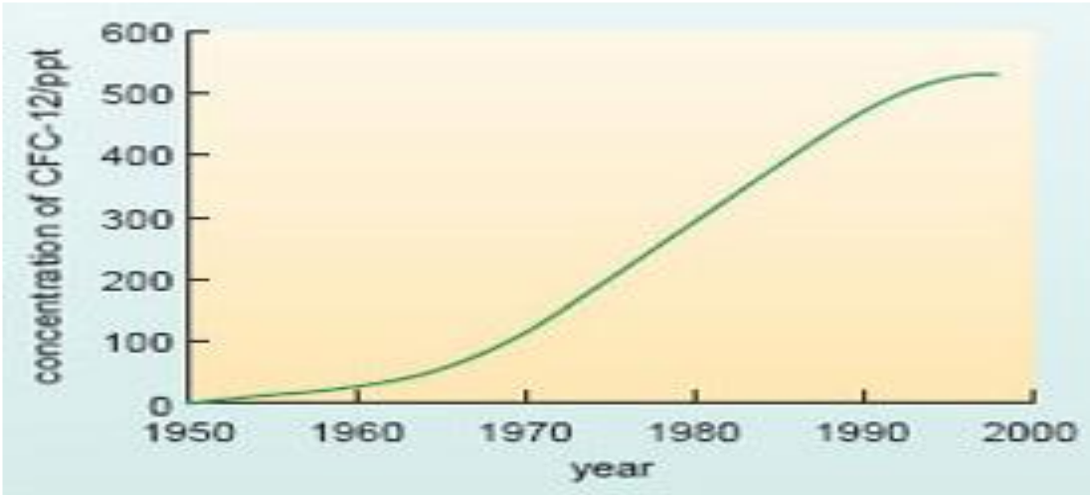


Fig. 3.3 The trend in the atmospheric concentration of CFC-12 over the period 1950 to 1998. Thanks to the Montreal Protocol, the growth rate has slowed and then levelled off, but it will take many decades for natural processes to remove all of the CFC-12 already stored in the atmosphere.

This point is made more forcibly by the information collected under the heading 'Global Warming Potential' (GWP) in the final column of Table 3.1. This is a complicated index, designed mainly for use in a policy-making context. Put simply, it is a measure of the radiative forcing induced by adding to the atmosphere a given mass (1 kg, say) of a particular greenhouse gas relative to that induced by adding the same mass of carbon dioxide; this is why the entry for CO_2 is '1'. So we can think of the GWP value as a measure of the 'effectiveness' of a greenhouse gas as a climate change agent relative to carbon dioxide – but only on a mass-for-mass basis. This proviso is important. At first sight, the GWP values listed in Table 3.1 would suggest that CO_2 is a relatively weak greenhouse gas; certainly the halocarbons are a factor of at least 10^3 times more effective, when comparing the release of equal masses of the compounds. The reason CO_2 is given such prominence is that humans are responsible for generating so much more of this gas than any other.

The atmospheric content of purely synthetic compounds like the halocarbons can be wholly ascribed to human activities. But what about the greenhouse gases that do occur naturally? Atmospheric CO_2 is part of the global carbon cycle – and so too is the methane in the atmosphere, though this is probably a less familiar idea. Likewise, N_2O is part of the natural nitrogen cycle.

For each of these gases, there are natural processes that release them into the atmosphere (**sources**), and other natural processes that remove them again (**sinks**). The relatively stable atmospheric concentrations that prevailed in the pre-industrial world tell us that these sources and sinks were in balance (more or less) at that time. Clearly, this natural balance has been disturbed over the past 200 years or so – a period marked by an explosive growth in the human population. At the end of the 18th century, there were fewer than 1 billion people on the planet; there are over 6.3 billion today, and official estimates suggest that the upward trend is likely to continue for some time to come (Fig. 3.4).

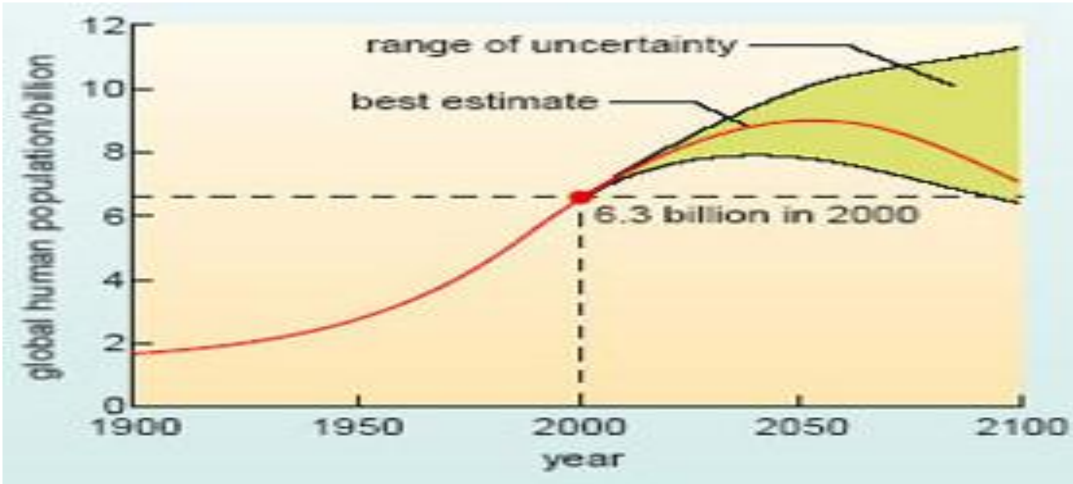


Fig. 3.4 According to current best estimates, the human population is projected to peak at around nine billion by 2050, though some experts believe that it could go on increasing throughout the 21st century.

For the most part, the human impact on the atmospheric burden of natural greenhouse gases can be traced back to activities that effectively add a new source of the gas and/or increase natural emissions in various ways. Take CO_2, for example. Despite being the feature that characterizes the industrial age, burning fossil fuels is not the only anthropogenic source of CO_2. For centuries, people have been clearing forests, burning the wood and turning vast tracts of land over to agricultural use in order to feed an ever-expanding population. The process of **'deforestation and land-use change'** also adds to the CO_2 content of the atmosphere. The range of human activities that have augmented natural emissions of CH_4 and N_2O are summarized in **Box 3.1**, along with a brief comment about another natural greenhouse gas – tropospheric ozone. Study the material in the box, and then work through the following questions.

Box 3.1. Sources of other greenhouse gases – the human connection

Methane *is generated during the breakdown of organic matter by bacteria that thrive in* anaerobic *(i.e. oxygen-free) environments – principally in waterlogged soils (bogs, swamps and other wetlands, whence methane's common name of 'marsh gas') and in the guts of termites and grazing animals. But today, only some 30% of global* CH_4 *emissions come from natural sources, with natural wetlands accounting for about two-thirds of the total. Rice paddies, effectively artificial marshes, contribute a further 11%, and an astonishing 16% is due to the flatulence of grazing livestock (cattle, sheep, etc.)! While such sources are undoubtedly biogenic in origin, they also clearly have an anthropogenic element – closely linked to human food production, in this case.*

Waste management (e.g. organic matter rotting in landfill sites) adds a further anthropogenic source of CH_4 *(around 17% of global emissions). And since natural gas is mainly methane, so too does leakage from natural gas pipelines and the common practice of venting the gas to the atmosphere at oil production sites and from coal mines (a further 19%). Finally, burning vegetation can also generate* CH_4*, depending on the way it burns (i.e. smoldering as opposed to flaming).*

Nitrous oxide *is part of the natural nitrogen cycle; it is produced by the activities of micro-organisms in soils and sediments. Again, the increase in its atmospheric concentration is thought to result mainly from agricultural activities, such as the application of nitrogenous fertilizers to boost crop yields; some of the nitrogen ends up in the air as* N_2O*. In addition, the high temperature combustion of fossil fuels (or indeed, any kind of vegetation) in air produces some* N_2O *(through reaction between* N_2 *and* O_2 *in the air), along with other nitrogen oxides (notably nitric oxide, NO).*

Ozone *is also a natural component of the lower atmosphere (due in part to transport down from the stratosphere), but the normal background level is low. However, enhanced concentrations of tropospheric ozone are now found in many polluted environments, especially over densely populated industrialized regions. Here, ozone is generated close to the surface by the action of sunlight on the mix of gaseous pollutants that is typically found in vehicle exhaust fumes – unburnt hydrocarbons, carbon monoxide (CO) and nitric oxide (NO). Ozone is one of the more noxious components of 'photochemical smog', since exposure to enhanced levels of the gas is harmful to both human health and plant growth.*

Test 3.4

Question:	*How does the extraction, distribution and burning of fossil fuels add to the atmospheric burden of other greenhouse gases, as well as CO_2?*
Answer:	*It does so both directly (e.g. N_2O formed during combustion; CH_4 released at fuel extraction sites and through leakage from gas pipelines) and indirectly (emissions of O_3 precursors from vehicles and power stations).*
Question:	*What other activity that is fundamental to human welfare also seems to have played a major role?*
Answer:	*Food production. Agricultural activities increase emissions of both CH_4 (rice paddies and livestock) and N_2O (fertiliser use). Since burning vegetation often goes along with clearing land for agricultural use, we can add that in as well (a source*

Unlike the well-mixed greenhouse gases in Table 3.1, tropospheric ozone is relatively short-lived and there are marked regional variations in its concentration. This has made it difficult to track long-term changes in the total amount of ozone in the troposphere, though recent estimates suggest a significant increase since pre-industrial times, by an estimated 36 percent.

Translating the buildup of each of the greenhouse gases into an estimate of the corresponding positive radiative forcing gives the figures collected in Table 3; the relative contributions are shown in a more immediately striking form in the 'pie diagram' in Fig. 19. Evidently, the dominant contribution to date has indeed come from the large increase in atmospheric CO_2. Nevertheless, the buildup of the other gases, coupled with their greenhouse efficiency, means that they too are now playing a significant role as climate change agents; together they account for nearly 50% of the historical greenhouse forcing. This is why the Kyoto Protocol does, in fact, cover a 'basket' of greenhouse gases (including CH_4, N_2O and halocarbons not included in the Montreal Protocol) as well as CO_2. In later discussions focusing chiefly on carbon dioxide, it is important not to forget the additional contributions of the other greenhouse gases.

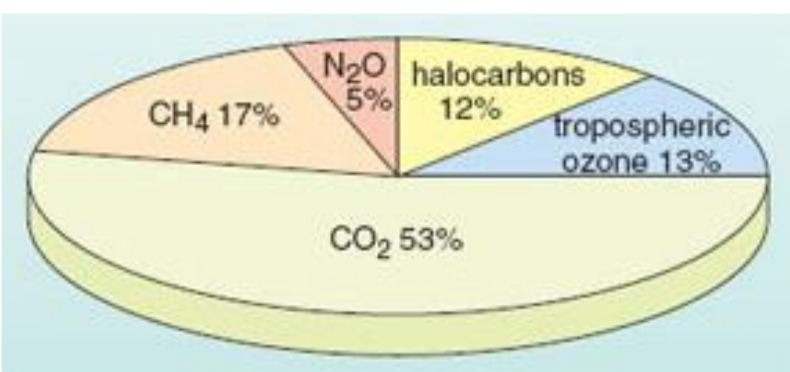


Fig. 3.5 Relative contributions of various gases to the total greenhouse forcing of climate over the period 1750 to 2000.

Table 3.2 Estimated contributions to the greenhouse forcing of climate over the period 1750 to 2000 (IPCC, 2001a).

Gas	Radiative forcing/W m^{-2}	% Contribution
long-lived		
CO_2	1.46	53
CH_4	0.48	17
N_2O	0.15	5
Halocarbons	0.34	12
short-lived		
tropospheric O_3	0.35	13
total	2.78	100

Test 3.5

Question: *What other natural greenhouse gas has not been mentioned in this section?*

Answer: *Water vapor, the most important of all*

As noted earlier, the water vapor content of the air depends on temperature, and on very little else. The total amount of water vapor in the atmosphere is not directly affected by human actions. However, it can be affected indirectly – and in a way that has important implications for the global climatic response to the buildup of other greenhouse gases.

There is also something else to think about in the context of 'the human impact on the atmosphere'. Since the dawn of the industrial age, human activities have been pumping a cocktail of particulate matter, as well as greenhouse gases, into the lower atmosphere. In particular, coal often has a high sulfur content, released as SO_2 when the fuel burns (in a power station, industrial process, fireplace, etc.), as illustrated by fig. 2.2. The 'unpolluted' troposphere naturally contains a certain background level of sulfate aerosols derived from various sulfur-containing gases of both volcanic and biogenic origin. Anthropogenic emissions of SO_2 add to the background aerosol load, and that has the same direct radiative effect as the episodic injection of volcanic aerosols into the stratosphere: it increases the back-scattering of solar radiation.

The ‘urban haze’ typical of many industrialized regions with a high traffic density also contains ‘carbon-based’ particulate matter derived from fossil-fuel combustion – including droplets of organic compounds, together with varying amounts of black graphitic and tarry carbon particles (collectively known as ‘**black carbon**’). Similar **‘carbonaceous’ aerosols** are found in the dense smoke plumes generated by the large-scale burning of vegetation that occurs on a regular basis in many parts of the world. In some regions, natural wildfires (ignited by a lightning strike) are supplemented by fires set deliberately for forest clearance (e.g. in Amazonia and parts of south-east Asia), or as part of the annual agricultural cycle (e.g. to stimulate a flush of new grass for livestock in the savannah grasslands of southern Africa). Data from satellite-borne instruments (Fig. 3.6) are helping researchers to map the distribution of fine aerosols (whether sulfates or carbonaceous material) typical of anthropogenic sources (Fig. 3.6a) – and to distinguish these from the coarser particles (dust and salt-spray) that have largely natural origins (Fig. 3.6b).

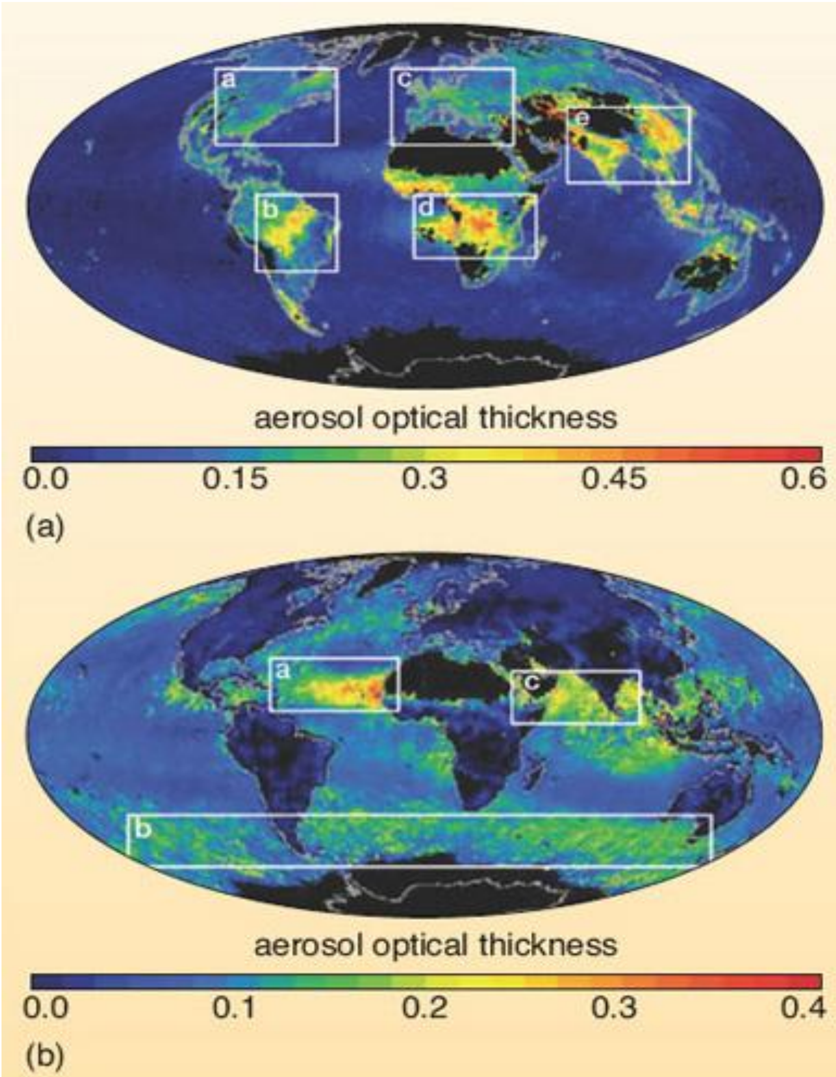


Fig. 3.6 Distribution of (a) fine and (b) coarse aerosols from measurements taken by the NASA Terra satellite for September 2000.

The radiative forcing produced by the buildup of well-mixed greenhouse gases is both positive (i.e. it has a warming effect) and occurs everywhere around the globe. The climatic effects of an increased load of tropospheric aerosols are different in three important ways.

1. Like sulfates, most aerosols are highly reflective, so they effectively increase the planet's albedo, producing a negative forcing (i.e. they cool the surface). Black carbon is an exception to this general rule: it strongly absorbs both incoming sunlight and outgoing longwave radiation, and it is thought that this has a warming effect at the surface.
2. Anthropogenic aerosols are short-lived in the lower atmosphere (sulfates return to the surface as ‘acid rain’), so concentrations vary considerably by region (a pattern evident

in Fig. 3.6a) and over time. The radiative effects of an increased load of tropospheric aerosols therefore act on a regional, rather than a truly global, scale.

3. Anthropogenic aerosols (especially sulfates) also have a potentially important indirect effect on the Earth's radiation balance, linked to their role as cloud condensation nuclei. In polluted regions, the numerous aerosol particles share the condensed water during cloud formation, producing a higher number of small liquid droplets; such clouds are more reflective (i.e. they have a higher albedo), which makes for an additional cooling effect at the surface. This is known as the **indirect aerosol effect**.

The aerosol optical thickness is a measure of the total aerosol load (in each size group) in the lower atmosphere, and is represented by the color scale. In Fig. 3.6 the white boxes indicate regions with high aerosol concentrations. (a) The image shows fine particles in pollution from North America, Europe and south and east Asia (regions 1, 2 and 3), and in dense plumes downwind from vegetation fires in South America and southern Africa (regions 4 and 5). (b) The image shows coarse dust from Africa (region 6), salt particles generated in the windy conditions of the Southern Ocean (region 8) and desert dust (region 7).

The cooling influence (both direct and indirect) of sulfate aerosols in the troposphere has been appreciated for over a decade: it featured in the first IPCC report in 1990, for example. Research since then has begun to unravel the climatic effects of other anthropogenic aerosols, but the extraordinary diversity of these particles (in size, chemical composition, radiative properties, etc.) means that this is turning out to be another complicated and uncertain part of the climate change puzzle. The general view is that tropospheric aerosols mostly produce negative forcing, but there is little confidence in the ability to quantify the total human-related effect, and the way it has evolved over time during the industrial age.

We shall come back to this issue later, once we have examined the evidence that the Earth really is warming up.

3.1.2 Summary (take home points)

- A proportion (the planetary albedo) of the incoming shortwave radiation from the Sun is reflected (or scattered) directly back to space, mainly by clouds and the Earth's surface (especially snow and ice cover), but also by aerosols (e.g. dust, salt particles, etc.). Most of the rest is absorbed by the surface, thereby warming it.
- Outgoing longwave (infrared) radiation from the Earth's surface is repeatedly absorbed and re-emitted by greenhouse gases naturally present in the atmosphere (mainly water vapour and CO2, but also methane, nitrous oxide and ozone); this warms the lower atmosphere (or troposphere). Some of the re-emitted radiation ultimately goes out to space, maintaining an overall radiation balance at the top of the atmosphere. But back radiation from the atmosphere keeps the Earth's surface over 30 °C warmer than it otherwise would be – the natural greenhouse effect.

- Clouds both cool the surface (by reflecting solar radiation) and warm it (by absorbing and re-emitting outgoing long-wave radiation). Globally, the net effect is a slight cooling of the planet.
- Energy is also transferred from the surface to the atmosphere as heat (through conduction and convection) and through the evaporation/condensation of water (latent heat transfer).
- The troposphere is heated from below whereas the stratosphere is heated from above, mainly by the absorption of incoming uv radiation from the Sun by the ozone layer. This produces the characteristic variation of temperature with altitude from the surface up to the stratopause (Fig. 1.7).
- Radiative forcing is an imbalance between the solar radiation absorbed by the Earth-atmosphere system and the long-wave radiation emitted to space. It can be either positive (which has a warming effect) or negative (which has a cooling effect). Natural sources of radiative forcing include variations in the solar constant (either up or down) and episodic injections of large amounts of volcanic sulfate aerosols into the stratosphere (which has a short-term cooling effect at the surface).
- Various human activities (including the extraction, distribution and burning of fossil fuels; industry; burning vegetation and land-use change; agriculture; waste management, etc.) have increased emissions of natural greenhouse gases (or their precursors in the case of tropospheric ozone). As a result, the atmospheric concentrations of these gases have increased since pre-industrial times, by about 31% for CO2, 149% for CH4, 16% for N2O and 36% for O3. The use of entirely synthetic compounds (halocarbons, e.g. CFCs) has also added new (and potent) greenhouse gases to the atmosphere. This has produced a positive radiative forcing (greenhouse forcing) of climate, which is expected to lead to global warming.
- Human activities also increase the tropospheric load of sulfate aerosols (due to SO2 emissions) and various carbonaceous particles (from fossil fuel and vegetation burning). Anthropogenic aerosols mostly produce negative forcing, both directly (by back-scattering solar radiation) and indirectly (through their influence on cloud albedo).
- Long-lived gases (CO2, CH4, N2O and halocarbons) are well-mixed in the troposphere. By contrast, the concentrations of relatively short-lived species (e.g. ozone and aerosols) are variable in both space and time.

3.1.3 3.3.3 TEACHER'S GUIDE for Bellwork

Bell Work: Student Conceptions of Weather and Climate

Students are not expected to have all of the following answers for bell work, but they should have an understanding of a few variables that affect climate and weather and how these differ.

Bell Work Question:

A) Why does someone in Brazil experience different climate from someone in the Bay Area?

Correct Answers:

1) The Earth is relatively the same distance from the Sun all year, but the tilt and curvature of the Earth is responsible for the differences between the two locations. Brazil is close to the equator and receives the direct rays of the Sun whereas the Bay Area is at higher latitudes and receives indirect rays (See Fig.3.7). The tilt of the axis causes the seasons in places like the Bay Area.

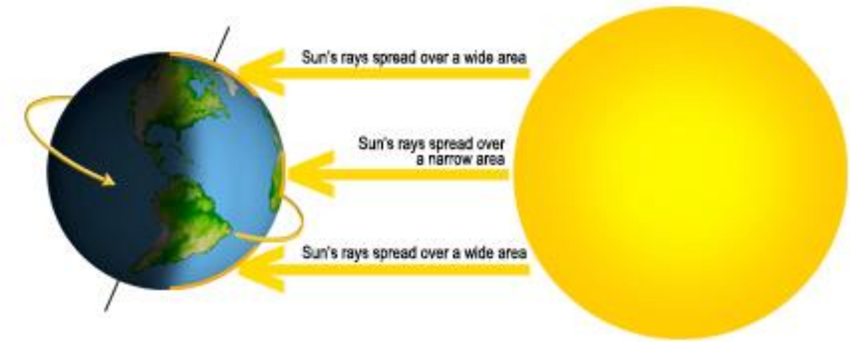


Fig. 3.7 Tilted orbiting of the earth around the sun

2) The Bay Areas and parts of Brazil may have different altitudes. The climate changes as one gets higher or lower in the atmosphere.

3) In the figure above, the ocean currents bring cold water from the north that affects the climate in the Bay Area. However, the water that reaches the Brazilian coastline has traveled across the Atlantic at the equator and is much warmer. Water temperature has an effect on land temperatures as well.

Common Misconception:

The seasonal or regional differences in climate are based on how close the Earth is to the Sun at any given point. When the Earth is close to the Sun, it is summer and hottest and when it is furthest from the Sun it is coldest. (See Correct Answer 1 for a proper explanation).

3.1.4 Teacher's Guide: Sun-Earth Modeling Activity

Teacher Instructions & Debrief Questions

This activity can be used as a whole class demonstration or for small group activities.

Classroom Demonstration Materials:

- LCD Projector

- Globe or blow up globe
- The light of the LCD projector models the light from the sun.
- Small Group Activity Materials: one set for each pair of students
- Flashlight or light source
- 4” Styrofoam ball (white or painted)
- rubber band that fits around the ball

Turn off the lights so that the light can be seen reflecting off the ball. (Painting the balls can help, as can placing a pen or pencil into the ball to hold it.)

1) Begin the activity with a few questions. Then pass out the materials to each group. Explain what the materials represent.

Ask students:

a) Where does Earth get its energy? Energy drives climate and life. (Sun)
b) Does all of the light from the Sun reach the Earth? (no)
c) What happens to light that doesn’t reach the Earth? (continues past Earth)

NB. Tell students that they have been given a model Sun (the flashlight) and a model Earth (Styrofoam ball).

2) Tell students that their challenge is to think about how the Sun’s radiation hits the Earth.

a) Does the Earth get equal amounts of sunlight everywhere? (More at equator)
b) What are the implications of unequal amount of sunlight? (Climate)

Allow students some time to play around with the flashlight and the ball and see what they come up with. After a few minutes, ask students to share their ideas. It isn’t necessary for all students to come up with a correct answer. It’s much more important that they realize the variables that are involved with the answer: distance from the Sun & size of the Earth.

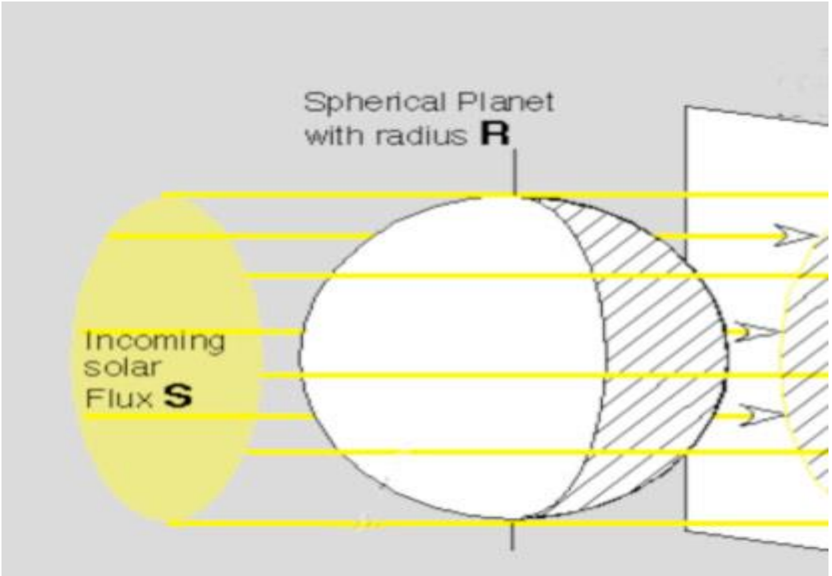


Fig. 3.8 Incoming solar flux

3) Pass out a rubber band to each group. This represents the equator. Students should put the rubber band around the Earth where the equator is, and then hold the Earth model in the proper angel to the plane of rotation. Tell students that Earth's axis of rotation (line from pole to pole) is tilted 23° from the plane about which Earth. The teacher should show what the correct orientation is.

4) Discuss with students the intensity of the radiation at various illuminated parts of the globe. A location at the equator will receive much more intense and direct sunlight at noon than it will at sunrise or sunset. This is effectively because one hemisphere is receiving only a circle's area worth of radiation.

NB. Be sure students know what the word variable means. Ask students about quantifying the solar input to Earth.

a) What factors would change the amount of energy (sunlight) reaching a planet? (size of planet, distance from Sun, sunspots).
b) Would the rate of rotation or revolution or the tilt of a planet change the total solar energy (amount of sunlight) reaching a planet?

Response:

i) The rate of rotating around the Sun will not change the amount of solar input on average, nor will the length of a day (revolution around Earth's axis).
ii) The tilt of the axis does not change the total energy. Instead, the tilt of the axis changes when and where that solar energy is.

Additional discussion and debrief questions:

1) How often does the Earth make a full rotation?
2) What happens if you rotate the Earth?
3) What happens if you move the Sun farther away? How would this affect the Earth's temperature?
4) Does the Earth get the same amount of sunlight in every place? If not, what part of Earth receives the brightest (most) sunlight?
5) Based on your observation, what part of the Earth would be the hottest? What part of the Earth would be the coldest?

Student Task Card: How Sunlight Affects the Earth

Materials:

You have been given:

- a model Sun (the lamp)
- a model Earth (the Styrofoam ball)

Task:

1) Draw the Earth on the styrofoam ball.
2) Put the rubber band around the middle of the ball to show the equator.
3) Use the toothpick to place the ball on the cup. First, put the model Earth on the cup straight up and down.
4) Shine the light from the lamp on the model Earth.
5) Think about the questions:

    a) How does the Sun's light hit the Earth?
    b) Does the Earth get the same amount of sunlight in every place?

6) Now put the model Earth at tilt.
7) Shine the light from the lamp on the model Earth.

8) Think about the questions:

    a) How does the Sun's light hit the Earth?
    b) Does the Earth get the same amount of sunlight in every place?
    c) What are the effects (results) of the amounts of sunlight that different parts of the Earth get?

Energy Slides

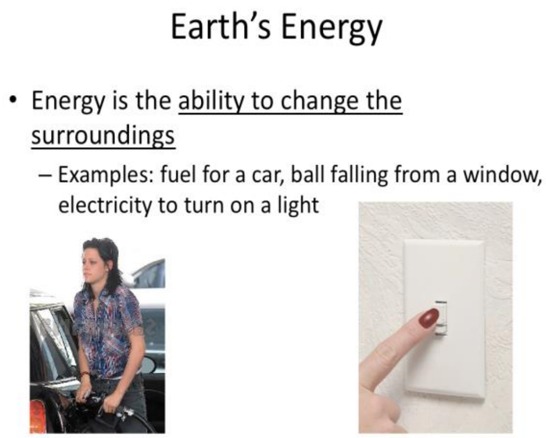


Fig. 3.9 Examples of energy forms

Energy is all around us. It can take many forms hence a difficult concept to understand but is important for many things that we do. Energy helps us to play sports, drive our cars, play television, and stay warm. Just like people, the earth is affected by many different forms of energy which determine how warm or cold the earth is.

- **Budget: Budget is the amount of incoming or outgoing energy allocated to a system - just like money or time**

The amount of energy is not constant. While energy cannot be created or destroyed, it does move from place to place and it can change form. Thus just like the bank account where money can go in and out, the earth has an energy budget. Energy enters and exits and, in the process, can change its surroundings. Specifically, energy changes the temperature and climate of the earth.

- **Equilibrium: Equilibrium is the state of balance between things**

  - ✓ Emotional
  - ✓ Chemical reactions
  - ✓ Forces

- **Equilibrium means that the total amount may change over time, but the proportion in the budget parts stays fairly the same.**

In this lesson, the focus is on temperature equilibrium. Equilibrium is very important as we shall demonstrate in the next lesson. Most organisms need a balanced environment so that their bodies don't get too cold or too hot. While an equilibrium point might change over time i.e. the temperature over a time period, normally it stays within a small range. This allows organisms to live, work and reproduce. The earth also has an equilibrium that is established by its energy budget.

We are going to examine the incoming sunlight in hands on activity.
Go to the sun activity description

The Sun – Earth Model

- ➢ What in the model is the sun?
- ➢ What in the model is the earth?

  - ✓ Where is the equator?
  - ✓ Where is the north pole?
  - ✓ Where are you?

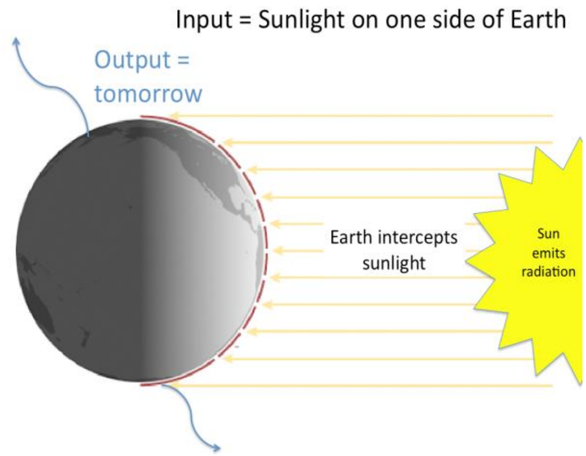


Fig. 3.10 Earth receiving solar energy and emitting back to the atmosphere

This slide is another model of the Sun-Earth system. The sun is the source of the incoming radiation (light) on the right. Point out that the right side of the earth in this picture is lit up just like the Styrofoam ball in the 3-D model.

Sunlight Energy: Sunlight comes in a range of short wavelengths called visible light

NB. Use this slight to introduce the idea that light can be divided into wave lengths.

Goal: Students will see that the rope can move in different wave lengths. This demo will be repeated later.

Demonstration:

With a 2 m long rope, have one student hold one end while the teacher holds the other end. Rotate the rope to get a wave pattern. Have students count the number of waves. Make sure everyone is counting the same thing. Now increase the amount of energy and there should be more waves. Ask students to compare the amount of energy that is put into the rope if there are more waves (shorter) or fewer waves (longer). They should see that you have to put in more energy to create shorter waves. Explain that with sunlight the waves are short and in the visible range so that we can see sunlight.

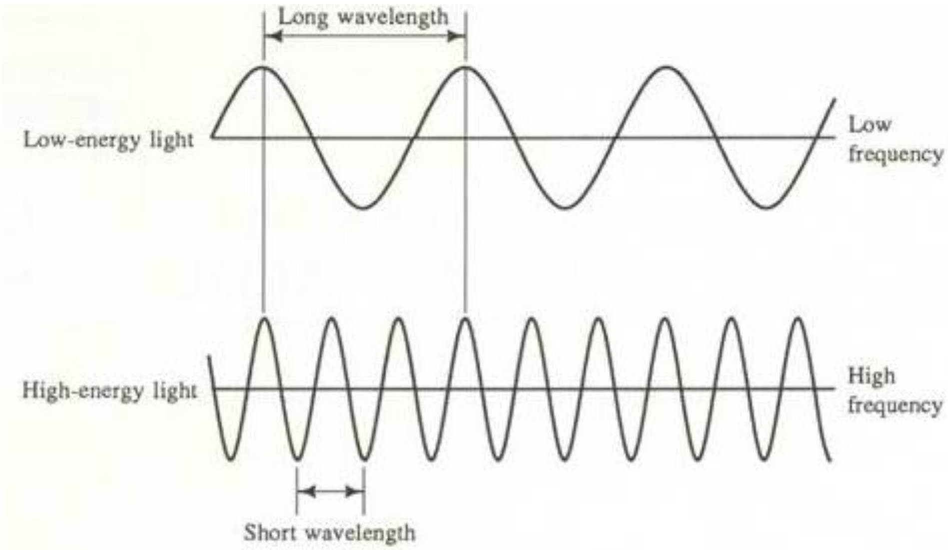


Fig.3.11 Wave lengths and relationship with energy level

This image is to talk about the different wave lengths. Sunlight has short wave lengths. The length of the wave is dependent on the amount of energy. The sun is very hot and produces short waves of light – We see it as visible.

Once the sunlight reaches the earth's surface: What happens?

- Ask students to share their ideas
- When they say reflection or light bounces off, move to the next slide
- Reflected - bounces off
- Absorbed – taken or held in

NB. The rest of this lesson is on reflection, while absorption will be covered in the next lesson.

- What is one way to describe the energy that is absorbed?
- How much is absorbed?
- What does reflected mean?
- How much is reflected?

NB. Following the energy, we need to understand the three different arrows here to see how the energy leaves the earth's system.

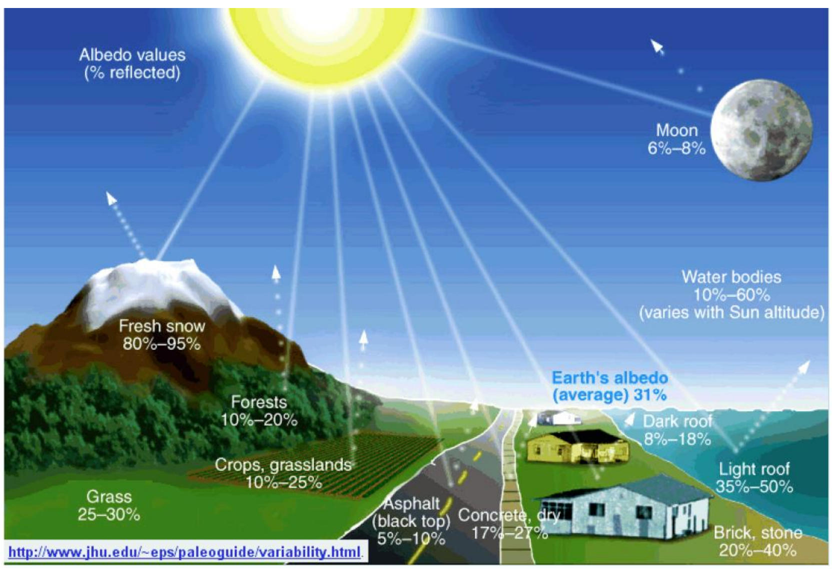
Albedo = Reflection

- How much is reflected?
- Scale is 0-1
- White =1,
  - High reflectivity
- Black = 0
  - Low reflectivity

- What do you think?
  High or low albedo?
- Grass
- Ice
- Rocks
- Asphalt
- Concrete

➢ The list of material is on the next figure.

Glass = 0.3; Ice = 0.9 (high); Asphalt = 0.05 (very low); Concrete = 0.25 (low)



Albedo = Reflection

Fig.3.12 Albedo of various surfaces

➢ **Look at the figure and discuss which surfaces have a high albedo and what types have a low albedo.**

✓ How did they do on their predictions?

➢ The average albedo for the earth = 0.31.
➢ What happens where there is a large volcanic explosion?
➢ What happens where there is a forest fire?

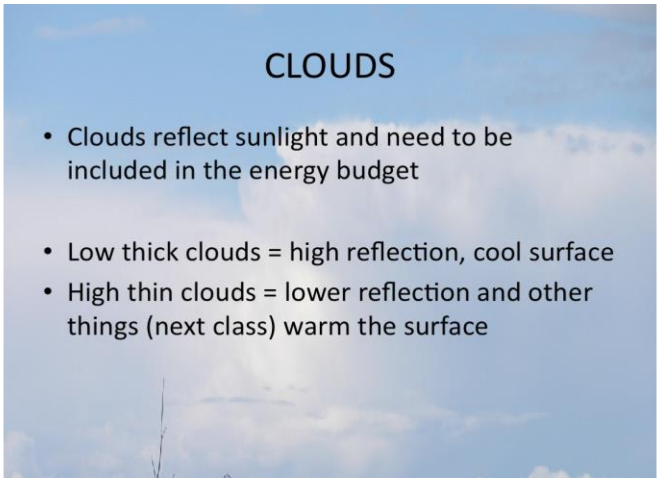


Fig. 3.13 Properties of clouds and reflexivity

- **Clouds are part of the energy budget. They are important in both incoming radiation because they reflect some incoming radiation. And as will be discussed later, clouds also absorb the long wave radiation emitted by the earth.**

Goal: the goal of this slide is for students to include clouds in their understanding of what impacts the energy budget.

- Because a cloud usually has a higher albedo than the surface beneath it, the cloud reflects more shortwave radiation back to space that the surface would in the absence of the cloud. Thus leaving less solar energy available to heat the surface and atmosphere. Hence this "cloud albedo forcing: take by itself, tends to cause a cooling or "negative forcing" of the earth's climate.
- The study of clouds, where they occur, and their characteristics, play a key role in the understanding of climate change.

  - ✓ Low, thick clouds primarily reflect solar radiation and cool the surface of the earth.
  - ✓ High, thin clouds primarily transmit incoming solar radiation
  - ✓ At the same time, they trap some of the outgoing infrared radiation emitted by the earth and radiate it back downward, thereby warming the surface of the earth.
  - ✓ Whether a given cloud will heat or cool the surface depends on several factors including:

    - ❖ Cloud altitude
    - ❖ Cloud size
    - ❖ The makeup of the particles that form the cloud

  - ✓ The balance between the cooling and warming actions of clouds is very close although, overall, averaging the effects of all the clouds around the globe, cooling predominates.

- Point out the addition to our model – 30 % is reflected

- ➢ This is the earth's cumulative albedo

What happens to the energy that enters the earth system?

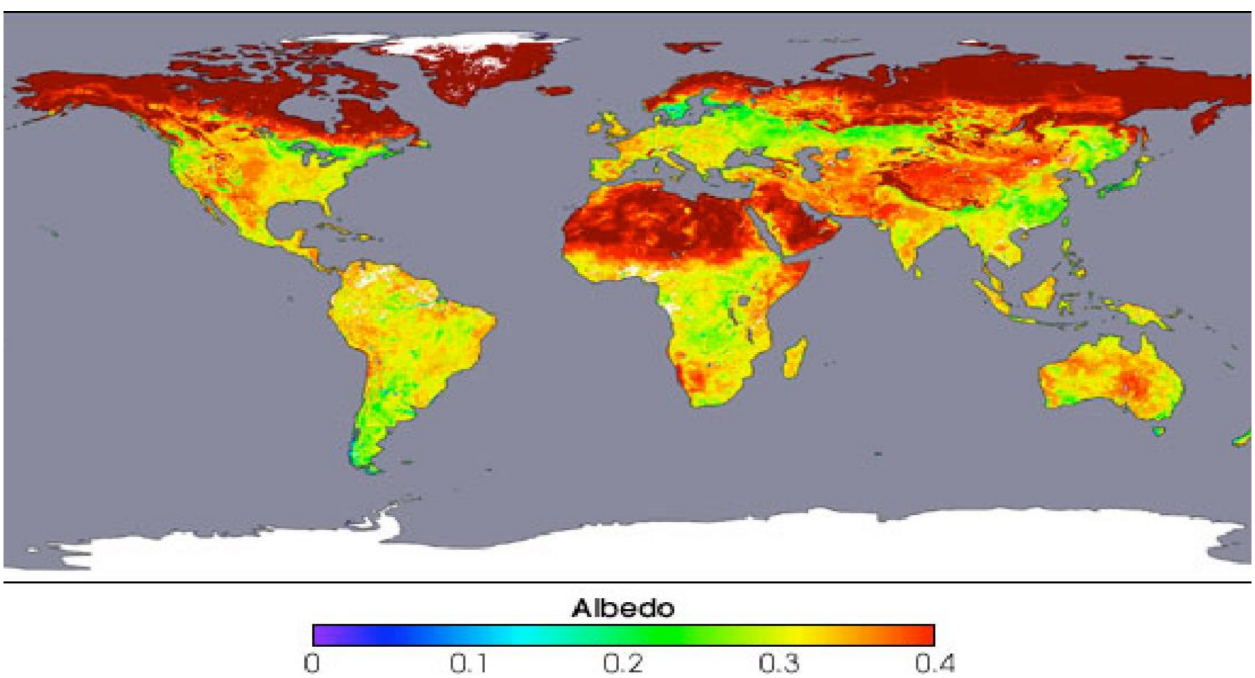
- ☐ **Concept map additions**
  - ➢ **Sun or sunlight**
  - ➢ **Earth**
  - ➢ **Energy budget**
  - ➢ **Albedo**

- ☐ Have the students work in pairs to discuss how they will add the words to their concept maps.

  What types of areas of earth have:

  - ➢ **High albedo**
  - ➢ **Low albedo**

    (Think urban, farmland, desert etc.)
    NB. This is to prepare students for the next slight



Earth's albedo

Collected by NASA satellite and averaged. Does not include the ocean and no data for white areas.

Fig. 3.14 The earth's albedo

- **The colors in this image emphasize the albedo over the earth's land surfaces, ranging from 0.00 to 0.40.**

  - ✓ Areas colored red show the brightest, most reflective regions;
  - ✓ yellows and greens are intermediate values; and
  - ✓ blues and violets show relatively dark surfaces.
  - ✓ White indicates where no data were available, and no albedo data are provided over the oceans.

- **Remind students of what they learned about the distribution of sunlight with the sun-earth model. The sunlight does not reach everywhere equally.**

  - ✓ A low albedo means that lots of energy is absorbed and only some is reflected.
  - ✓ A high albedo like snow and ice means little absorption and lots of reflection.
  - ✓ The most northern and southern areas are shown in white which means no data available

- **Ask students**

  - ✓ What would you predict for Antarctica?
  - ✓ What would you predict about the temperature from these data?
  - ✓ Does this give us the whole picture of climate? What about weather? What might cause change in albedo in one location?

3.1.5 Dynamic Balance Activity or Demonstration

Background:

The energy budget of Earth is just one example of a system on Earth that is in dynamic balance. There are influences that cause increases and there are influences that cause decreases, but the over - all result is that the total amount of the "planet thing" tends to remain the same.

The amount of water in each of the reservoirs of the water cycle stays fairly constant even though water is constantly flowing into and out of that reservoir. We call this kind of situation dynamic balance. Dynamic means things are happening. Balance means there is no total change. Water in the ocean is dynamic - it keeps leaving through evaporation and returning through precipitation and runoff. Yet, the total amount of water in the ocean is not changing, so we say it is in balance.

Purpose:

Many different Earth systems demonstrate stability even though matter and energy are constantly flowing through them. These systems are examples of dynamic balance. The "Dynamic Balance in a Bottle" experiment illustrates the phenomenon of dynamic balance. It provides direct experience of how changes to a system can alter the existing dynamic balance. This experiment can help explain a wide variety of phenomena including each of the cycles of matter, Earth's energy budget, and the issues of ozone depletion and global climate change.

Equipment and Supplies:

For each group:

- 1 empty 2 - liter plastic bottle with paper label removed
- 1 measuring cup (2 cup size is better than 1 cup size) or 500 ml graduated cylinder
- 1 Thumb tack
- 1 Funnel
- Duct tape or other good tape
- Stopwatch or clock
- Ruler
- 2 five gallon buckets

Teacher Preparation:

Carefully using the thumb tack, poke 20 evenly - spaced holes in the bottle along the outside about 1.5 cm up from the bottom.

Procedures:

PART A

1) Fill one bucket of water. The second bucket is to catch all the water.
2) Practice pouring the water at a rate of 400 ml per minute or about 1.5 cups per minute. Use the stop watch to see how long it takes to fill 1.5 cups.
3) Put the bottle (and funnel if it helps) under the pouring bucket so all the water flows into it.
5) Carefully watch what happens with the water in the bottle. Write down your observations from the beginning until there is no longer any measurable change. If you do not get a steady level, adjust the flow rate so you do.

6). When the first bucket is empty, switch buckets quickly.

PART B

1) Experiment with increasing the rate at which water enters the bottle. Determine a rate that increases the level without overflowing the bottle. Measure that rate and record it. Record any observations that may help explain your result.
2) Reduce the flow rate back to the rate used in Part A. Using the tape, experiment with covering some of the holes in the bottle. Determine a number of holes covered that increases the level without overflowing the bottle. Record your procedure and results.

Analysis

1) Discuss whether Part A of this experiment models dynamic balance.
2) Describe how the exit flow rate from the holes changes as the level of water in the bottle increases. Discuss how this change in rate affects the establishing of a stable level.
3) Compare the effects of increasing the flow rate, covering the holes, and increasing the number of holes.

Conclusions and Discussion

1) Which of the experiments provides a model of how the amount of water in the atmosphere remains the same even though water is constantly entering and leaving the atmosphere?
2) One example of something that humans are doing to change an existing balance on planet Earth is that we are burning oil, coal and gas. This results in extra carbon dioxide going into the air. Before humans started burning large amounts of these fossil fuels, the amount of carbon dioxide in the atmosphere had been fairly constant for many hundreds of years. Which experiment models a change in dynamic balance due to increasing the rate of in-flow?
3) These experiments can also be used to model Earth's energy budget. In that case, what does the rate of water flowing into the bottle represent? What does the rate of water leaving the bottle represent? What does the level of the water in the bottle represent?
4) Which experiment models how increasing the greenhouse effect may affect the Earth system? Based on that experiment, what would you predict will be the result of increasing the greenhouse effect?

DON'T WASTE THE WATER: Many of us are concerned about wasting water. Don't waste the water. The idea is that doing these experiments helps all of us understand that there are natural balances in the kinds and amounts of things and living organisms on our planet. The amount of fresh, usable water is limited. It is the result of a dynamic balance among processes that increase that amount and processes that decrease it. Now that you understand dynamic balance, hopefully you will do things that save lots more water than the amount you used in these experiments. Reuse the water for all classes, then pour.

Quiz Lesson One & Two

Questions and answers.

1) You have a friend that lives in the desert where it almost never rains. You talk to him on the phone and he says that it has rained for the last three days. He says that the climate must be changing. How do you respond?

I would tell my friend that climate is weather that happens over a long period, often 30 years. He experienced some odd weather, but this is not evidence for or against climate change.

2. In what form does the energy emitted from the sun travel?
   A. Long-wave radiation
   B. Medium wave
   C. Non-wave radiation
   D. Short-wave radiation

3) In what form does the energy that is emitted from the Earth travel?
   A. Long-wave radiation
   B. Medium wave radiation
   C. Non-wave radiation
   D. Short-wave radiation

4) A volcano in Mount Kilimanjaro erupted and shot out a lot of ash. This ash formed huge thick clouds over Africa. What did this volcanic eruption do to the albedo over Africa?

   A. Decrease the albedo
   B. Increase the albedo
   C. Keep the albedo the same
   D. Make the albedo neutral

3.1.6 Objective 4: To understand and teach scientific content relevant to explaining and understanding the fundamental mechanism of climate change

The following are the summarized atmospheric processes that lead to global warming;

- The earth's surface absorbs (mostly visible) sunlight /solar radiation and subsequently emits infrared light /radiation
- Greenhouse gases selectively absorb and retain (because these molecules can become asymmetrical) infrared radiation in the process release heat energy
- Heat energy leaves more slowly warming the earth.

3.1.7 Greenhouse Gases and Global Warming: Implication on the Earth's Energy Budget

3.1.7.1 Greenhouse gas concept

- What are greenhouse gases?
- Where do greenhouse gases come from?
- What role do they (GHG) play?
- How do they course climate change?

List of Resources

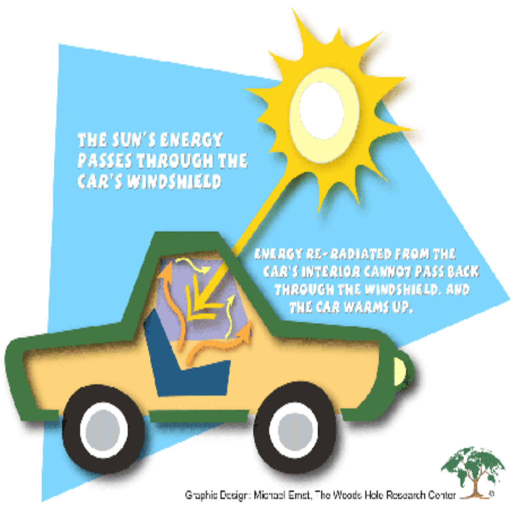
- Quiz LP1 & LP2
- Greenhouse Gases Slides
- Student Notes Handout (for use during slides and resonance model activity)
- Resonance Model Making Instructions
- Resonance Model Task Card (to use with models)
- Reading: Carbon Dioxide and Greenhouse Gases
- Greenhouse Gas Lab WRITTEN
- Concept Map Homework
- Bathtub Thoughts Handout
- Gas Files Activity
- Mitigation Strategies Slides
- A Mitigation Notes Handout
- Concept Map Homework
- Pictures of Power Plants OPTIONAL

Supplies

Materials for greenhouse effect activity

- 2L soft drink bottles, empty
- thermometers
- 2 ways to make carbon dioxide
- Alka-seltzer tablets + water = carbon dioxide
- Vinegar + baking soda = carbon dioxide
- A heat source (light bulbs)
- Resonance models with tennis balls

What is the greenhouse effect?



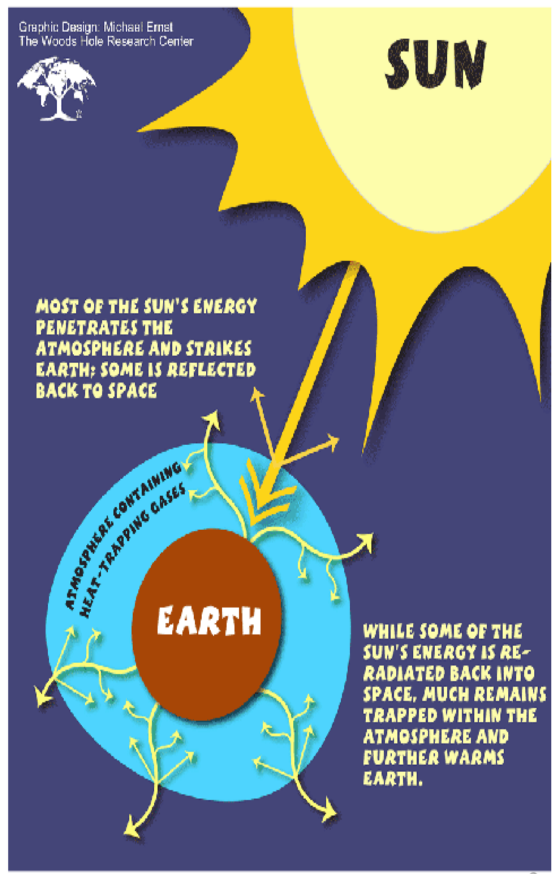


Fig.3.15 Examples of greenhouse effect

- *Student might also have experienced this feeling when they get into a car on a hot day. It feels warmer inside the car because of the trapped air.*

  - ✓ *So, it is different from the greenhouse effect but a connection to their experience*
  - ✓ *Students might be able to come up with other examples as well.*

- *Air in the car is trapped and can't get out.*
- *On earth there is no physical boundary, so it is the gases that actually work to hold the heat. NB: After these slides, students should be able to fill out the graphic organizer comparing and contrasting a greenhouse with the "greenhouse effect"*

☐ ***Resonance Model***

- *Most of our atmosphere is nitrogen & oxygen, neither of which is a greenhouse gas.*
- *The GHGs in our atmosphere are less than 0.1% of the total amount of gas in the atmosphere and yet they are what make our planet habitable.*
- *Without the small amount of GHGs, the average temperature on the planet would be $< 0^oC$.*
- ***There is a major misconception that the hole in the ozone layer is the primary reason for climate change.***

  - ✓ *It is correct to say that the ozone hole has a small effect on the climate change but it is not the main cause.*
  - ✓ *The other connection between these issues is that CFCs and their non-ozone destroying replacements are very potent GHGs, which contribute to climate change*

NB. Students may or may not bring up these ideas in their discussions.

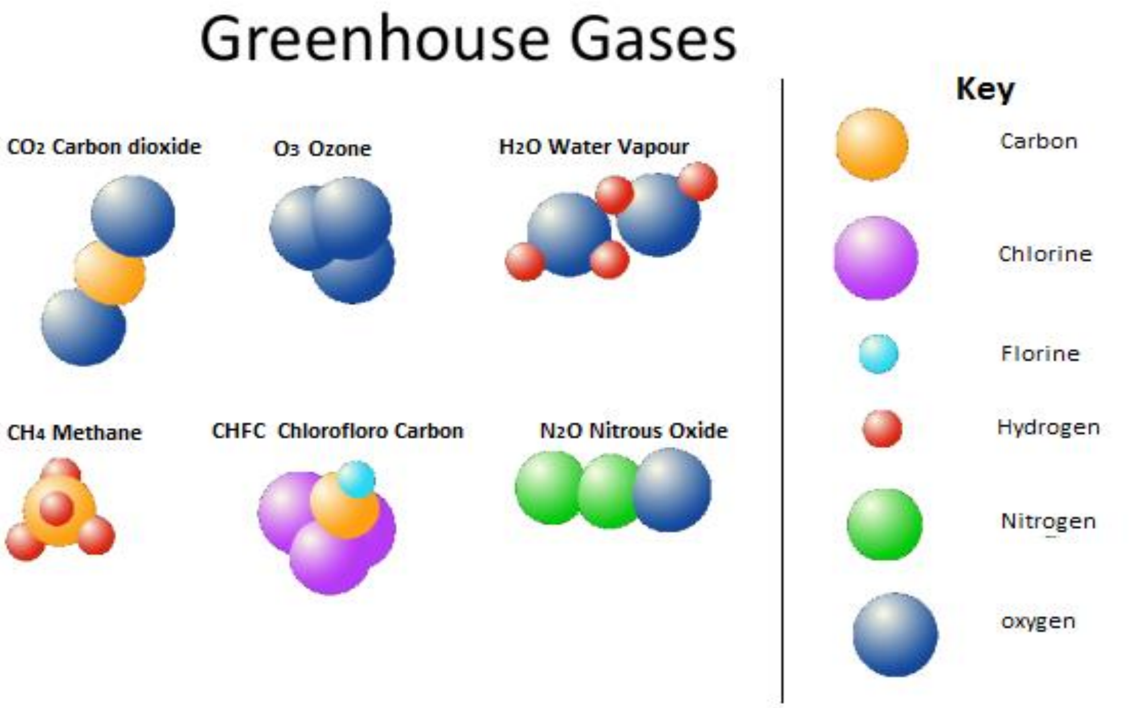


Fig. 3.15 Molecular structures of greenhouse gases

- ☐ ***Resonance Models:*** *Show the tennis ball models of the gases while this slide is up. Students will complete the task card to use the models and discuss the following questions. You could also do this entirely as a demonstration.*
- ☐ *Is there a frequency at which it is much easier to keep the model vibrating?*

  - ✓ *At this frequency your model molecule better absorbs and retains your energy output.*
  - ✓ *If there is such a frequency, determine what it is in vibrations per second by counting the number of vibrations in 5 seconds interval and dividing by 5.*
  - ✓ *Do at least three trials, letting different members of your group experiment and obtain the range of frequencies at which the maximum energy is absorbed.*
  - ✓ *Repeat this procedure for all three models.*

- ☐ ***Questions***
  - ➢ *How do the resonance frequencies of the 3 models compare?*
  - ➢ *What hypothesis can you formulate to explain your observation?*

NB. Physicists tell us that the behavior of the models build from the tennis balls is a good analogy of the behavior of real molecules of CO_2, CH_4 & N_2.

  - ➢ *From the observations of your models, can you explain why some gases in the atmosphere absorb infrared radiation and others do not?*
  - ➢ *Why do you think greenhouse gases absorb infrared radiation and do not absorb visible light?*

Methane model

1) Insert one 10-inch hacksaw blade through the carbon atom with four slits so the end sticks out about one inch on the other side.
2) Repeat the procedure with another hacksaw blade from the other side.
3) Repeat steps 1 and 2 through the other pair of slits. You should now have a carbon atom with 4 arms.
4) Add one hydrogen atom to each of the arms so that the distance between each hydrogen and the central carbon is 5 inches.

Nitrogen model

1) Insert one short piece of hacksaw blade into each of the 3 slits in one of the nitrogen atoms.
2) Add the remaining nitrogen atom by inserting the 3 blade ends into its slits.

What to Do

Hold a gas model by the center atom and shake it (for nitrogen, hold one of the ends). Keep the amplitude of vibration (the shaking distance) less than 6 inches. First try very slow shaking (~2/second) and increase the speed of shaking. You are looking for the speed of shaking (frequency) that makes the molecule move the easiest, with the least jerky movements. Do this with all three gases.

Observations

Is there a frequency at which it is much easier to keep the model vibrating? At this frequency the model molecule absorbs and retains your energy output better. Less energy is lost to random movements. If there is such a frequency, determine what it is in vibrations per second by counting the number of vibrations in a 5-second interval and dividing by 5. Do at least three trials, letting different member of your group experiment and obtain the range of frequencies at which the maximum energy is absorbed. Repeat this procedure for all three models.

Frequency (# of vibrations per second)

Gas Trial 1, Trial 2 & Trial 3

Gas	Trial		
	1	2	3
Carbon dioxide			
Methane			
Nitrogen			

Record your group's results on the board. Look at the results obtained by other groups and discuss how your results compare to those obtained by other members of the class.

1) Compare the resonant frequencies of the 3 models.

2) What hypothesis can you formulate to explain your observations?

3) Physicists tell us that the behavior of the models built from the tennis balls is a good analogy of the behavior of real molecules of carbon dioxide, methane, and nitrogen. From the observations of your models, can you explain why some gases in the atmosphere absorb infrared radiation and others do not?

4) Nitrogen is not a greenhouse gas, and carbon dioxide and methane are greenhouse gases. Why do you think greenhouse gases absorb infrared radiation and nitrogen doesn't?

T**ASK CARD: Resonance Models – Carbon Dioxide, Methane and Nitrogen**

You will be exploring three different greenhouse gases, each one represented by a model. Your group will use the models to make observations about the Resonant Frequency of each gas.

WHAT TO DO

Hold your model by the center atom and shake it (for nitrogen, hold one of the ends). Keep the amplitude of vibration (the shaking distance) less than 15 cm. Be sure to try very slow frequencies (~2/second) as well as fast ones.

OBSERVATIONS

When is it much easier to keep the model vibrating? At this frequency your model molecule better absorbs and retains your energy output. If there is such a frequency, determine what it is in vibrations per second by counting the number of vibrations in a 5-second interval and dividing by 5. When told rotate through different stations or switch models with other groups. Repeat this procedure for all three models.

DATA

Record your data on the back of your greenhouse gas notes and then add to the classroom data table.

DISCUSSION: As a group, discuss the following questions.

1) How do the resonant frequencies of the 3 models compare?
2) What hypothesis can you formulate to explain your observations?

Gas Files Activity
The Gas Files: Teacher Information:

There are 5 greenhouse gases that will be discussed in this activity. Students should have a task card, a recording sheet and the first 4 resource cards. Resource cards 5 and 6 show emission profiles by gas and source for developed vs developing countries and fossil fuel usage per capita. They can be used if you have the time and inclination.

More information on Greenhouse gases:

Water vapor (H_2O).

The most abundant greenhouse gas. It acts as a feedback to the climate. Water vapor increases as the Earth's atmosphere warms, but so does the possibility of clouds and precipitation, making these some of the most important feedback mechanisms to the greenhouse effect.

Carbon dioxide (CO_2).

A minor but very important component of the atmosphere (in terms of concentration). Carbon dioxide is released through natural processes such as respiration and volcano eruptions and through human activities such as deforestation, land use changes, and burning fossil fuels. Humans have increased atmospheric CO_2 concentration by more than a third since the Industrial Revolution began. This is the most important long-lived "forcing" of climate change.

Methane (CH_4).

A hydrocarbon gas produced both through natural sources and human activities, including the decomposition of wastes in landfills, agriculture, and especially rice cultivation, as well as cattle digestion and manure management associated with domestic livestock. On a molecule-for-molecule basis, methane is a far more active greenhouse gas than carbon dioxide, but also one which is much less abundant in the atmosphere.

Nitrous oxide (NO_2).

A powerful greenhouse gas produced by soil cultivation practices, especially the use of commercial and organic fertilizers, fossil fuel combustion, nitric acid production, and biomass burning.

Chlorofluorocarbons (CFCs).

Synthetic compounds of entirely of industrial origin used in a number of applications, but now largely regulated in production and release to the atmosphere by international agreement for their ability to contribute to destruction of the ozone layer. CFCs are also greenhouse gases and so are the compounds we have made to replace them.

RESOURCE CARD 2: The GAS Files

Major Greenhouse Gases and their Sources

Greenhouse gas	**Main sources**
Water vapor	Water in the air as clouds or vapor
Carbon dioxide	Burning of fossil fuels, deforestation, land use changes, respiration, volcanic eruption
Methane	Decomposition of wastes in landfills, agriculture (especially rice production), cattle digestion, manure management
Nitrous Oxide	Soil cultivation practices (how we grow plants), use of fertilizers, burning of fossil fuels, biomass burning, microbial denitrification
Chlorofluorocarbons (CFCs)	Human made compounds originally made to use as a coolant in refrigerators and air conditioners. Now regulated in production and atmosphere release because of international agreements to limit use

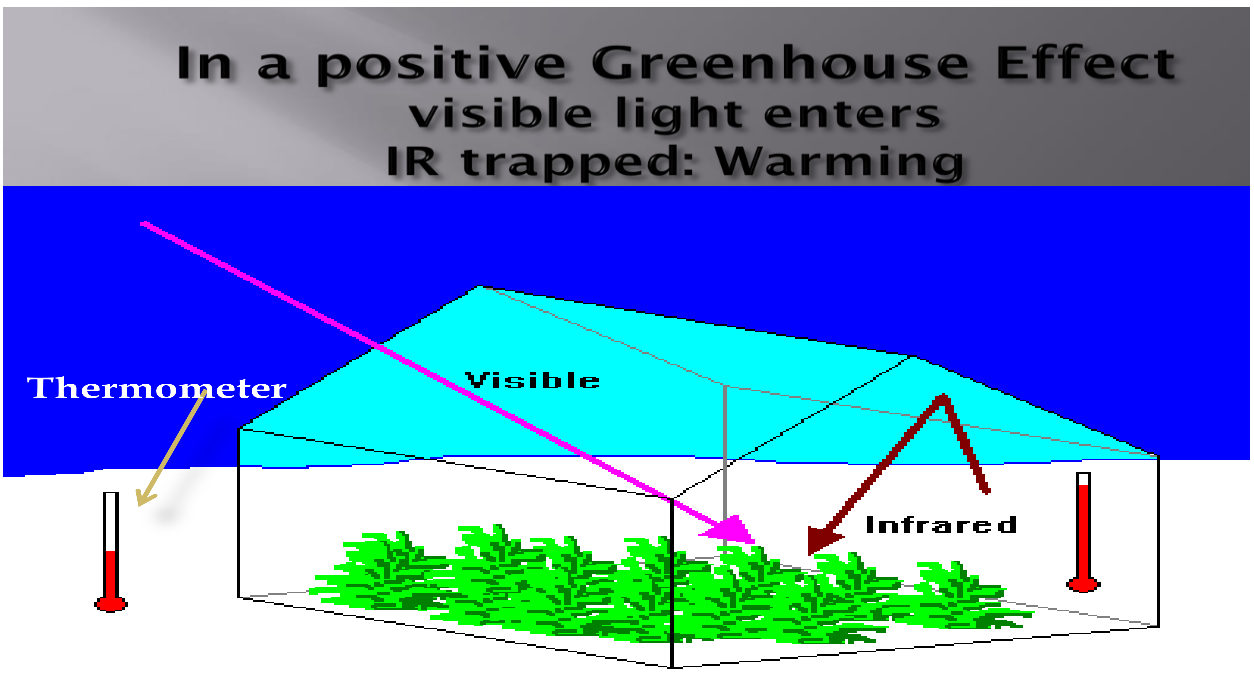


Fig.3.16 Positive greenhouse effect

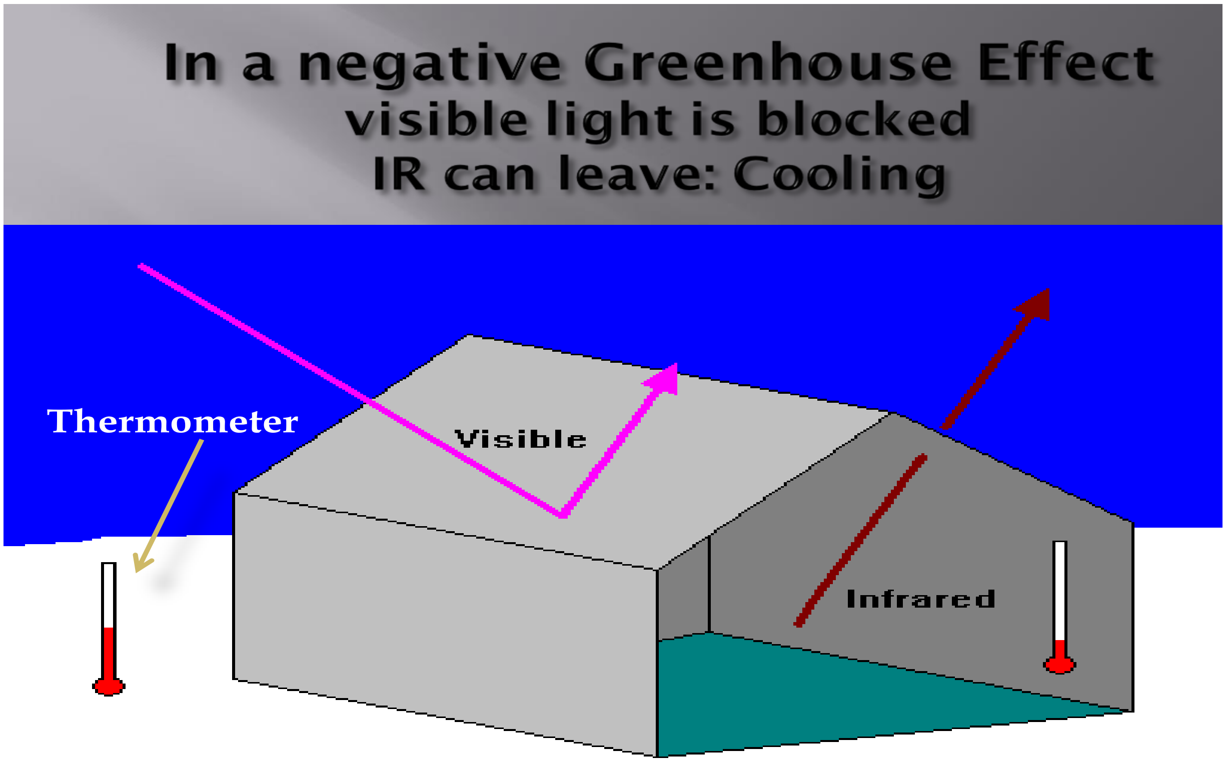


Fig. 3.17 Negative greenhouse effect

- *The blanket of gases in the atmosphere forms a greenhouse effect*
  - *a concept based on the idea that the gases 'trap' heat like the glass walls of a greenhouse do.*

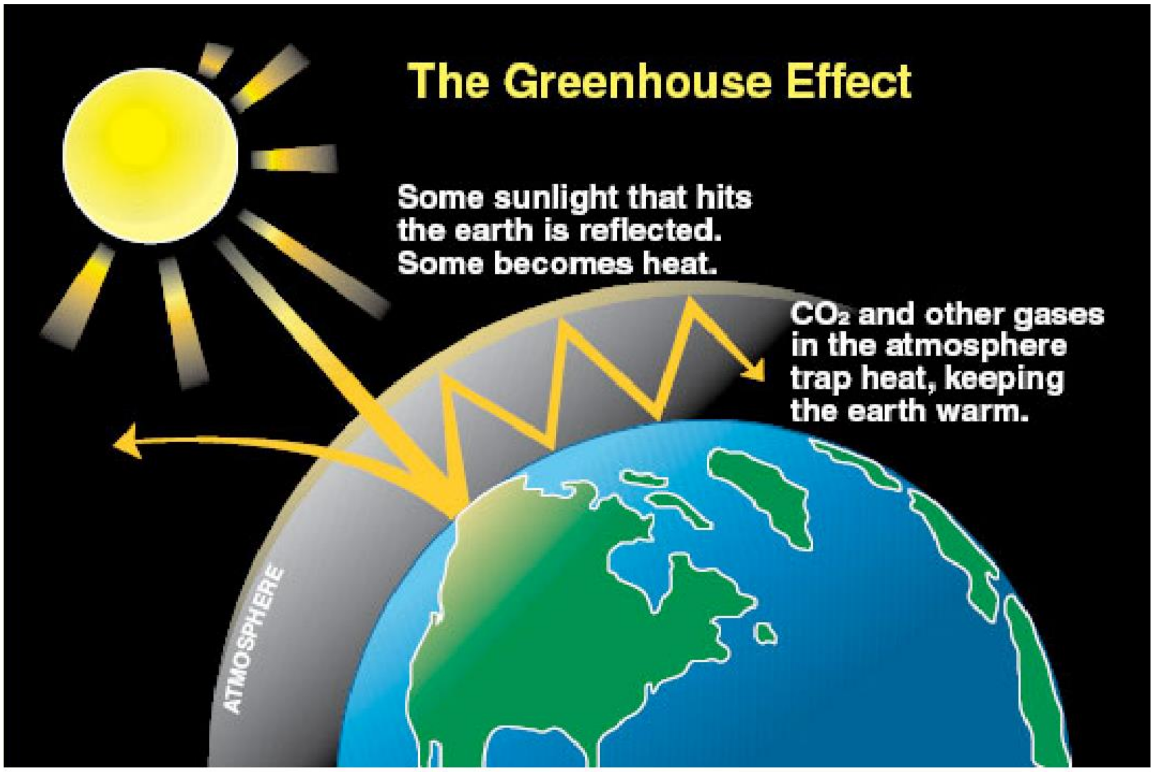


Fig. 3.18 Greenhouse effect in the atmosphere

NB. Use this slide to relate back to and debrief the laboratory. What are the comparisons between the greenhouse gas laboratory and this picture (fig. 3.18)? Ask students for similarities and differences. There is space on their laboratory notes to write their comments.

- ☐ *The earth's greenhouse effect*
  - *Some gases preferentially absorb certain wavelengths of radiation and are transparent to others.*
    - ✓ *This is attributed to resonance effects*
    - ✓ *As we saw in the amount of shaking in GHG models, they shake more or less depending on how much energy you put into them.*
    - ✓ *The long wave radiation happens to hit the greenhouse gases just right.*

Homework Reading: Carbon Dioxide and the Greenhouse Effect

The greenhouse effect is important. Without the greenhouse effect, the Earth would not be warm enough for humans to live. But as the greenhouse effect becomes stronger, it is making the Earth warmer than usual. Even a little extra warming can cause problems for humans, plants, and animals. Carbon dioxide is currently responsible for over 60% of the enhanced greenhouse effect. This gas occurs naturally in the atmosphere, but burning coal, oil, and natural gas releases the carbon stored in these fossil fuels and increases the amount of carbon dioxide in the atmosphere.

Deforestation, or cutting down trees to make more space for farms and homes, increases the amount of carbon dioxide in the atmosphere as well. Trees, like all living organisms, are made mostly of carbon; when forests are burned to clear land, the carbon in the trees is released as carbon dioxide.

Carbon dioxide produced by human activity enters the natural carbon cycle. Many billions of tons of carbon are exchanged naturally each year between the atmosphere, the oceans, and land plants. This exchange is known as the carbon cycle. The exchanges in this natural system are well balanced; carbon dioxide levels appear to have varied little for the 10,000 years before 1800. In the last 200 years, however, levels of carbon dioxide in the atmosphere have increased well above those levels.

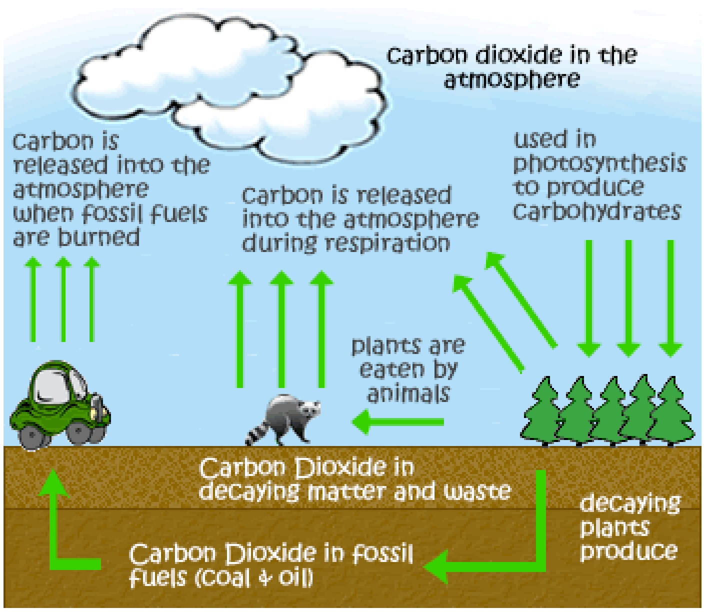


Fig. 3.19 Carbon Cycle

The Carbon Cycle (image from kidsgeo.com) Adapted from Climate Change Information Kit and Climate Change 101: Science and Impacts

- ☐ *Why is the greenhouse effect so important?*
  - *This slide compares the temperature on the three planets with and without greenhouse gases.*
  - *All of them experience warmer temperatures with the gases.*

NB: Recent calculations by NASA actually put the temperature change due to GHGs at on 20^{o}C and not the 33^{o}C in the chart. The difference is attributed to using a different albedo number to consider the effects of solar and long wave radiation on the planetary albedo.

RESOURCE CARD 1: The GAS Files

Figure 3.20 below shows the emissions of GHGs per sector, with Energy sector emitting the most, followed by Agriculture.

Sources	CO_2	CH_4	N_2O	Total Sinks/ removals
Energy	805.03	11.00	0.14	
Industrial Processes	0.00	0.00	0.00	
Agriculture		40.83	4.44	
Land-use Change and Forestry (LUCF)*	200.58	0.00	0.00	-1,578.56
Waste		8.03	0.10	
Total GHG Emissions by Gases	805.03	59.86	4.68	
GWP**	1.00	21.00	310.00	
Total CO_2 Equivalent	805.03	1,257.06	1,450.80	

Fig.3.20 Lesotho's greenhouse gas emission by sector in the year 2002 (Gg)

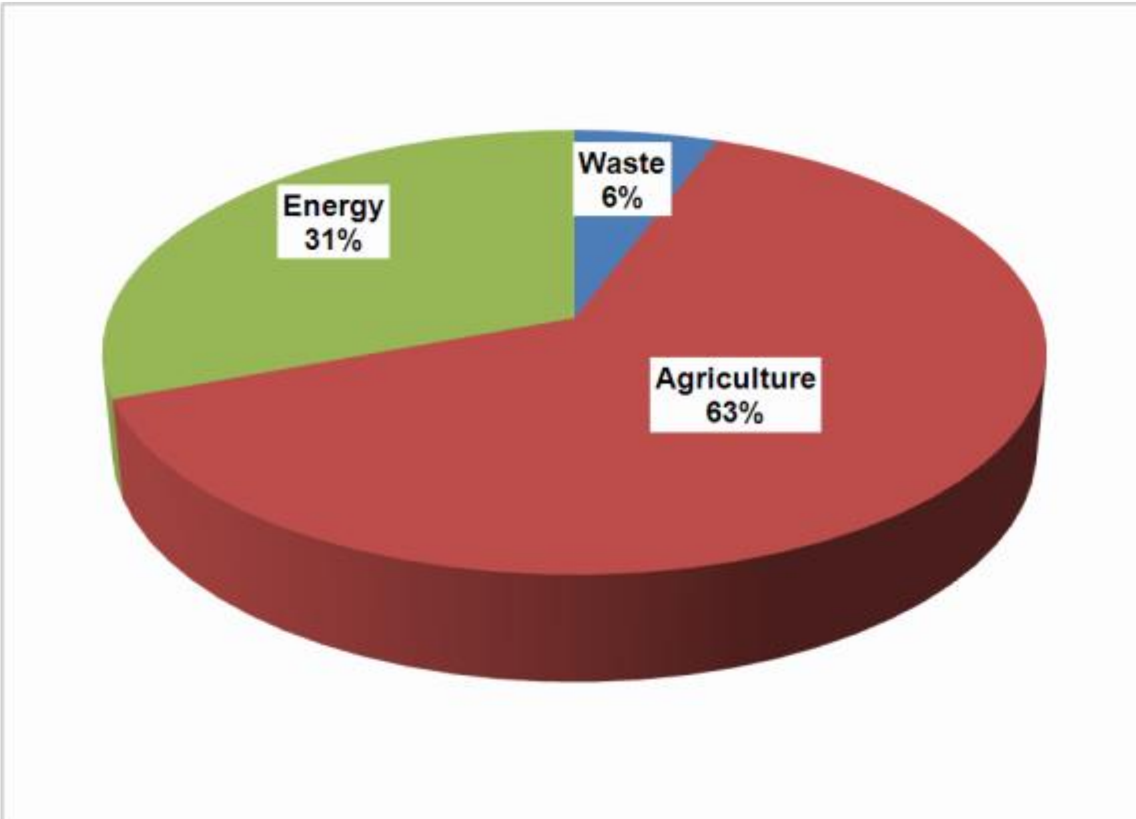


Fig. 3.21 Lesotho's sectorial contribution to 2000 C_2O Eq. emissions without LUCF

- ***This is an example of why we want to have greenhouse gases***

  - *They make our planet habitable and bring the temperature up to a level humans can live*
  - *It does not mean that the temperature everywhere is on a daily basis equal to 15°C, but just that there is a dramatic change because of the GHGs.*
  - *We know this because we can look at other planets e.g. Mars and Venus and compare their temperatures and atmosphere to ours (See Goldilocks Principle).*

- *This slide is optional. If you have time and inclination at this point, you could repeat the rope experiment from the other day. Students will see that different amounts of energy causes the rope to vibrate at different frequencies.*

- ***Background***

  - ✓ *Every object that is free to vibrate has its own natural frequencies.*

- ☐ *If you vibrate an object near one of its natural frequencies, its motion may grow to quite large values, a process we call resonance.*
- ☐ *Molecules behave in the same manner: they absorb energy near their resonant frequencies and vibrate, creating heat.*
- ☐ *In this demonstration of model molecules of atmospheric gases, students can make observations about resonant frequencies.*

1) ***Be careful that the students do not confuse the wavelength of the radiation (long and short wave) with the resonance frequency, although they are closely related.***

  - ✓ *A molecule moves at a certain frequency and it is a certain wavelength of light that is absorbed by a specific molecule.*

Resonance Model Making

Resonance and Greenhouse Gases

Adapted from Operation Chemistry and Global Warming Activities for High School Science Classes, Rosenthal and Golden, 1991

Directions to Build Gas Models

Your team will build three molecules: carbon dioxide, methane, and nitrogen. These three gases are found in the atmosphere at different concentrations. You will use these models to figure out their resonance frequency which relates to the wavelength of light that they absorb.

Carbon dioxide model

1) Insert one 15 cm hacksaw blade through a carbon atom with two slits. Let it stick out

about one 2.5 cm on the other side.

2) Repeat the procedure with another hacksaw blade from the other side.
3) Add an oxygen atom to each end so that the distance between each oxygen and the center carbon is 5 inches.

Resource Card 3 – The Gas Files

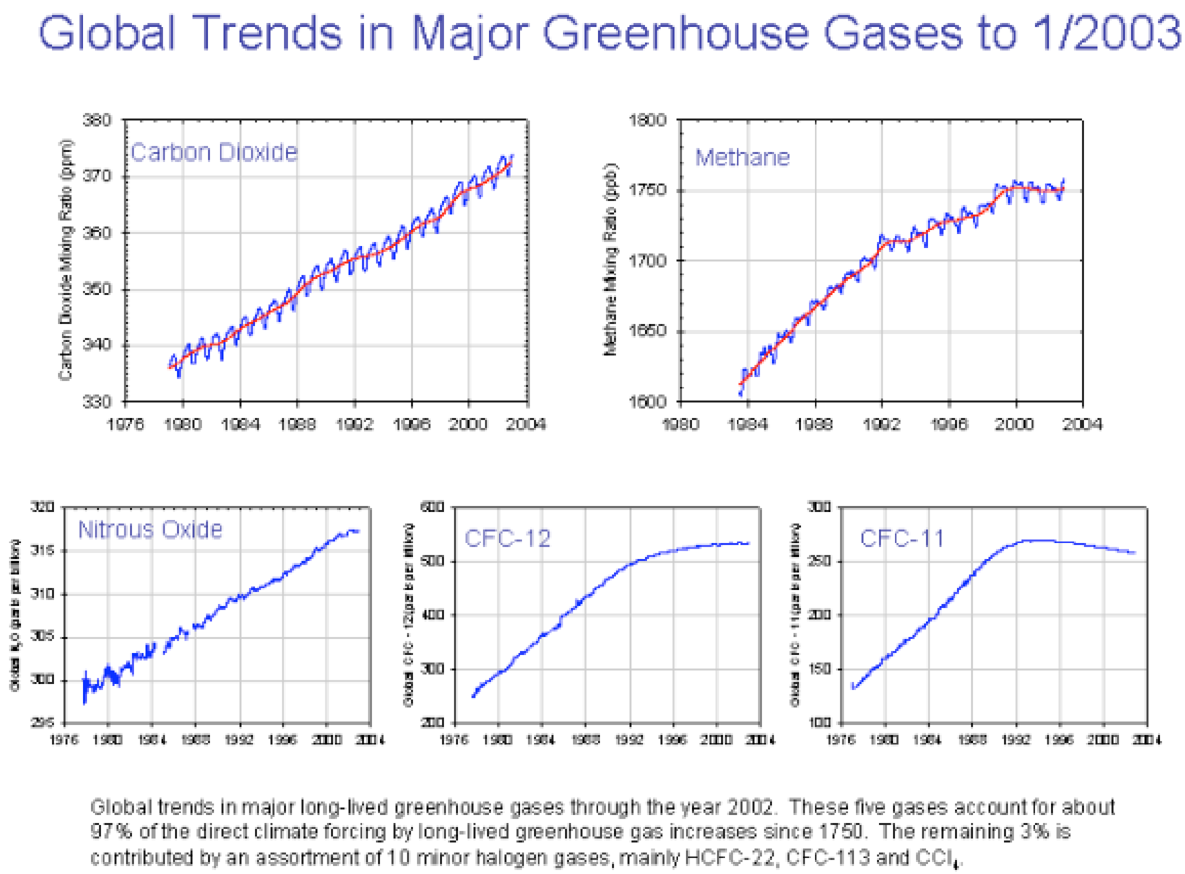


Fig. 3.22 Global trends of major GHGs

RESOURCE CARD 4: The GAS Files

Amount of Carbon Released or Stored by Different Sources per Year
Where does carbon go?

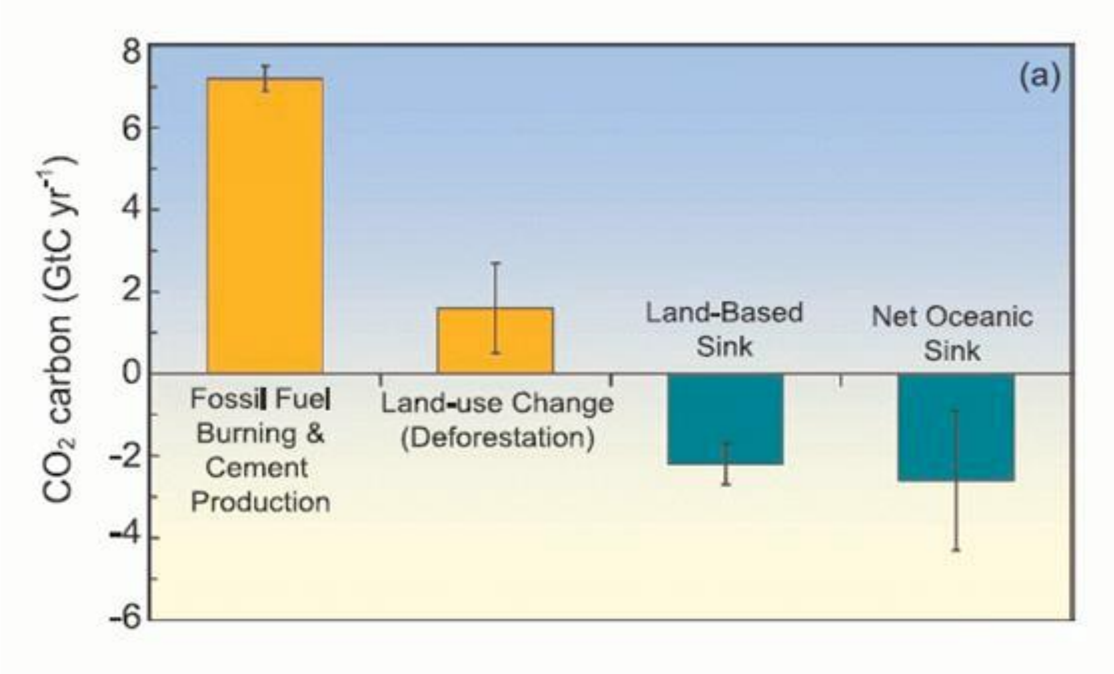


Fig. 3.23 Carbon cycle

Carbon is released from the respiration of plants and the burning of fossil fuels. It is stored in the atmosphere (the air), the biosphere (plants and soil) and the ocean.

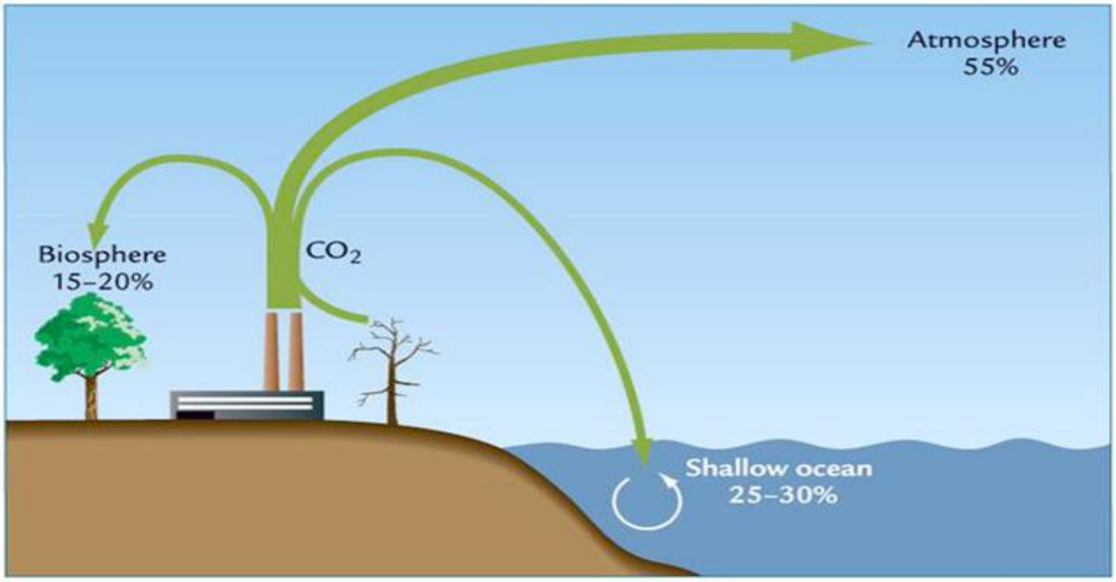


Fig. 3.24 Carbon cycle

Resource Card 5: The Gas Files

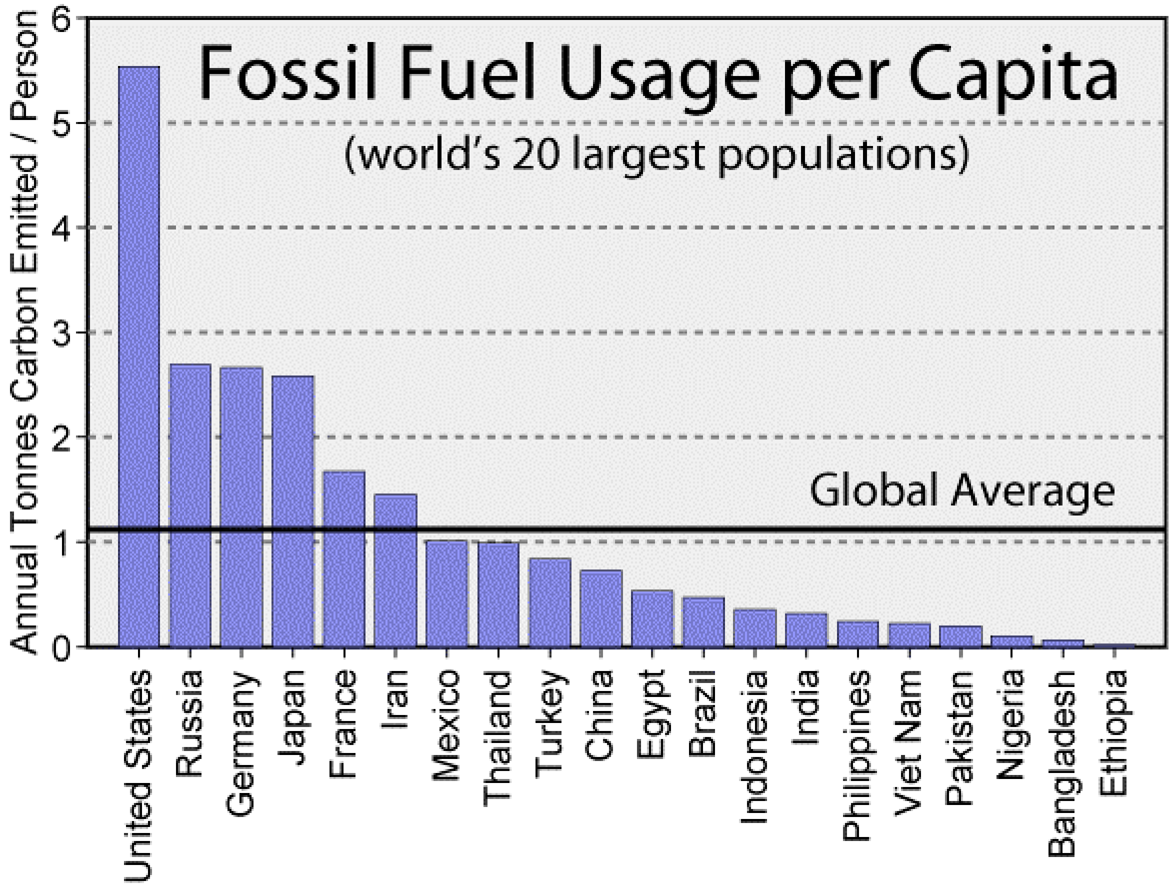


Fig. 3.25 Fuel usage in the world's largest population countries

TASK CARD: The GAS Files

Greenhouse gases are invisible. They are in the atmosphere. They are produced both naturally and because of human activity. We call this either: **NATURAL** - caused by nature or **ANTHROPOGENIC**- caused by humans.

Using the resource cards as references, DISCUSS the following questions with your group:

1) What are the main greenhouse gases in the atmosphere? According to Resource Card 1 what is the most abundant greenhouse gas?

2) According to Resource Cards 1 and 2, there are many sources of greenhouse gases. On your table, record the 5 main greenhouse gases and give one natural and one human source for each one. These are **SOURCES** for greenhouse gases.

3) What trends do you notice in greenhouse gas emissions over time? (Resource Card 3) Why do you think this is happening?

4) For each of the 4 gases humans release (not counting water vapor), what is one thing that could be done to decrease the amount we are emitting?

5) Where are the major **SINKS** or places to store carbon? Is this natural or caused by humans? Some people are proposing that we capture and store carbon dioxide underground. Do you think this will work? Why?

(Resource Card 4)

6) Using at least two graphs, give an example relating the graphs and explaining the evidence scientists use to support climate change.

Name:________________ _______________ Date: ____________________

RECORDING SHEET: The GAS Files

List the main greenhouse gases and at least two sources for each one. Divide the sources by **human** causes (anthropogenic) and **natural** causes. Not all may have both human and natural causes.

(Resource Card 1 and 2)

Greenhouse Gas	Human Cause	Natural Cause

Using Resource Card 3, what trends do you notice for greenhouse gases over time?

For each of the 4 gases humans release (not counting water vapor), what is one thing that could be done to decrease the amount we are emitting?

Where are the major SINKS or places to store carbon? Is this natural or caused by humans? (Resource Card 4)

What does Resource Card 5 show? Why is this important to understand?

Student Handout Notes

Name: ____ Date:____________________

1.0 What are the percentages of different components of the atmosphere?

Gas	%
Nitrogen	
Oxygen	
Argon	

2.0 Greenhouse Gases

2.1 What are some greenhouse gases?

2.2 What would happen to the Earth if the greenhouse effect did not exist?

2.3 Why is the small (less than 1%) amount of greenhouse gases so important to the average temperature of the Earth?

2.4 Where is one place where greenhouse gases are produced?

4 UNIT 3: CLIMATE CHANGE ADAPTATION AND MITIGATION

4.1 Objective 6: To understand the concept of adaptation and teach environmental content relevant to climate change adaptation

Students will be able to (SWBAT):

a. Describe adaptation and mitigation of climate change

b. Tree planting & forest management

c. Land and water management

d. Soil and water conservation practices

e. Lifestyle changes e.g. transport, water and energy conservation

4.1.1 Adaptation to Climate Change

- **What is adaptation**

What is Adaptation?

- Reacting or changing to fit the new circumstance
- Coping with impacts that cannot be avoided

Examples:

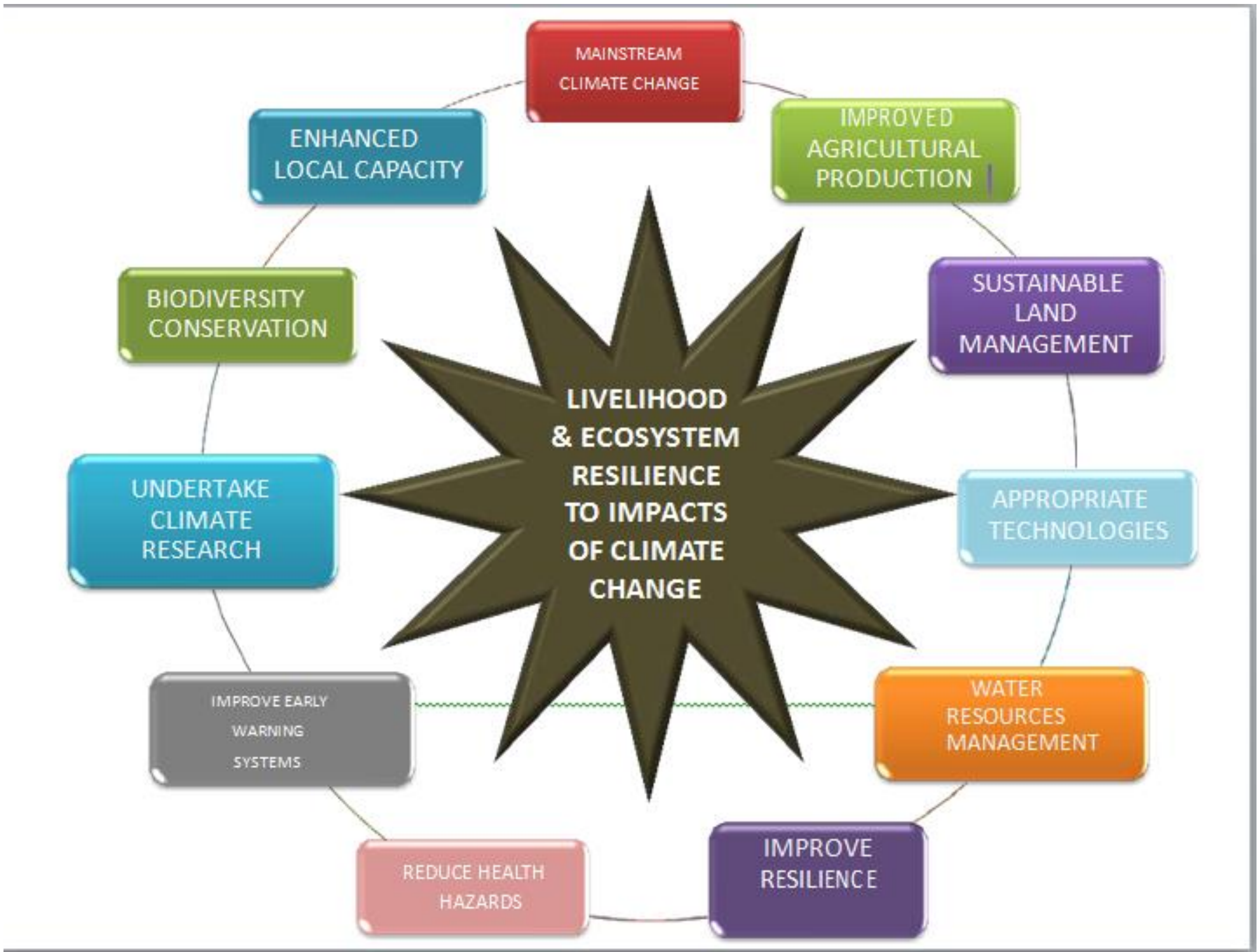
- farmers planting different crops for different seasons
- wildlife migrating to more suitable habitats as the seasons change.
- Building levees against sea level rise

> - *There still some aspects of mitigation & adaptation that will require tradeoff or generative synergies e.g. An adaptation strategy to deal with more heat waves could be wider adoption of air conditioning leading to increased energy usage and higher greenhouse gas emissions (if electricity is generated using fossil fuels). On the other hand, greater adoption of drought tolerant crops could reduce agricultural water usage and associated pumping of water which also could reduce energy usage.*
> - *There is also a possibility of "maladaptation". For example, building better levees can encourage more development in flood plains and even worse damages if /when those levees are compromised.*

Climate change education for adaptation prepares learners for uncertain futures that hold both risks and opportunities (UNESCO/UNEP, 2011). The overall goal should be to increase their adaptive capacities and resilience to climate change related hazards.

- ☐ **Teacher/Student Resources:**

Climate Change Adaptation Strategies


MAINSTREAM CLIMATE CHANGE
IMPROVED AGRICULTURAL PRODUCTION
SUSTAINABLE LAND MANAGEMENT
APPROPRIATE TECHNOLOGIES
WATER RESOURCES MANAGEMENT
IMPROVE RESILIENCE
REDUCE HEALTH HAZARDS
IMPROVE EARLY WARNING SYSTEMS
UNDERTAKE CLIMATE RESEARCH
BIODIVERSITY CONSERVATION
ENHANCED LOCAL CAPACITY
LIVELIHOOD & ECOSYSTEM RESILIENCE TO IMPACTS OF CLIMATE CHANGE

SECTORS	*INTERVENTION*	*AFTER INTERVENTION*
AGRICULTURE *Introduction of resilient crops varieties*		
RANGELANDS *Rehabilitation of rangelands – stone*		
WATER *Water harvesting*		
WATER *Construction of earth dams for irrigation and livestock*		
RANGELANDS - Bush control – restoration of rangelands through removal of alien species		

Figure 4.1: Examples of local adaptation measures

Box 4.1: Impacts and proposed adaptation interventions for T'sana-talana community council (Source LMS, 2012)

Tšana-Talana Community Council (E06)

- *This area has continuously experienced severe droughts; frequent hail storms; high temperatures in summer; and strong wind. Torrential rain events are also sometimes experienced.*
  - *Recurrent droughts have led to drastic decline in agricultural production, drying up of natural water sources, and degradation of rangeland resources.*
  - *Heavy rainfall exacerbates the problem of soil erosion in the area where desertification (i.e. a loss of vegetation cover and soil erosion) is already a widespread threat.*
- *In integrating climate change adaptation into the Council's development plan, Tšana-Talana Community Council has identified protection of water sources such as wetlands as one of the most important adaptation measures.*
- *The Council has planned to work with the relevant government departments to implement relevant legislation and demarcate and protect all important natural areas within the Community Council.*
- *The plan highlights rangeland management activities as vital adaptation interventions.*
  - *In particular activities such as removal of invasive species and reseeding of exposed areas with grasses are integrated with rangeland management practices to be carried out.*
  - *Promoting production of fodder crops by livestock farmers to provide supplementary feed is promoted as a strategy to reduce livestock pressure on grazing areas.*
  - *Measures to control soil erosion, such as planting grasses and trees, construction of small retaining dams and terraces, implementing rehabilitation initiatives such as stone packing, and planting indigenous grasses are some of the activities highlighted in the plan.*
  - *The Council also recognizes that it has a vital role to play in planning and coordinating developments in the area, such as road constructions and allocation of land for housing, to avoid negative environmental consequences such as erosion or degradation of water courses.*
  - *Finally, the plan explores opportunities to enhance the resilience of livelihoods for example through improvement of livestock and food production.*

Box 4.1: Impacts and proposed adaptation interventions for Qibing community council (Source LMS, 2012)

Qibing Community Council (E07)

- Challenges associated with climate variability and change that are being experienced locally include long and recurrent spells of drought, extreme temperatures (i.e. very high temperatures in summer and very low temperatures in winter), unseasonal snowfall, and erratic rainfalls.
- In response to these challenges the Qibing Community Council has developed a plan that aims to address environmental problems and strengthen livelihood strategies for the communities.
- Projects identified include:
    - *Soil erosion control*
    - *Improvement of agricultural production*
    - *Diversification of livelihood strategies*
    - *Education of communities on issues of climate change*
    - *Protection of wetlands and other important water sources*
- The Council has recognized that soil erosion has worsened in recent times due to very heavy rainfall. The Council's adaptation plan therefore includes expanding the catchment management initiatives through planting trees and grasses. and donga rehabilitation through construction of silt traps.
- The adaptation plan maps activities that aim at protecting wetlands and other water sources, for example by developing grazing plans that will ensure grazing in wetlands areas is avoided or controlled.
- Water scarcity is one of the greatest challenges in this Council. Simple and affordable water harvesting techniques such as rain water harvesting from roofs are therefore to be widely promoted across the area.
- Improvement of agricultural production to improve food security focus on promotion of conservation agriculture and use of keyhole gardening for vegetable production.
- The adaptation plan recognizes the importance of diversifying livelihood strategies not only to mitigate the risks involved in farming, but also taking into account that not all households are able to farm and meet their food security needs.
- Finally, the Council recognizes the need to liaise with the relevant Government Departments and Civil Society Organizations to educate the communities about the impacts of climate change and adaptation opportunities.

Climatic Stresses	Impact	Current Adaptation / Mitigation measure	Proposed Future adaptation / Mitigation Measure
CU			

TABLE 4.1: Current and proposed local adaptation measures

Climatic Stresses	Impact	Current Adaptation / Mitigation measure	Proposed Future adaptation / Mitigation Measure
ENERGY SECTORS			
Drought	• Water shortages and reduced hydropower generation	• Formulation of energy policy	• Development and promotion of renewable energy technologies (wind, solar, biogas)
SOILS AND FORESTRY			
Intense drought	• Poor soil fertility • Deforestation	• Reforestation • Community and individual tree nurseries • Adoption of soil conservation practices e.g. agroforestry, • contour cropping, terracing and others	• Reforestation of multi-purpose trees • Introduction of grafted trees and varieties
Extremely high temperatures in summer	• Forest fires • Increase in tree bugs and diseases • Increased soil moisture loss	• Reforestation	• Regenerating damaged areas with different tree species • Fire prevention • Capacity building and policy reform
Heavy floods	• Increased soil sedimentation • Increased gully formation	• Construction of silt traps and diversion furrows • Construction of waterways	• Promote land management practices and use land reclamation techniques. • Construction of water conservation and collection dams • Promote biological erosion measures: planting trees and grasses

Drought	• Extinction of indigenous medicinal plants and herbs • Migration of rare wild animals • Increased incidences of alien species • Decline in biodiversity	• Policy reform through Environment Act 2008 • Protection and conservation of plants	• Establishment of botanical gardens
RANGE AND LIVESOCK SUB-SECTORS			
Drought	• Poor rangelands • Increased livestock mortality/death • Water sources dry up • Poor quality of livestock and livestock products(wool, mohair and hides) • Increased soil erosion and gully formations	• Construction of conservation dams • Plant fodder to feed animals • Promote communal grazing system • Registration of livestock	• Rear well bred animals to withstand extreme weather (drought tolerant breeds) • Promotion of rangelands sharing within communities • Improve animal nutrition • Planting fodder to feed animals
High temperatures	• Increased incidence of animal disease • Wild fires	• Use of veterinary services • Anti-fire awareness campaigns	• Promote use of fire breaks • Increase public awareness on fire hazards and management
Extreme cold spells and heavy snowfall in winter	• Shrinkageof grazing land due to snowfall • Increased livestock mortality	• Provision of animal feeds (crop residues)	• Introduction of dairy livestock breed that would not heavily rely on rangelands • Planting animal feeds

Strong winds	• Dust storms • Increased soil erosion	• Forestry and rangelands conservation programmes • Grazing associations and livestock improvement • programmes being practiced	• Intensify afforestation programmees • Use conservation agriculture with soil cover crops • Increase use Land reclamation programmes
WATER SECTOR			
Shortened rainfall season	• Underground water not adequately recharged • Water sources dry up	• Rainwater harvesting from roof-tops • Development of well fields for water supply	• Build small dams • Drilling boreholes • Promotion of rain water harvesting • Increase coverage of well fields • Rehabilitation of boreholes
Drought	• Decline in water availability • Stagnant water causes diseases • Poor water quality • Outbreak of water borne diseases e.g. cholera	• Conserve water sources • Water rationing • Encourage communities to protect natural springs and • Wetlands Rehabilitation	• Demand management and leak detection • Promotion of water recycling and procurement of requisite equipment e.g. water testing kits • Conservation of wetlands and mountain sponges • Dredging of existing ponds and water collection points that have been silted over the years
Floods	• Outbreak of water borne diseases e.g. typhoid	• Use domestic water purification systems	• Intensify investments in purification technologies

Climatic Stresses	Impact	Current Adaptation measure	Proposed Future adaptation Measure
CROP SECTOR			
Drought	• Delays in ploughing • Stagnated Crop Growth • An increase in disease and insects	• Use of fertilizers and lime • Use of drought resistant cultivars • Construction of irrigation tanks	• Introduce improved drought resistant crop varieties • Promote use of irrigation technologies

	pests • Famine and food shortage	• Conservation Agriculture • Short lived reservoirs • Conservative irrigation	• Improve efficiency of irrigation equipment • Improve of early warning systems • Increase cooperation amongst all stakeholders • Improve market potential • Construct of earth and check dams including spring tanks • Promote climate smart agriculture (CSA)
High Temperatures and Heat waves	• Crops wilt • High soil moisture loss	• Application of herbicides • Timing of planting • Construction of irrigation tanks • Conservation agriculture	• Promotion of crop diversification • Use of irrigation technologies
Strong winds and dust storms	• High loss of moisture • Soil erosion increased	• tree planting • Rehabilitate gullied areas • Planting cover crops	• Land reclamation and gully rehabilitation • Wind breaks • Covers crops
Early and late Frost	• Plants wilt • Poor harvest	• Short season cultivars • Early planting	• Promotion of use of short season cultivars • Promotion of small-scale cash crops • Early planting
Floods and hail	• Heavy soil erosion • Damage to crops • Water logging	• Hail shields • Diversion furrows	• Promotion of use of hail shields • Construction of diversion furrows and terraces
HEALTH SECTOR			
Drought	• Poor water quality • Famine (malnutrition) • Disease outbreaks	• Introduction of water purification programmes • Promotion of use of sanitary services	• Promotion of water purification programmes
Heat waves	• Diseases (heat stroke) • Increase level of discomfort • Multiplication of bacteria	• Stay in shady areas	• Improve house ventilation

Wind storms	• Increase in air-borne diseases		• Cover water storage containers
Cold winters	• Increase incidences of colds and influenza	• Use of traditional herbal practices & Influenza vaccines • Reliance on biomass fuels for heating	• Promote conservation and regeneration of biodiversity • Promote use of renewable energy technologies for heating and cooking

4.1.1.1 Conservation Agriculture & Climate Change Adaptation

4.1.1.1.1 Why do farmers till the soil?

Reasons farmers till the soil: The Conventional Tillage Argument	**Is it necessary: the counter argument for Conservation Agriculture**
To soften the soil and prepare a uniform seedbed for placing seed at a suitable depth to ensure uniform seed germination	This argument was true before the invention of CA planters which can cut through the residues to place seed & ensure the uniform seed germination

Fig.4.2 Conservation agriculture

Farmers plough the fields for purposes of weed control and management	➢ Crop residues cover and live mulches suppress weed germination and early manual weeding reduces the labour requirements significantly. ➢ Herbicides technology is much cheaper than manual weed control and does a better job

Fig.4.3 Cropping activities in summer

<table>
<tr><th colspan="3">Is Tillage Required to Improve Soil Fertility?</th></tr>
<tr><td>❑ Tillage is need to incorporate crop residue in order to speed up the rate of mineralization & nutrient cycling.
❑ Many soil amendments and their nutrients are available if they are incorporated into the root zone</td><td colspan="2">➢ Crop residues are as easily decomposed on the surface where they also serve an equally important role of protecting the soil agaisnt erosion agents.
➢ Nutrient placement studies show that surface placement of nutrients is not necessarily inferior to incorporation</td></tr>
<tr><th colspan="3">Does Tillage Improve Soil Physical Properties?</th></tr>
<tr><td>❑ Tillage gives temporary relief from compaction using implements that are able to hatter below ground compaction layers formed in the soil.</td><td colspan="2">➢ This is true ... but the plough layer is caused by ploughing in the first place. No tillage no plough layer.
➢ Tillage pulverises the soil particles into fine dust and makes it more erodible
➢ Tillage interrupts the continuity of macropores</td></tr>
<tr><th colspan="3">Does Tillage Enhance Control of Diseases & Pests?</th></tr>
<tr><td>❑ Tillage was determined to be a critical management practice for controlling soil-borne diseases & some insects.</td><td colspan="2">➢ Crop rotations are economically & environmentally more friendly management practices for disease and pest control.
➢ Agrochemicals and /or integrated pest management technologies are now available for disease & pest control practice</td></tr>
<tr><th colspan="3">What is the Cost Benefit Analysis of Tillage?</th></tr>
<tr><td rowspan="3">❑ To establish a crop under conventional agriculture the following cultural operation are needed:
➢ Winter ploughing,
➢ Summer ploughing
➢ Harrowing /Disking
➢ Planting operation
➢ Interrow cultivation for weeding
➢ Interrow cultivation for ridging</td><td colspan="2">❑ The list of cultural operation for conservation agriculture is much shorter and cheaper</td></tr>
<tr><td>❑ Manual CA perations</td><td>❑ Mechanized CA: oxen or Tractor</td></tr>
<tr><td>➢ Digging basins
➢ Planting
➢ Hoeing (2x)</td><td>➢ Planting
➢ Weeding: Herbicide application</td></tr>
</table>

The Negative Impacts of Tillage on Soil Properties and Sustainability Indixes

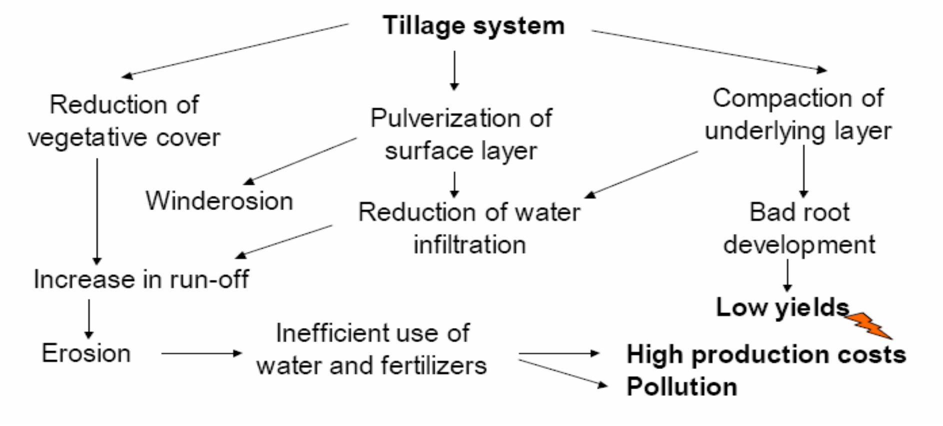


Fig4.4 Impacts of tillage on soil properties

What is Your Verdict?

There is no doubt that this list of tillage benefits had its advantages though at a cost to the farmer, the environment & the natural resource base on which farming depended.

This is an issue of sustainability &
Adaptation to Climate Change Imperatives

Conservation Agriculture & Climate Change
The Three Principles of Conservation Agriculture

The First Principle: Minimum Tillage using mechanical or manual techniques


Fig.4.5 Agricultural best practices in Lesotho

- ❑ Advantages of minimum tillage
  - ➢ Protects the soil from erosion by water and wind
  - ➢ Improves soil organic matter
  - ➢ Improves infiltration and conserves soil water
  - ➢ Improves fertilizer and manure use efficiency
  - ➢ Cost saving: fuel costs and time

The Second Principle 2 - Permanent soil cover with crop residues

- ❑ Leave approximately 30 percent of crop residues on the field

Fig.4.6 Best practices

- ❑ The residues are cut or rolled on the field to provide mulch

Fig.4.7 **The crop residue cut down and spread on the field to provide mulch**

❑ Advantages of crop residue mulch

- ✓ Protects the soil from erosion by water or wind
- ✓ Improves organic matter accumulation & carbon sequestration
- ✓ Improves recycling of nutrients
- ✓ Suppresses weed germination and growth

- ❑ Live mulches: legume cover crops and /or legume-grass mixtures

Fig.4.8 Cover crop e.g. grazing vetch: Adjacent plots with & without cover crops

- ❑ Advantages of live mulches or cover crops

  - ✓ Legume cover crops fix nitrogen and improve soil fertility
  - ✓ Protect the soil from erosion by water and /or wind
  - ✓ Provide livestock fodder
  - ✓ Suppress weed germination and growth

- ❑ **Demonstrating how mulches protect the soil from erosion agents**

Fig.4.8 Flooding in the fields due to heavy rainfall

Exercise 4.1 Four mini plots are set side by side on a sloping land. Two are ploughed with a spade and one is left bare while the second is covered with crop residues. The other two are not ploughed but one is covered with residues while the other is left bare of cover. Water is sprinkled with a watering can over the plots. The runoff water is collected in a small trench on the down slope side of the mini-plots. Learners are asked to record their observations. The observations are shared in a facilitated class discussion.

Fig.4.9 Use of residue to reduce loss of moisture through CA

The Third Principle: Crop Rotation & Intercropping

Fig.4.10 Beans planted directly into wheat residues demonstrating a cereal-legume rotation

- ❑ In principle means that different crops sequences, preferably cereal-legume, are sequentially planted on the same piece of land to provide the legume effect of nitrogen fixation.

➢ **Advantages of crop rotations & intercropping**

i) **Disease and pest management**: different crops are susceptible to different disease and pest agents. Therefore, growing such crops in rotation will reduce the incidence of diseases and pests.

ii) **Nutrient cycling & use:** Crops have different rooting patterns which take up nutrients at different soil depths. This helps to utilize soil nutrients more efficiently. In addition, legumes fix nitrogen in the soil for the benefit of successive cereal crops in a rotation.

iii) **Soil water management**: Crops with different rooting systems also utilize soil water at different soil depths.

4.2 Objective 7: To understand the concept of mitigation and teach environmental content relevant to climate change mitigation

4.2.1 Mitigation of Climate Change

☐ **What is mitigation?**

- ➢ To decrease force or intensity …. To lower risk
- ➢ To moderate in force or intensity, to alleviate … to lessen in force or intensity
- ➢ Elimination or reduction in frequency, magnitude or severity of exposure to climate related disasters such as floods and drought.

NB. An informal definition that could be used to discuss the idea: Basically to make something that could be very bad less bad.

Climate change mitigation

- ➢ Thus climate change education for mitigation needs to make students aware of negative impacts caused to climate by greenhouse gas emissions resulting from unsustainable human consumption patterns and lifestyles. It should also teach alternative and sustainable solution as well as development opportunities arising from participating in climate change mitigation strategies.

Activity 4.1 on Mitigation

☐ **Discussion: Ask for examples of things people do to mitigate for the following environmental effects:**

- ➢ Floods – build houses outside of flood plains; make walls so that water can't get in; make dams
- ➢ Climate change – mostly involve decreasing amount of greenhouse gases e.g. CO_2, methane (CH_4), in the atmosphere.

For the most part mitigation cannot reverse warming that has already occurred. It can only slow or stop what would come without any changes.

- ☐ **Trends in carbon dioxide concentration**

This graph is called the Keeling Curve. Charles David Keeling started to measure CO_2 levels at the Mauna Loa Observation Laboratory in Hawaii in 1958. This graph shows only atmospheric CO_2 concentrations (not any other greenhouse gas). The annual cycle is due to changes in photosynthesis and respiration depending on seasonal fluctuations. The basic idea here is to show that CO_2 concentrations are increasing

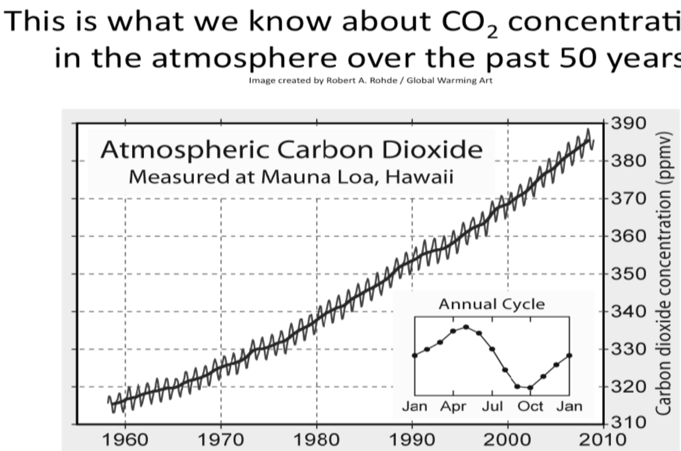


Fig.4.10 Carbon dioxide concentration trend in the atmosphere

This graph is from the GAS Files and shows annual emissions per sector. The emissions are mostly anthropogenic (human causes) especially CO_2. Use it if you think your students could benefit from more discussion of the sectors and where emissions come from.

- ☐ **Connecting CO_2 and Carbon Emissions leading to Climate change and mitigation**

  1. The increased amount of CO_2 in the atmosphere is from human activities that emit CO_2 e.g. burning fuel (wood, gas, coal). What are other human activities that contribute to increased CO_2 emissions refer to the pie chart?
  2. With more CO_2 in the atmosphere, the atmosphere is getting hotter and is changing the climate. Include all other effects.
  3. To mitigate (reduce the risk), carbon emissions need to be reduced to stop the increase of CO_2 in the atmosphere. State how mitigation is done.

- ☐ **The following diagrams are a first introduction to the mitigation wedge strategy used as final assessment. It shows historical emissions and then the amount that we need to decrease emissions in order to avoid doubling or tripling of CO_2 concentrations over time. The flat path shows where we need to go to avoid doubling CO_2 values. However, we actually need to bring emissions to lower than current values in order to decrease actual CO_2 concentrations.**

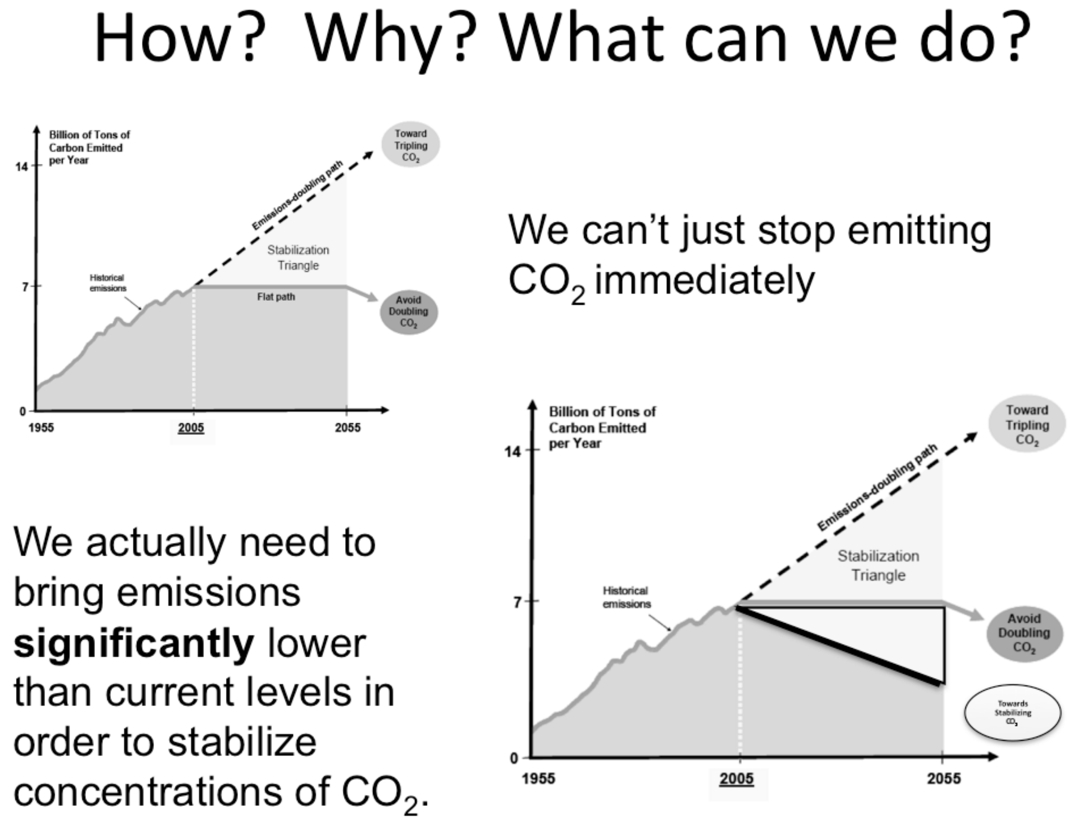


Fig.4.11 Achievable mitigation targets

- Bringing CO_2 values down this far will require significant investment of money and resources. When we do the final assessment, students will be working in groups to make choices about how to decrease or total emissions.
- Ask students for ideas since they just finished the wedge activity and should have ideas about sources, sinks, what is happening.

- The note at the top of the graph is to help remember questions:

  - ✓ How can we decrease carbon emissions?
  - ✓ Why do we want to reduce carbon emissions?
  - ✓ What can we do to reduce carbon emissions?

☐ **Mitigating Climate Change**: Actions we take to reduce concentrations of greenhouse gases

- For this lesson we will learn about 4 mitigation strategies which will help reduce the amount of CO_2 that is released into the atmosphere.

WHAT WE KNOW

The level of greenhouse gases in the atmosphere have increased, causing the Earth's temperature to rise.

One greenhouse gas in particular, carbon dioxide (CO_2) has steadily increased over the past century largely due to human activity (anthropogenic).

We know that emissions have a significant impact on the world around us. How can we reduce the amount of carbon that is emitted?

Fig. 4.12 Urgent need for reduction of CO_2 emissions

NB. This should be a review of earlier lesson

- **How can we reduce carbon emissions?**

  - Students work in pairs to talk about ways in which we could reduce (mitigate) carbon emissions in the following areas:

    - ✓ Transportation
    - ✓ Heating and cooling buildings
    - ✓ Industry carbon output
    - ✓ Electricity use

4.2.1.1 Mitigation strategy #1: Transportation Efficiency

Mitigation Strategy #1:
Transportation Efficiency

A car that gets 30 mpg releases 1 ton of carbon into the air for every 10,000 miles of driving

Fuel efficient cars get more miles per gallon (mpg)

Increasing the fuel efficiency of cars will reduce the amount of CO_2 emitted into the atmosphere

Fig.4.13 Use of fuel efficient car as strategy for reduction of emissions

NB. Convert miles and gallons to kilometers and liters respectively.

Quick formative assessment: make sure students remember what efficiency means.

4.2.1.2 Mitigation Strategy # 2: Transport Conservation

Fig.4.14 Efficient use of road transport

- *With more cars on the road, the amount of CO_2 emitted steadily increases.*
- *Reducing the time and number of cars on the road will reduce emissions.*
- *Increasing the use of public transportation would reduce the amount of individual driving.*

4.2.1.3 Mitigation Strategy # 3: Building Efficiency

Fig.4.15 Building efficiency

- *Providing electricity, transportation and heat for building produces high levels of CO_2 emission.*
- *Reducing heating and energy would reduce the amount of carbon released into the atmosphere.*
- *Insulating building, using alternative energy sources and solar water heating are ways to reduce emissions.*

4.2.1.4 Mitigation Strategy # 4: Efficient Electricity Production

Fig.4.16 Coal based power production

- *25 % of the world carbon emissions come from the production of electricity at coal plants.*
- *Since nearly 50 % of the electricity comes from coal combustion, improving coal plant efficiency will significantly reduce carbon emissions.*
- *To do this requires alternative ways of using coal to produce electricity.*

Activity 4.2 on Mitigation

1.0 The level of ____________________ in the atmosphere has increased, causing climate change. What name is given to a group of gases that cause the Earth's temperature to rise?

2.0 Which greenhouse gas in particular, ____________________has steadily increased in the atmosphere over the past century largely due to industrial activity.

3.0 Which of these phrases define mitigation? To:
a) increase risk
b) keep the same risk
c) reduce risk

4.0 Mitigation Strategies: State four areas where you can reduce emission. For each area you have stated suggest one way you can reduce emission.

1 ____

2. ____

3. ____

4.____

Concept Map and Homework: Continue to work on your Concept Map and add the following words to your map.

Mitigation
Power Plant
Fossil Fuel
Sinks
Sources

Power Plants and How They Work

- Principle

  - Energy is used to heat and boil water
  - The steam created by boiling water is used to turn the turbines
  - The turning of the turbines generates electricity

NB. Most of the electricity in the world is generated this way.

South Africa produces around 240,300 gigawatt-hours (865,000 TJ) electricity annually. Most of this electricity is consumed domestically, but around 12,000 gigawatt-hour is annually exported to Swaziland, Botswana, Mozambique, Lesotho, Namibia, Zambia, Zimbabwe and other Southern African Development Community countries participating in the Southern African Power Pool. Most power stations in South Africa are owned and operated by Eskom and these plants account for 95% of all the electricity produced in South Africa and 45% of all electricity produced on the African continent.

- There are many different ways to heat water to create steam

Fig. 4.16 water heating to create steam

  - Power plants use energy to heat water
  - Most commonly the power comes from burning coal.

- Diagram of a turbine

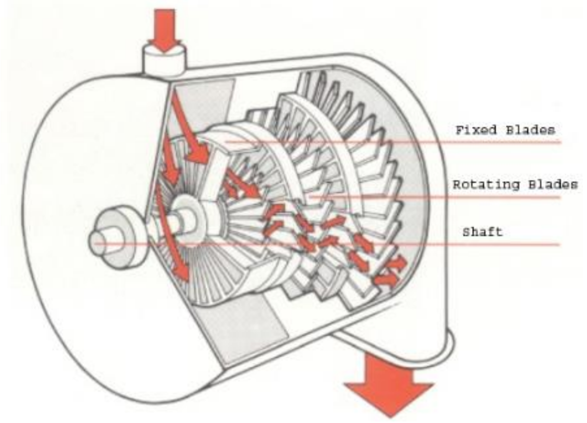


Fig.4.17 Turbine

- Steam from boiling water turns the blades around a shaft
- The turning generates electivity
- Most of our energy is created by somehow turning this turbine

- Example of a Coal fired plant in South Africa

Fig.4.18 The Anort Power Station in Mpumalanga

- Example of a hydropower plant in South Africa

Fig.4.19 The Gariep Hydropower Plant in the Free State

- Example of a Hydropower Plant at ‘Muela in Lesotho

➢ *The LHWP is primarily a water transfer system, but at 'Muela the water en route to South Africa is powers an underground hydroelectric power station that generates electricity to supply the needs of Lesotho.*
➢ *Water exits from the three 24MW turbines into the 'Muela tailpond, a 55m high, 6 million cubic metre capacity dam. Built on the Nqoe River, it provides the headwater for the continuation of water delivery to South Africa. A bell mouth intake in the dam takes water first into the Delivery Tunnel South and then Delivery Tunnel North for delivery to the Ash River Outfall.*

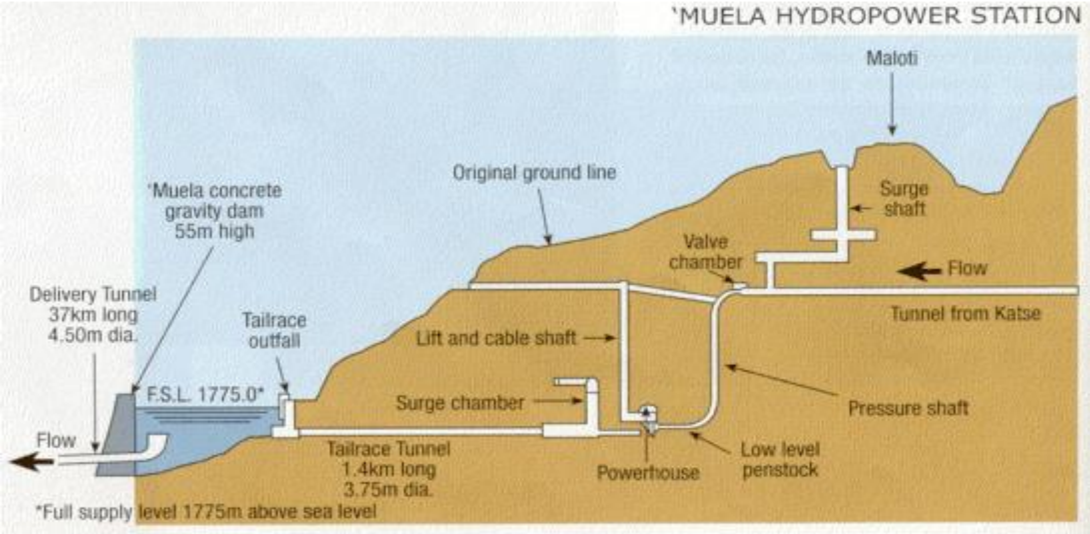


Fig.4.20 'Muela hydropower station

☐ Example of a Nuclear Power Plant in South Africa

Fig.4.21 The Koeberg Nuclear Power Plant in the Western Cape

NB. The two reactors at Koeberg are (as at 2010) the only commercial nuclear power plants on the African continent and accounts for around 5% of South Africa's electricity production. Low and intermediate nuclear waste is disposed of at Vaalputs Radioactive Waste Disposal Facility in the Northern Cape.

- Example of a Wind Driven Turbine in South Africa

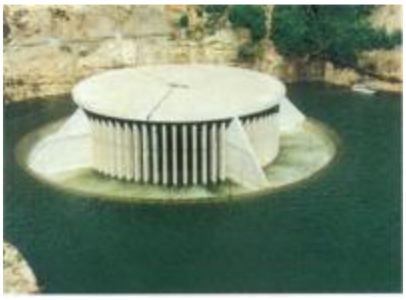


Fig.4.22 Wind farm in Eastern Cape, South Africa

There are currently no large scale wind farms operational in South Africa, though a number are in the initial planning stages. Most of these are earmarked for locations along the Eastern Cape coastline. Eskom has constructed one small scale prototype windfarm at Klipheuwel (Left) in the Western Cape and another demonstrator site is near Darling (Right) with phase 1 completed.

4.2.1.5 Lesotho Sectors Sensitive to Climate Change

Table 4.2: Sectors sensitive to climate change

Sector	Climate change impact	Short term adaptation actions	Long term adaptation actions
Public Health	Decreased air quality	Strictly enforce air quality standards and educate public on connections between air quality and climate change.	Implement monitoring to identify hotspots of vulnerability and enable flexible responses to surprises.
Water Supply	Degraded hydrological cycles in the alpine wetlands threaten sustainable perennial flow of rivers; Reduced snow accumulation and earlier annual melting; Less reliable water supply; Increased water demand	Implement water conservation programs, expand conjunctive use, and support infrastructure investments for water reservoir, storm-water and wastewater recovery.	Implement water conservation programs, expand conjunctive use, and support infrastructure investments for water reservoirs, storm- water and wastewater recovery.
Agriculture	Increasing threats to agricultural production due to less reliable water supply and increases in high temperature extremes	Increase water use efficiency for irrigation and enhance access to localized climate information,	Expand research, development, and deployment of heat and drought-tolerant crops.
Ecosystems	Loss of habitat, biodiversity; species extinction	Reduce existing non-climatic pressures on ecosystems – such as habitat fragmentation and pollution. Prioritize development of natural reserves containing a range climate conditions and habitat types.	Expand monitoring of networked protected areas to support species migration and adaptive responses to change.
Forestry & Range resources	Increased wildfire risk; increased pest outbreaks	Decrease non- climatic pressures on forests & rangelands such as air pollution. Use fire resistant building materials in vulnerable areas.	Modify planning and zoning processes to reduce development in fire- prone areas. Monitor to understand trends in vulnerability
Energy	Increased electricity demand	Strengthen energy efficiency in building codes and implement pricing schemes to reduce peak electricity demand.	Enhance capacity to meet peak demand through renewable energy sources.

5 LESOTHO GOVERNMENT POLICIES AND PLANS RELATED TO CLIMATE CHANGE

5.1 OVERVIEW

In response to environmental concerns, the country has ratified a number of multi-lateral environmental agreements, conventions and protocols such as: United Nations Convention on Biological Diversity (UNCBD); United Nations Framework Convention on Climate Change (UNFCCC), Convention on Wetlands of international importance especially as waterfowl habit (RAMSAR); Convention on International Trade in Endangered Species of Flora and Fauna (CITES); United Nations Convention to Combat Desertification (UNCCD), Montreal Protocol for the Protection of the Ozone Layer, Cartagena Protocol on Bio-safety and Basel Convention on Trans-boundary movement of hazardous wastes and their disposal.

Climate change derives its mandate from the Constitution of Lesotho, section 36, which states that: "Lesotho shall adopt policies designed to protect and enhance the natural and cultural environment of Lesotho for the benefit of both present and future generations and shall endeavour to ensure to all citizens a sound and safe environment adequate for their health and well-being''.

5.2 NATIONAL POLICIES AND PLANS

Lesotho during the past decade embarked on developing policies and plans that focus on the attainment of sustainable economic growth and development. Lesotho developed a national policy, Vision 2020 that provides a long-term perspective within which short to medium term plans could be made. The vision statement states that by year 2020, "Lesotho shall have a well managed environment" and the statement forms pillar five of the Vision 2020. Nonetheless, the Vision does not make reference to climate change.

In an effort of attaining the Vision 2020, the National Strategic Development Plan (NSDP) 2012/13-2016/17 was developed in 2012. The NSDP provides guidance on how the country can drastically transform its economy in a sustainable manner. The NSDP has a chapter on "reverse environmental degradation and adapt to climate change", as one of the national priorities. This chapter advocates for building a climate resilient nation and promotion of the green economy, which can be attained through:

- Undertaking or reviewing vulnerability assessments and review sector plans and programmes to improve mainstreaming of climate change
- Consolidating the national climate change policy and adaptation strategy, agenda and investment programme

- Upgrading standards for infrastructure development to climate-proof investments
- Developing mechanisms to improve access to climate change adaptation technology and use
- Promoting cost-effective and clean energy generation
- Promoting foreign and domestic investment in the production and use of environment friendly technology
- Promoting research and private participation in "green" technology development
- Exploring options for carbon trading and tapping different international funds

5.3 SECTORAL POLICIES AND PLANS

In an effort to achieve accelerated and sustainable socio-economic growth and a friendly environment, Lesotho is concerting efforts at all levels by adopting a number of sectoral policies that also address climate change issues. They include the following:

5.3.1 Finance Sector

The guiding plan that governs the Lesotho finance sector is the Financial Sector Development Strategy 2010 – 2014 whose primary objective is to facilitate, coordinate and allocate financial resources for proper implementation of development activities in the country. The financial sector plays a pivotal role in achieving sustained growth and providing a basis for achievement of green growth in the face of climate change.

5.3.2 Environmental Sector

In 1998, Lesotho adopted the National Environment Policy (NEP) which is a harmonized version of the National Environment Action Plan (NEAP) and National Action Plan (NAP). The main aim of the NEP is to "ensure the protection and conservation of the environment with a view to achieving sustainable development for Lesotho". To enforce this Policy, the Environment Act 2008 was enacted.

In 2009, the Environmental Education Strategy was developed. The strategy echoes the importance of environmental education in achieving sustainable development in Lesotho.

5.3.3 Disaster Management Sector

The National Disaster Risk Reduction Policy was developed in 2007, by the Prime Minister's Office, Department of Disaster Management Authority (DMA). It sets out strategies necessary to enhance capacities required for reducing risks and building community resilience to disasters in Lesotho.

5.3.4 Energy Sector

Lesotho has developed the Energy Policy 2015 – 2025 which stipulates that "energy shall be universally accessible and affordable in a sustainable manner, with minimal negative impact on the environment." There is also the Draft Renewable Energy Policy 2013, whose aim is to create a progressive, long-term policy framework that would promote use of locally available renewable energy sources (e.g. Solar, Hydro and Wind) in Lesotho.

5.3.5 Land Management Sector

The land management sector is governed by the legal frameworks and policies such as:

- **National Range Resources Management Policy, 2014** - The policy provides the legal framework for supporting sustainable rangelands management in the country. It advocates for establishment of multi-level institutional arrangements necessary to enable the implementation of sustainable land management practices within the country and reverse land degradation.

- **National Rangelands Action Plan, 2015** – The Action plan seeks to identify strategic actions that are necessary to implement the National Range Resources management Policy.

- **National Forestry Policy, 2008 –** The policy calls for sustainable forest management and associated socio-economic dimensions, including enhanced stakeholder participation in the forestry sector.

- **UNCCD Lesotho National Action Programme, 2015 –** The programme deals with diversification of livelihoods base and generation of income from Sustainable Land Management including reduction of environmental and socio-economic vulnerability of affected populations to drought, climate change and climate variability.

5.3.6 Agriculture Sector

The policy framework that governs the agricultural sector in Lesotho is provided for by a number of policies and strategies including the Agriculture Sector Strategy 2003, the National Conservation Agriculture Strategy Framework 2012 – 2017, Lesotho Food Security Policy 2005 and the resultant National Action Plan for Food Security 2007 – 2017 which is meant to implement the Food Security Policy. These policies and strategies are aimed at improving income distribution and increasing the share of agriculture in the national GDP. They also promote conservation agriculture as a strategy that can ensure improvement of soil fertility and maintenance of soil moisture, ensure minimal soil disturbance hence promote microbial activity and help control soil erosion which is one of the major threats to the sector.

5.3.7 Water Sector

The management of water resources in Lesotho is guided by the Water and Sanitation Policy (2007) and its implementation is facilitated by the Long Term Water and Sanitation Strategy (2014). The strategy sets pathways for implementing the Water and Sanitation Policy as well as the Water Act (2008), by establishing enabling institutional mechanisms and setting clear goals to be achieved by 2020. The National Wetlands Conservation Strategy 2013/14 – 2017/18 provides guidance on how to achieve the coordinated management of rangelands and wetlands ecosystems within the framework of catchment management; while promoting conservation and sustainable utilization of the ecological infrastructure.

5.3.8 Health Sector

The sector is governed by the 2012 National Health Policy which guides the implementation of interventions in the health sector. The plan is implemented by the National Health Sector Strategic Plan (HSSP) 2012/13 – 2016/17 which is a successor plan to the 2000 – 2010 HSSP. The aim of the strategy is to achieve among others a "healthy population, living a quality and productive life" which will be attained by significantly reducing morbidity, mortality and inequality in accessing health care services.

5.3.9 Transport Sector

In order to have an overarching policy for the Transport Sector, the Ministry of Public Works and Transport developed the Transport Sector Policy in 2006. This policy states that "the Government will provide an enabling environment for efficient, cost effective and safe transport, within Lesotho, regionally and internationally, to facilitate the sustainable development of the economy, social services and of the population in general". It also calls for rationalization where necessary and upgrading or extending where justified, transport infrastructure in accordance with the planning for the integrated transport system.

5.3.10 Gender Sector

The Gender and Development Policy was developed in 2014. The overall goal of the Policy is to take gender concerns into account in all national and sectoral policies, programmes, budgets and plans in order to achieve gender equality in the development process. The Policy advocates for development and implementation of gender sensitive sectoral policies and strategies of all critical areas identified by Beijing Platform for Action.

5.4 Climate Change

Although there are a number of policies and plans in place, an overarching policy on climate change is yet to be developed to guide implementation and coordination of climate change initiatives in the country. The Lesotho climate change Policy has to create an enabling environment for the implementation of appropriate actions aimed at addressing climate change in particular adaptation and mitigation.

5.4.1 Mainstreaming Climate Change

The need to integrate climate change into development planning and in decision-making processes has become increasingly apparent with the general recognition of the linkages between development and climate change (LMS, 2015). Integrating or mainstreaming, climate change considerations into national and sectoral decision-making processes is therefore critical to meeting different challenges. Mainstreaming of climate change into national and or sectoral plans and policies is crucial to ensure long-term sustainability of actions taken in the country. This may call for the review of existing strategies and policies.

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Enhancing climate change education at early stage

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