Climate change and environment

In this number of ***Vidurava***, an initiative has been taken to create a broad-spectrum awareness on the distressing features of Climate Change, caused largely by the anthropogenic release of what are commonly referred to as Greenhouse Gases (GHG).

Greenhouse gases comprising largely carbon dioxide, halocarbons, methane and nitrous oxide, accumulate in the atmosphere, disturbing the natural balance between incident solar radiation and energy re-radiated from the earth. This man-made destructive force is predicted to change the climate well into the future and impose stresses on human and natural systems.

Historically, the great revival of art, literature and culture that marked the Renaissance during the 14-16 centuries, which subsequently fuelled the industrial and scientific revolutions, set in motion the degradation processes on the life-supporting elements of the environment. It is significant but disheartening to realize that developmental strategies leading to capital growth, technology development, exploitation of natural resources, and the luxury consumption of energy of a small consortium of countries lying within the narrow geographical boundaries of Western Europe could cause the global ambient atmospheric carbon dioxide concentration to rise from 280 parts per million (by volume) in the 17th century to 390 ppm (by volume) in the mid 20th century. As a result of this process ambient atmospheric temperatures rose by 0.6 percent every 100 years, while the sea level rose by 16 cm during the same period, largely caused by mass melting of the polar ice caps. According to reports of the Intergovernmental Panel on Climate Change, Arctic ice has thinned by 42 percent, while 27 percent of the World's coral reefs are known to have been lost during the last century, suggesting that some of the world's life supporting ecological systems are under threat.

According to recent scientific evidence, competition for natural resources due to intensified globalization and privatization, has caused many critical ecosystems to face destruction. In this context, the consensual principle that "Polluter Pays and the Victim Recompensed", finds no relevance, because Nature makes no distinction between North/South, or East/West, or developed and less developed, or for that matter even between the Polluter and the Victim in the dispensation of its reprisal.

Nevertheless it is still not too late to make amends both at national and global levels to contain, if not to minimize the process of environmental degradation, and consequently of actions leading to climate change. Although cost effective approaches to mitigate impacts of climate change have been extensively discussed, unless a Global consensus on mitigation responses is forthcoming, the prospect of ensuring a healthy living natural environment for future generations is like to remain bleak.

Asoka De Silva

Cover Story 1

Climate Change and Depletion of the Ozone Layer

Dr W. L. Sumathipala

Introduction

Climate change and thinning of the ozone layer are common environmental issues that world community faces today. Both these are mainly due to man made activities which bring significant threats to the living beings on the planet.

Ozone-climate interaction is complex, and impacts of one issue induce consequences on the other. Both ozone depleting substances (ODSs), many of which are also greenhouse gases (GHGs) and other gases, affect incoming and outgoing radiation, thus enhancing global warming. Until recent times these two global issues were treated separately and international agreements on control measures have also been adapted separately. For example, the Vienna Convention for the protection of the ozone layer and Montreal Protocol on substances that deplete the ozone layer, are global initiatives to bring back the stratospheric ozone layer to its original condition. The United Nations Framework Convention on Climate Change (UNFCCC) and the Kyoto Protocol have been adapted internationally to reduce greenhouse gas emission to the atmosphere. These are international responses to ozone depletion and climate change, as global control measures. However, now scientists have revealed that ozone depletion and climate change have significant interactions, affecting the entire globe, and hence they cannot be treated in isolation. Either ODSs or GHGs emitted from man made sources enter the same atmosphere that lies around the earth surface as a thin layer. Both these issues lead to significant changes in the atmospheric chemistry and disrupt its normal functions.

Now policy makers on environmental issues take greater interest in tackling this problem, considering both issues together and not separately. However, since some of the powerful countries have not signed the Kyoto Protocol, still there remains a barrier for collective global action.

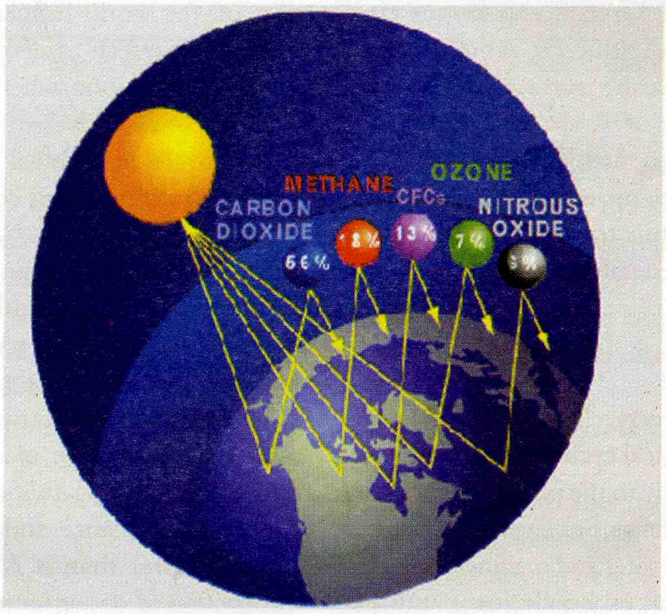

Figure 1: Greenhouse gases trap IR radiation and tend to warm the earth surface
Adapted from *www.koshland-science-museum.org*

Climate change

Climate Change has been identified as a serious problem that the world community faces today. Responding to these climate issues has become a significant challenge especially in developing countries. High concentrations of GHGs in the atmosphere, mainly due to man made activities, produce global warming which considerably affect climate change. The observed changes today and the anticipated changes in the future in climate will affect both human and natural ecosystems in many ways. Thunder storms, floods, drought and severe and frequent cyclones are ongoing consequences which bring great climatic variability. Floods and drought due to variations in rainfall are already serious issues for nations whose economy is primarily based on agriculture.

Developing countries are more vulnerable to climate change than developed nations mainly due to their inability to take appropriate actions. GHG emissions from developing countries are negligible as compared to developed countries whose energy consumption is high. Poor nations whose economy is mainly based on agriculture have to face difficulties due to irregularities in the hydrological cycle caused by global warming and climate change.

Greenhouse effect

Earth surface absorbs radiation emanating from the sun and causes terrestrial warming. Much of the radiation is reemitted by the heated earth surface to the atmosphere, especially long wave radiation (Infra Red-IR), which are trapped by greenhouse gases present in the atmosphere leading to enhanced warming. This phenomenon is known as the greenhouse effect .The most abundant greenhouse gases, in order of their relative abundance are carbon dioxide, methane, nitrous oxide, ozone and CFCs. Increased levels of Greenhouse Gases from anthropogenic (man made) sources, which lead to temperature rise near the earth's surface, is known as Global Warming. Emissions of Carbon Dioxide (CO_2) have been increasing due to fuel burning and forest clearing. Industrialized nations are mainly responsible for such emissions contributing to greenhouse effect. Methane (CH_4) is mainly generated from wetlands due to anaerobic activities.

Effects of climate change

Global warming brings adverse climatic consequences such as thunder storms, tropical cyclones and hurricanes causing destructions especially to the people living in low lying coastal areas and river deltas. Sea level rise as a result of thermal expansion of sea water and melting of glaciers is also likely to be significant, especially for islands like Sri Lanka. Melting of polar ice caps leads to a significant increase of water in oceans. Coastal inhabitants are highly vulnerable to sea level rise which may also bring big threats to the global biodiversity. Mean global temperature has increased by 0.3-0.6 ^{0}C over the past 100 years and corresponding sea level rise was between 10 to 20cm.

Some of the direct health impacts of climate change are cardiovascular diseases and respiratory diseases while indirect effects include algal toxicity, cholera, vector born diseases such as malaria, dengue, malnutrition, asthma etc. The forest acts as a possible sink for carbon dioxide (CO_2) which facilitates maintaining the natural balance of the atmosphere. Forest cover seems to be a natural defense to ensure survival of life on earth. Intake of CO_2 by green tissues during photosynthesis known as carbon fixing, regulates the CO_2 concentration in the atmosphere. An increased level of deforestation (removing forest cover) due to over exploitation results in elevated CO_2 levels in the atmosphere leading to disruption of the natural balance. The ultimate result would be inadequate forest cover for absorbing CO_2, thus enhancing global warming and climate change. Deforestation is happening at an alarming rate, especially in tropical countries due to their development activities both in Industry and Agriculture.

Emissions are not confined to particular nations which are responsible for it, and dispersion occurs through the atmosphere over different nations, since the global atmosphere has no boundaries, and emissions from any part of the world influence the whole earth, bringing undesirable effects to all countries. This is known as trans-boundary pollution where the developing nations may also have to face adverse consequences of it. Thick dense forest cover in tropical areas tends to absorb GHG emitted from northern countries.

Depletion of the ozone layer

Ozone is being constantly produced and destroyed by chemical reactions that take place in the atmosphere. For over 600 million years there has been a balance between this natural production and destruction process. Anthropogenic (man made) substances released to the atmosphere during this century has started to disrupt this natural balance and make the ozone destruction process faster than it is being created. This leads to destruction of ozone increasingly and bringing the ozone level down.

This enhanced ozone depletion happens as a result of Ozone Depleting Substances emitted into the atmosphere. These products are mainly man made and released through human activities. Substances used in the industrial and agricultural sectors such as Chlorofluorocarbon (CFC), Halons, Carbon tetrachloride (CTC) and Methyl Bromide (MeBr) are mainly responsible for ozone depletion.

These chemically inert and very stable substances slowly reach the upper atmosphere and high energy Ultra Violet (UV) radiation emanating from the sun breaks them apart in to their atomic constituents. Chlorine and Bromine atoms released in this way act as catalysts for chemical reactions that lead to acceleration of the ozone destruction process. Each atom can destroy thousands of ozone molecules due to its catalytic property, before being removed from the atmosphere.

important as primary producers in aquatic food webs. Reduced plankton levels leads to diminished fish stock in the oceanic environment through a chain reaction. An elevated level of UV reaches the earth surface threatening microbial life on earth. For example Cyanobacteria which

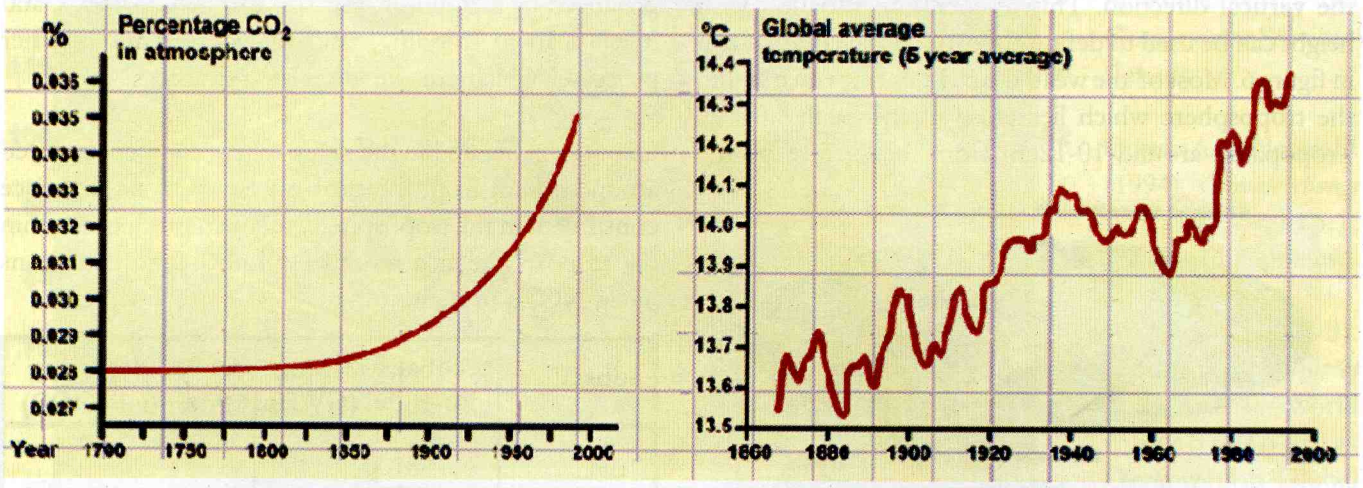

Figure 2: Graphs of rise in global atmospheric CO_2 concentration and global average temperatures. Adapted from *www.bbc.co.uk/.../weatherhumansrev*

Accumulation of Chlorine and Bromine atoms in the upper atmosphere make the ozone destruction process faster which leads to the ozone level being brought down. The severe depletion of ozone was first observed in the 1980s in the Antarctic, which came to be known as the "ozone hole" caused by destructive reactions of halogens. Ozone layer depletion is being monitored and observations indicate that there is destruction of ozone every where, and even over the tropics the ozone layer is very thin.

The Stratospheric Ozone layer acts as a protective shield for UV radiation which comes from the sun. It absorbs UV radiation and hence reduces the amount reaching the earth surface. UV rays which are considered to be harmful for life on earth, has significant potential to produce skin cancers, cataracts and immune suppression in human beings. Many studies have shown that there is a strong relationship between skin cancers and UV-B exposure. Higher UV levels have a significant impact on the human immune system thus suppressing immunity. Increased levels of UV reaching the earth surface leads to increase ground level ozone concentrations which bring toxic effects to the life on earth. Increased UV levels due to decreased ozone level have significant impacts on plants thus inhibiting their growth. It may also affect photosynthesis in planktons which are vitally

play an important role in fixing atmospheric Nitrogen in legumes is highly sensitive to UV rays.

Thinning of the ozone layer brings significant impacts on climate change both directly and indirectly.

Link between climate change and ozone layer depletion

Identification of the interaction between Ozone depletion and climate change has critical importance since it affects the atmosphere around us. The atmosphere is an open system, being subjected to both matter and energy inputs and out puts. Within the troposphere, absorption of terrestrial radiation by atmospheric gases cause the earth surface to grow warmer and this phenomenon is called Greenhouse Effect. Most of the Ozone Depleting Substances are potential GHGs. For example, Halons which are very effective firefighting substances and CFC used as a refrigerant and in many other industries are strong ozone depleting substances, while they are also greenhouse gases with a high global warming potential.

Atmospheric composition mainly depends on the energy it absorbs. UV radiation absorbed by the stratospheric ozone determines the chemical and physical structure of the stratosphere. Energy absorbed by ozone in the region around 25-30 km from the surface of the earth creates the temperature inversion (increase of temperature with altitude - see Fig. 5) which creates stratosphere. This non uniform energy absorption creates an atmospheric temperature profile which is zigzag in the vertical direction. This temperature variation with height can be used to define atmospheric layers as shown in figure 6. Most of the weather activities take place within the troposphere which lies close to the earth surface. Tropopause around 10-12km from the surface of the earth acts as a barrier for vertical motion and limits or determines the cloud height. If the ozone layer is destroyed tropopause will move up almost up to the mesopause which is around 80km high, and thus the cloud height can be as high as 80km. Therefore, rain produced by a cloud of that size can be enormous, and it will lead to flooding, land slides and various other processes which are climate related disasters.

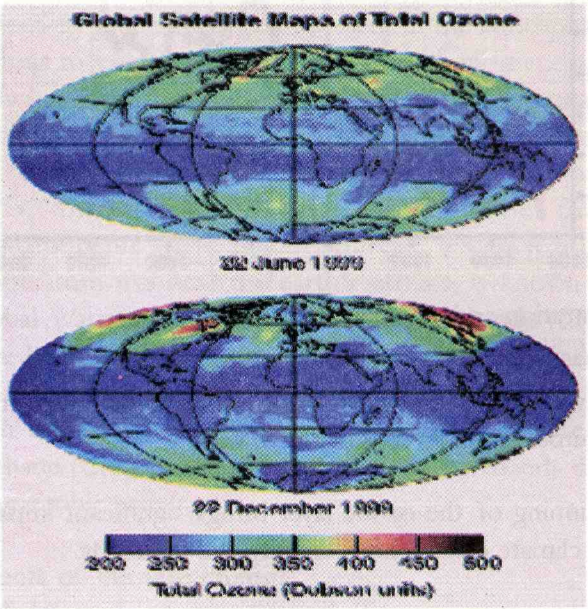

Figure 3: Distribution of ozone over the earth surface. Courtesy of NASA

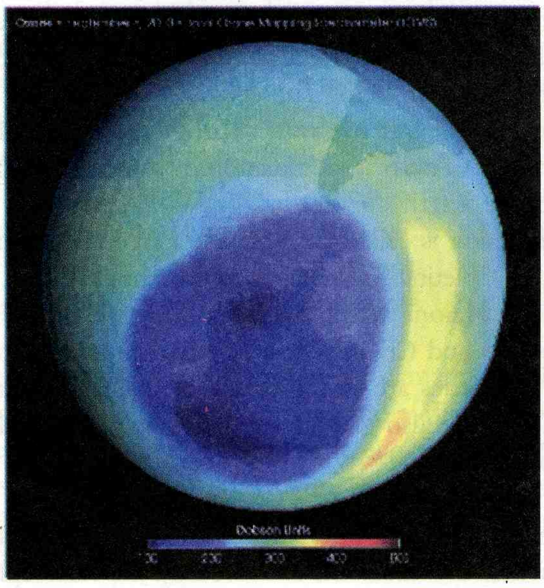

Figure 4: Ozone Hole over Antarctica as observed by NASA, September 2000.

Ozone is generated in the stratosphere and concentrated around 30 km from the earth surface. Ozone is a trace constituent in the troposphere. It is also produced within the troposphere as a result of photochemical reactions when NO_2 is present.

Substance	Global warming Potential (GWP)	Ozone depleting Potential (ODP)
CFC	8100	1
HCFC	1500	0.055
Halon	6500	10.00

Table 1: GWP and ODP of a few selected manmade chemicals.

UV radiation absorbed by the stratosphere has a direct influence on the chemical composition of the troposphere. Ozone layer depletion allows more high energy solar radiation to reach the earth surface thus warming the lower atmosphere and cooling of the stratosphere. This leads to greater temperature gradient in the vertical direction, which in turn produces enhanced vertical motion and severe weather conditions. Enhanced energy and associated temperature increase of the earth will change the weather and climatic pattern of the globe at an enhanced rate.

Cooling effect of the stratosphere due to loss of ozone leads to the forming of Polar Stratospheric Clouds (PSCs) in polar regions during winter season. These polar stratospheric clouds act as a medium for many chemical reactions. Halogens such as Chlorine and Bromine get dissolved here and are converted to more reactive forms. When spring comes these active halogens cause the ozone destruction process to become faster through a series of reactions. Massive ozone holes in polar regions during spring are made in this way.

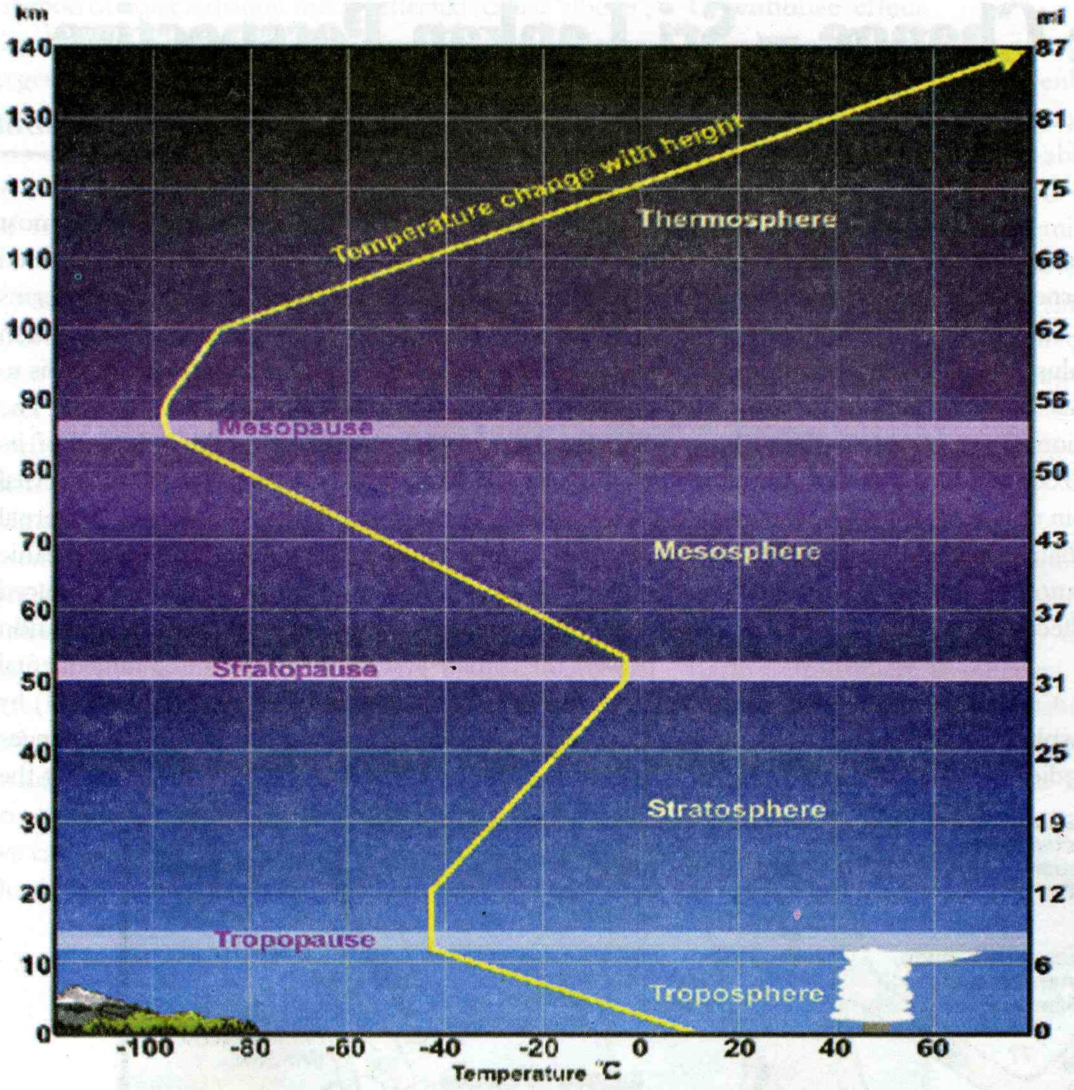

Figure 5: Atmospheric temperature profile. Figure illustrates the temperature variation with height.

Ozone depletion and climate change affects chemical and physical processes of the atmosphere separately as well as through their interactions. Climate change will influence the chemistry, dynamic and radiation process of the whole atmosphere. Changes in atmospheric circulation patterns due to thinning of ozone layer and increased energy at the earth surface bring harmful climatic effects causing health, economic, social and environmental problems to human beings.

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Climate Change – Sri Lankan Perspective

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Introduction
Since the mid – 1990's scientists and governments have been increasingly concerned about the effect of human activities on the Earth's climate system. The burning of fossil fuels, increased industrialization, deforestation and certain land use practices have caused an increase of atmospheric concentration in greenhouse gases such as carbon dioxide, nitrous oxide and methane. If these gases continue to accumulate in the atmosphere at the current rates, many predict a change in the global climate due mainly to the intensification of the Earth's natural heat retaining greenhouse effect.

The climate system is a complex, interactive system consisting of the atmosphere, land surface, snow and ice, oceans and other bodies of water, and living things. The atmospheric component of the climate system most obviously characterizes climate; climate is often defined as 'average weather'. Climate is usually described in terms of the mean and variability of temperature, precipitation and wind over a period of time, ranging from months to millions of years (the classical period is 30 years). The climate system evolves in time under the influence of its own internal dynamics and due to changes in external factors that affect climate (called 'forcings'). External forcings include natural phenomena such as volcanic eruptions and solar variations, as well as human-induced changes in atmospheric composition. Solar radiation powers the climate system. There are three fundamental ways to change the radiation balance of the Earth: 1) by changing the incoming solar radiation (e.g., by changes in Earth's orbit or in the Sun itself); 2) by changing the

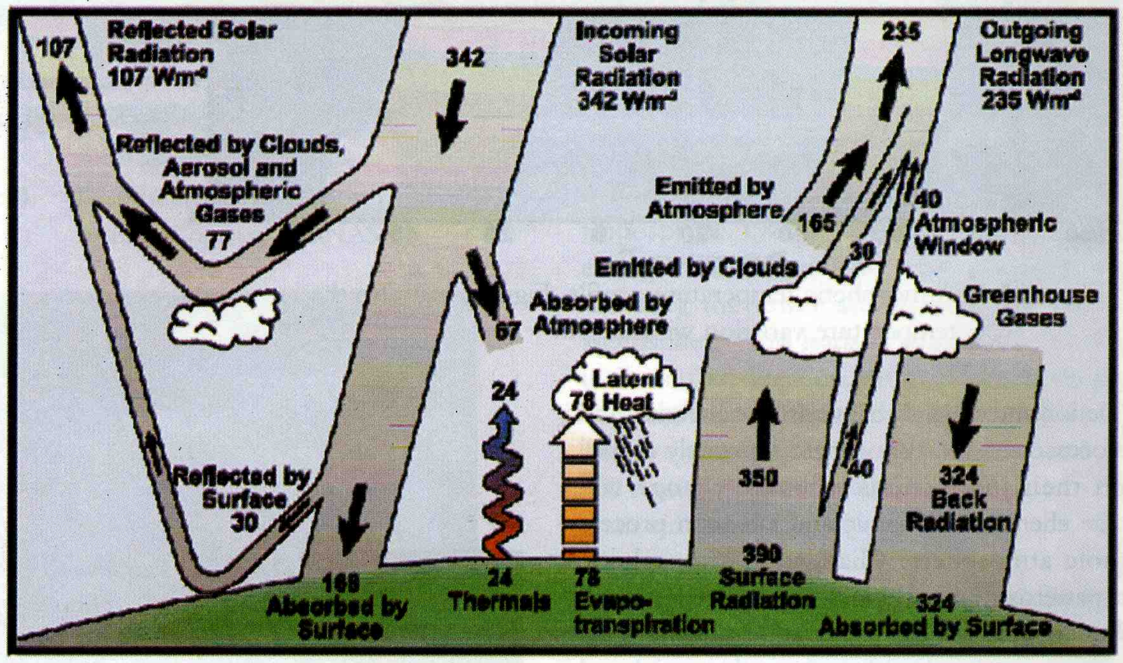


Figure 1: Estimate of the Earth's annual and global mean energy balance. Over the long term, the amount of incoming solar radiation absorbed by the Earth and atmosphere is balanced by Earth and atmosphere releasing the same amount of outgoing longwave radiation. About half of the incoming solar radiation is absorbed by the Earth's surface. This energy is transferred to the atmosphere by warming the air in contact with the surface (thermals), by evapo-transpiration and by longwave radiation that is absorbed by clouds and greenhouse gases. The atmosphere in turn radiates longwave energy back to Earth as well as out to space. Source: Kiehl and Trenberth (1997).

fraction of solar radiation that is reflected (called 'albedo'; e.g., by changes in cloud cover, atmospheric particles or vegetation); and 3) by altering the longwave radiation from Earth back towards space (e.g., by changing greenhouse gas concentrations). Climate, in turn, responds directly to such changes, as well as indirectly, through a variety of feedback mechanisms.

Climate change and weather are intertwined. Observations can show that there have been changes in weather, and it is the statistics of changes in weather over time that identifies climate change. While weather and climate are closely related, there are important differences. A common confusion between weather and climate arises when scientists are asked how they can predict climate 50 years from now when they cannot predict the weather a few weeks from now. The chaotic nature of weather makes it unpredictable beyond a few days. Projecting changes in climate (i.e., long-term average weather) due to changes in atmospheric composition or other factors is a very different and much more manageable issue. As an analogy, while it is impossible to predict the age at which any particular man will die, we can say with high confidence that the average age of death for men in industrialised countries is about 75.

Greenhouse effect

In order to understand the greenhouse effect on earth a good place to start is in a greenhouse. A greenhouse is kept warm because energy coming in from the sun (in the form of visible sunlight) is able to pass easily through the glass of the greenhouse and heat the soil and plants inside. But energy which is emitted from the soil and plants is in the form of invisible infrared radiation; this is not able to pass as easily through the glass of the greenhouse. Some of the infrared heat energy is trapped inside, and this is the main reason why a greenhouse is warmer than outside. However, this is a rather crude analogy to the way the greenhouse effect works on earth.

The Sun powers Earth's climate, radiating energy at very short wavelengths, predominantly in the visible or near-visible (e.g., ul-traviolet) part of the spectrum. Roughly one-third of the solar energy that reaches the top of Earth's atmosphere is reflected directly back to space. The remaining two-thirds is absorbed by the surface and, to a lesser extent, by the atmosphere. To balance the absorbed incoming energy, the Earth must on average, radiate the same amount of energy back to space. Because the Earth is much colder than the Sun, it radiates at much longer wavelengths, primarily in the infrared part of the

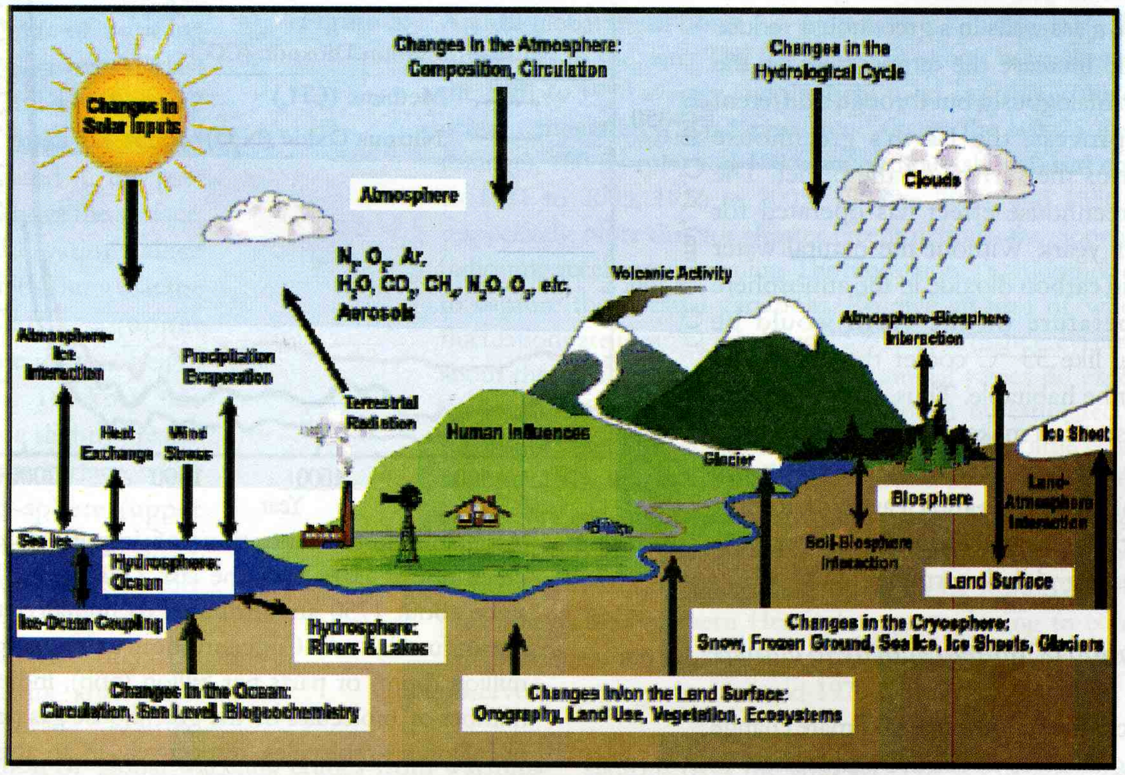


Figure 2: Schematic view of the components of the climate system, their processes and interactions

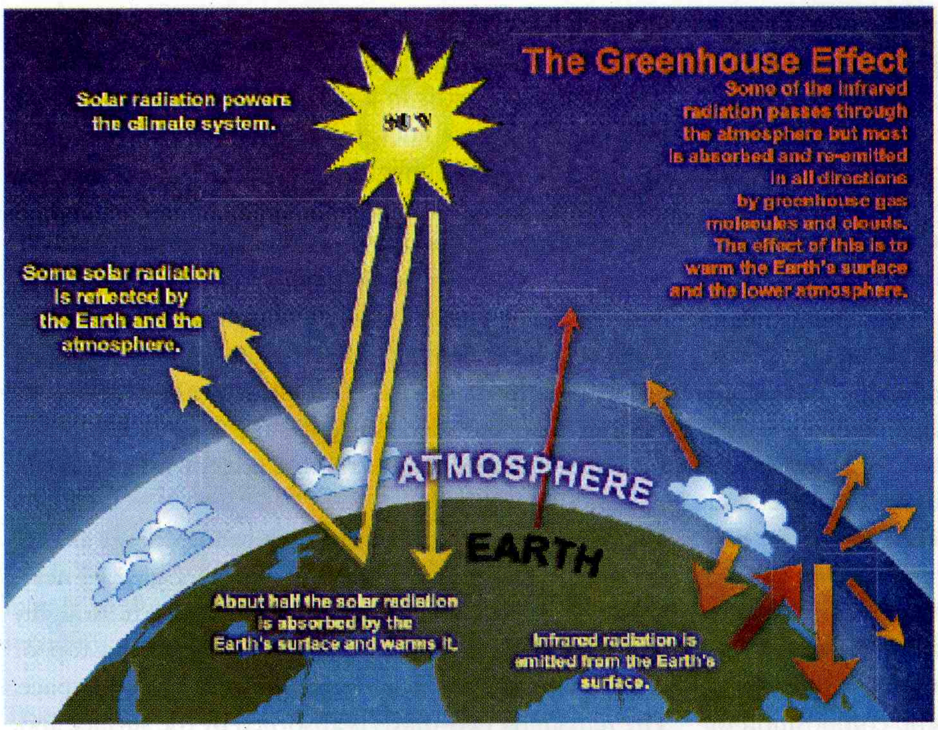


Figure 3: An idealised model of the natural greenhouse effect

spectrum. Much of this thermal radiation emitted by the land and ocean is absorbed by the atmosphere, including clouds, and re-radiated back to Earth. This is called the greenhouse effect. The glass walls in a greenhouse reduce airflow and increase the temperature of the air inside. Analogously, but through a different physical process, the Earth's greenhouse effect warms the surface of the planet. The natural greenhouse effect has operated for billions of years. Without the natural water vapour and carbon dioxide in the atmosphere the temperature of the earth would be something like 33 °C cooler than it is, and would not be habitable. Thus, Earth's natural greenhouse effect makes life in Earth possible. However, human activities, primarily the burning of fossil fuels and clearing of forests, have greatly intensified the natural greenhouse effect, causing global warming.

Contribution of human activity to climate change

Human activities contribute to climate change by causing changes in Earth's atmosphere in the amounts of greenhouse gases, aerosols (small particles). The largest known contribution comes from the burning of fossil fuels, which releases carbon dioxide gas to the atmosphere. Greenhouse gases and aerosols affect climate by altering incoming solar radiation and out-going infrared (thermal) radiation that are part of Earth's energy balance. Changing the atmospheric abundance or properties of these gases and particles can lead to a warming or cooling of the climate system. Since the start of the industrial era, the overall effect of human activities on climate has been a warming influence. The human impact on climate during this era greatly exceeds that due to known changes in natural processes, such as solar changes and volcanic eruptions.

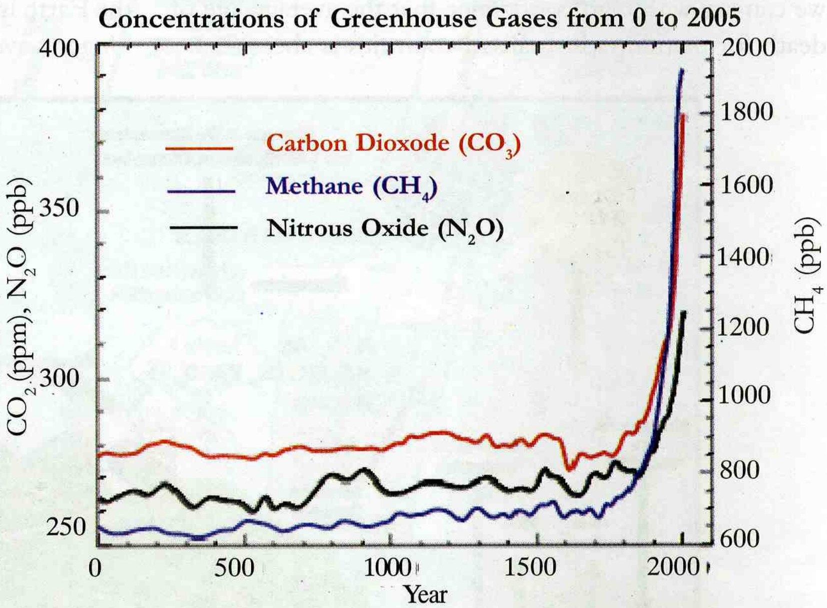


Figure 4: Atmospheric concentrations of important long-lived green-house gases over the last 2,000 years. Increases since about 1750 are attributed to human activities in the industrial era. Concentration units are parts per million (ppm) or parts per billion (ppb), indicating the number of molecules of the greenhouse gas per million or billion air molecules, respectively, in an atmospheric sample.

Human activities result in emissions of four principal greenhouse gases: carbon dioxide (CO_2), Methane (CH_4), Nitrous Oxide (N_2O) and the halocarbons (a group of gases containing fluorine, chlorine and/or bromine). These gases accumulate in the atmosphere, causing concentrations to increase with time. Significant increases in all these gases have occurred in the industrial era. All of these increases are attributable to human activities.

Monitoring the change

Instrumental observations over the past 157 years show that temperature at the surface has risen globally, with important regional variations. For the global average, warming in the last century has occurred in two phases, from the 1910s to the 1940s (0.35°C), and more strongly from the 1970s to the present (0.55°C). An increasing rate of warming has taken place over the last 25 years, and 11 of the 12 warmest years on record have occurred in the past 12 years. Above the surface, global observations since the late 1950s show that the troposphere (upper atmosphere up to a height of about 10 km) has warmed at a slightly greater rate than the surface, while the strato-sphere (upper atmosphere between 10–30 km) has cooled markedly since 1979. This is in accord with physical expectations and most model results. Confirmation of global warming comes from warming of the oceans, rising sea levels, glaciers melting, sea ice retreating in the Arctic and diminished snow cover in the Northern Hemisphere.

There is no single thermometer measuring the global temperature. Instead, individual thermometer measurements taken every day at several thousand stations over the land areas of the world are combined with thousands more measurements of sea surface

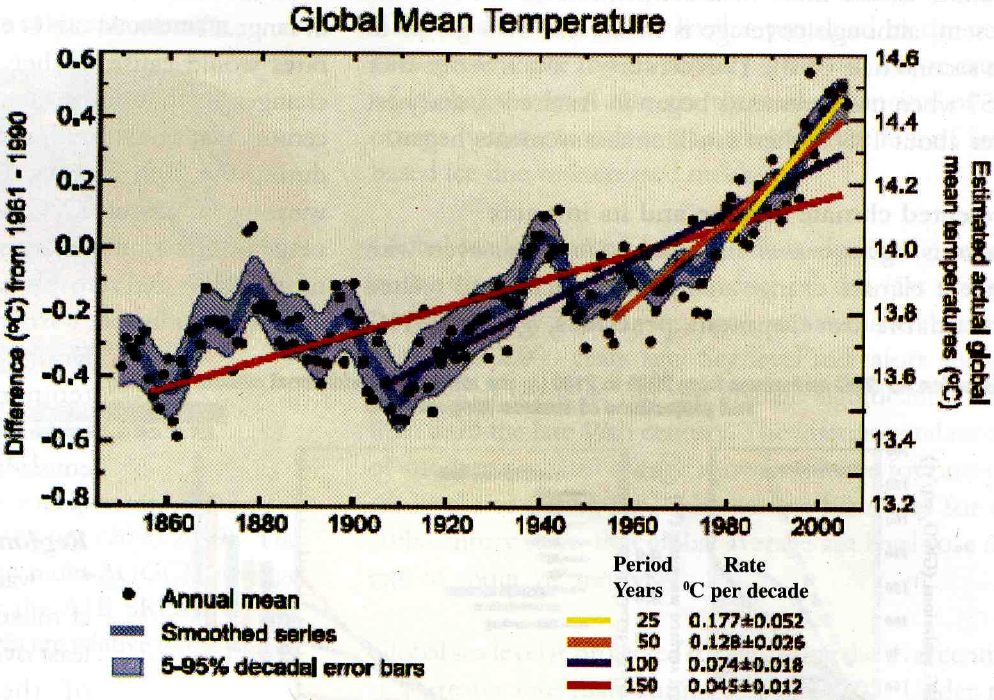


Figure 5: Annual global mean observed temperatures1 (black dots) along with simple fits to the data. The left hand axis shows anomalies relative to the 1961 to 1990 average and the right hand axis shows the estimated actual temperature (°C). Linear trend fits to the last 25 (yellow), 50 (orange), 100 (purple) and 150 years (red) are shown, and correspond to 1981 to 2005, 1956 to 2005, 1906 to 2005, and 1856 to 2005, respectively. Note that for shorter recent periods, the slope is greater, indicating accelerated warming. The blue curve is a smoothed depiction to capture the decadal variations. To give an idea of whether the fluctuations are meaningful, decadal 5% to 95% (light grey) error ranges about that line are given (accordingly, annual values do exceed those limits). Results from climate models driven by estimated radiative forcings for the 20th century suggest that there was little change prior to about 1915, and that a substantial fraction of the early 20th-century change was contributed by naturally occurring influences including solar radiation changes, volcanism and natural variability. From about 1940 to 1970 the increasing industrialisation following World War II increased pollution in the Northern Hemisphere, contributing to cooling, and increases in carbon dioxide and other greenhouse gases dominate the observed warming after the mid-1970s.

temperature taken from ships moving over the oceans, to produce an estimate of global average temperature every month. To obtain consistent changes over time, the main analysis is actually of anomalies (departures from the climatological mean at each site) as these are more robust to changes in data availability. It is now possible to use these measurements from 1850 to the present, although coverage is much less than global in the second half of the 19th century, is much better after 1957 when measurements began in Antarctica, and best after about 1980, when satellite measurements began.

Projected climate change and its impacts

There is *high agreement* and *much evidence* that even with current climate change mitigation policies and related sustainable development practices, global GHG emissions will continue to grow over the next few decades. The IPCC Special Report on Emission Scenarios (SRES, 2000) projects an increase of global GHG emissions by 25-90% (CO2-eq) between 2000 and 2030, with fossil fuels maintaining their dominant position in the global energy mix to 2030 and beyond. More recent scenarios without additional emissions mitigation are comparable in range. Continued GHG emissions at or above current rates would cause further warming and induce many changes in the global climate system during the 21st century that would *very likely* be larger than those observed during the 20th century. For the next two decades a warming of about 0.2°C per decade is projected for a range of emission scenarios. Even if the concentrations of all GHGs and aerosols had been kept constant at year 2000 levels, a further warming of about 0.1°C per decade would be expected. Afterwards temperature projections will increasingly depend on specific emission scenarios.

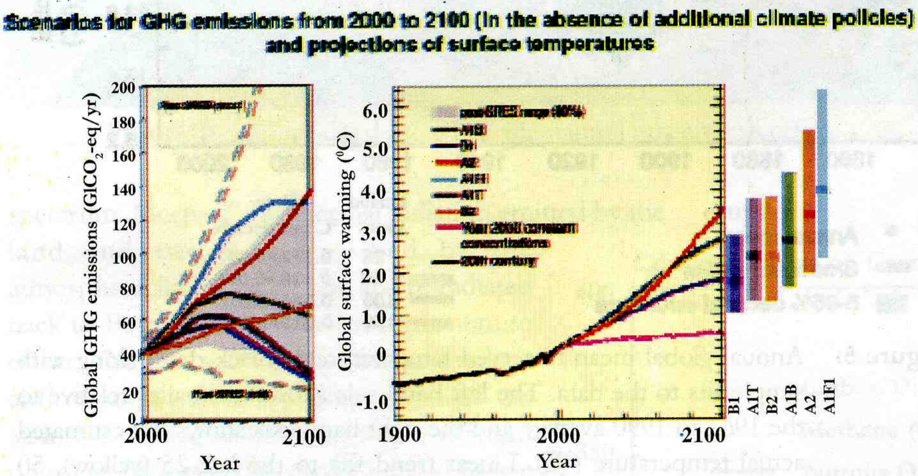


Figure 6: Left Panel: Global GHG emissions (in CO2-eq) in the absence of climate policies: six illustrative SRES marker scenarios (coloured lines) and the 80th percentile range of recent scenarios published since SRES (post-SRES) (gray shaded area). Dashed lines show the full range of post-SRES scenarios. The emissions cover CO2, CH4, N2O, and F-gases. Right Panel: Solid lines are multi-model global averages of surface warming for scenarios A2, A1B and B1, shown as continuations of the 20th-century simulations. These projections also take into account emissions of short-lived GHGs and aerosols. The pink line is not a scenario, but is for Atmosphere-Ocean General Circulation Model (AOGCM) simulations where atmospheric concentrations are held constant at year 2000 values. The bars at the right of the figure indicate the best estimate (solid line within each bar) and the likely range assessed for the six SRES marker scenarios at 2090-2099. All temperatures are relative to the period 1980-1999.

Regional-scale changes

- warming greatest over land and at most high northern latitudes and least over Southern Ocean and parts of the North Atlantic Ocean, continuing recent observed trends
- contraction of snow cover area increases in thaw depth over most permafrost regions, and decrease in sea ice extent; in some projections using SRES scenarios, Arctic late-summer sea ice disappears almost entirely by the latter part of the 21st century
- *very likely* increase in frequency of hot extremes, heat waves, and heavy precipitation
- *likely* increase in tropical cyclone intensity; less confidence in global decrease of tropical cyclone numbers
- poleward shift of extra-tropical storm tracks with consequent changes in wind, precipitation, and temperature patterns
- *very likely* precipitation increases in high latitudes and *likely* decreases

in most subtropical land regions, continuing observed recent trends.

There is *high confidence* that by mid-century, annual river runoff and water availability are projected to increase at high latitudes (and in some tropical wet areas) and

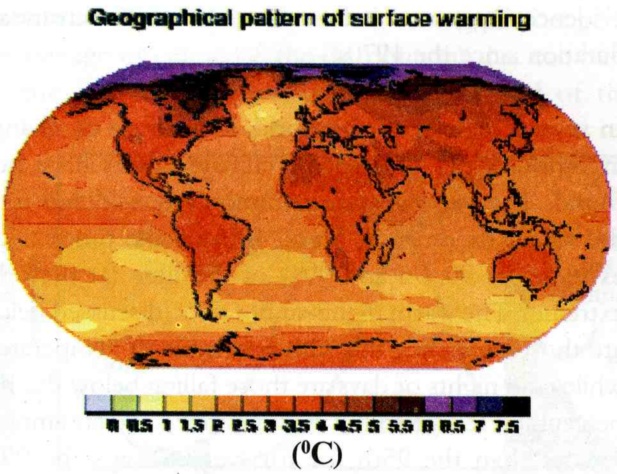


Figure 7: Projected surface temperature changes for the late 21st century (2090-2099). The map shows the multi-AOGCM average projection for the A1B SRES scenario. All temperatures are relative to the period 1980-1999.

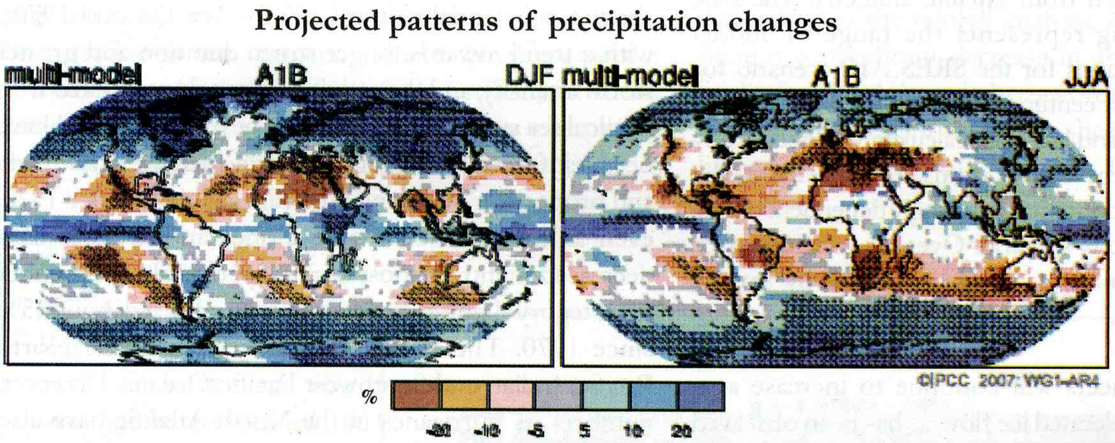


Figure 8: Relative changes in precipitation (in percent) for the period 2090–2099, relative to 1980–1999. Values are multi-model averages based on the SRES A1B scenario for December to February (left) and June to August (right). White areas are where less than 66% of the models agree in the sign of the change and stippled areas are where more than 90% of the models agree in the sign of the change.

decrease in some dry regions in the mid-latitudes and tropics. There is also *high confidence* that many semi-arid areas (e.g. Mediterranean basin, western United States, southern Africa and northeast Brazil) will suffer a decrease in water resources due to climate change.

Impact on sea level

There is strong evidence that global sea level gradually rose in the 20th century and is currently rising at an increased rate, after a period of little change between AD 0 and AD 1900. Sea level is projected to rise at an even greater rate in this century. The two major causes of global sea level rise are thermal expansion of the oceans (water expands as it warms) and the loss of land-based ice due to increased melting.

Global sea level rose by about 120 m during the several millennia that followed the end of the last ice age (approximately 21,000 years ago), and stabilised between 3,000 and 2,000 years ago. Sea level indicators suggest that global sea level did not change significantly from then until the late 19th century. The instrumental record of modern sea level change shows evidence for onset of sea level rise during the 19th century. Estimates for the 20th century show that global average sea level rose at a rate of about 1.7 mm yr–1.

Global sea level is projected to rise during the 21st century at a greater rate than during 1961 to 2003. Under the IPCC Special Report on Emission Scenarios (SRES) A1B scenario by the mid-2090s, for instance, global sea level reaches 0.22 to 0.44 m above 1990 levels, and is rising at about 4 mm yr–1. As in the past, sea level change in the future will not be geographically uniform, with regional sea level change varying within about ±0.15 m of the mean in a typical model projection. Thermal expansion is projected to contribute more than half of the average rise, but land ice will lose mass increasingly rapidly as the century progresses. An important uncertainty relates to whether discharge of ice from the ice sheets will continue to increase as a consequence of accelerated ice flow, as has been observed in recent years. This would add to the amount of sea level rise, but quantitative projections of how much it would add cannot be made with confidence, owing to limited understanding of the relevant processes.

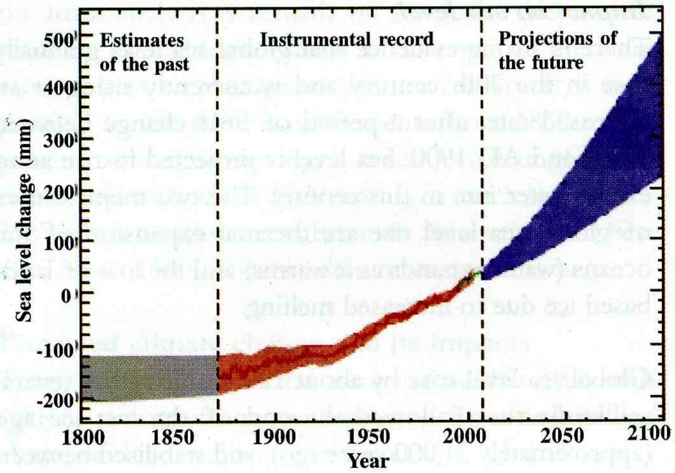


Figure 9: Time series of global mean sea level (deviation from the 1980-1999 mean) in the past and as projected for the future. For the period before 1870, global measurements of sea level are not available. The grey shading shows the uncertainty in the estimated long-term rate of sea level change. The red line is a reconstruction of global mean sea level from tide gauges, and the red shading denotes the range of variations from a smooth curve. The green line shows global mean sea level observed from satellite altimetry. The blue shading represents the range of model projections for the SRES A1B scenario for the 21st century, relative to the 1980 to 1999 mean, and has been calculated independently from the observations. Beyond 2100, the projections are increasingly dependent on the emissions scenario. Over many centuries or millennia, sea level could rise by several metres.

Impact on extreme weather events like heat waves, drought, floods and tropical cyclones

Since 1950, the number of heat waves has increased and wide-spread increases have occurred in the numbers of warm nights. The extent of regions affected by droughts has also increased as precipitation over land has marginally decreased while evapora-tion has increased due to warmer conditions. Generally, numbers of heavy daily precipitation events that lead to flooding have in-creased, but not everywhere. Tropical storm and hurricane frequencies vary considerably from year to year, but evidence suggests substantial increases in intensity and duration since the 1970s.

In several regions of the world, indications of changes in various types of extreme climate events have been found. The extremes are commonly considered to be the values exceeded 1, 5 and 10% of the time (at one extreme) or 90, 95 and 99% of the time (at the other extreme). The warm nights or hot days (discussed below) are those exceeding the 90th percentile of temperature, while cold nights or days are those falling below the 10th percentile. Heavy precipitation is defined as daily amounts greater than the 95th (or for 'very heavy', the 99th) percentile.

Changes in tropical storm and hurricane frequency and intensity are masked by large natural variability. The El Niño-Southern Oscillation greatly affects the location and activity of tropical storms around the world. Globally, estimates of the potential destructiveness of hurricanes show a substantial upward trend since the mid-1970s, with a trend towards longer storm duration and greater storm intensity, and the activity is strongly correlated with tropical sea surface temperature. These relationships have been reinforced by findings of a large increase in numbers and proportion of strong hurricanes globally since 1970, even as total numbers of cyclones and cyclone days decreased slightly in most basins. Specifically, the number of category 4 and 5 hurricanes increased by about 75% since 1970. The largest increases were in the North Pacific, Indian and Southwest Pacific Oceans. However, numbers of hurricanes in the North Atlantic have also been above normal in 9 of the last 11 years, culminating in the record-breaking 2005 season.

However, simple statistical reasoning indicates that substantial changes in the frequency of extreme events (and in the maximum feasible extreme, e.g., the maximum possible 24-hour rainfall at a specific location), can result from a relatively small shift of the distribution of a weather or climate variable.

Extremes are the infrequent events at the high and low end of the range of values of a particular variable. The probability of occurrence of values in this range is called a probability distribution function (PDF), that for some variables is shaped similarly to a 'Normal' or 'Gaussian' curve (the familiar 'bell' curve). Figure 10 shows a schematic diagram of a such a PDF, and illustrates the effect a small shift (corresponding to a small change in the average or centre of the distribution) that can have on the frequency of extremes at either end of the distribution. An increase in the frequency of one extreme (e.g., the number of hot days) will often be accompanied by a decline in the opposite extreme (in this case the number of cold days such as frosts). Changes in the variability or shape of the distribution can complicate this simple picture.

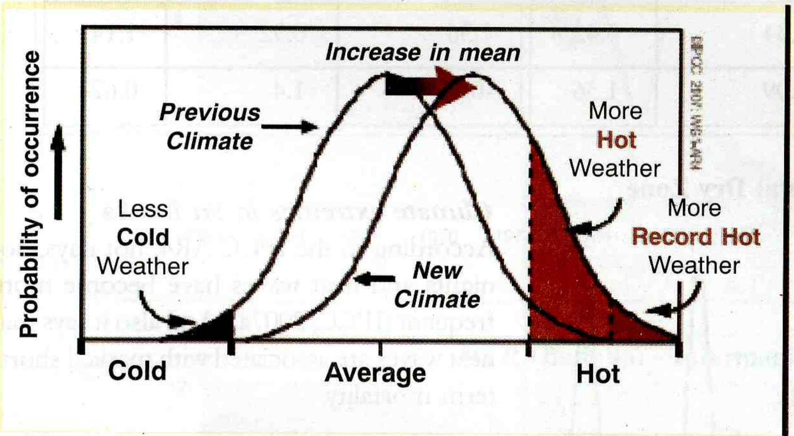


Figure 10: Schematic showing the effect on extreme temperatures when the mean temperature increases, for a normal temperature distribution.

Projected impacts on Asia

- By the 2050s, freshwater availability in Central, South, East and South-East Asia, particularly in large river basins, is projected to decrease
- Coastal areas, especially heavily-populated megadelta regions in South, East and South-East Asia, will be at greatest risk due to increased flooding from the sea and, in some megadeltas, flooding from the rivers
- Climate change is projected to compound the pressures on natural resources and the environment associated with rapid urbanization, industrialization and economic development
- Endemic morbidity and mortality due to diarrhoeal disease primarily associated with floods and droughts are expected to rise in East, South and South-East Asia due to projected changes in the hydrological cycle

Climate change: Sri Lanka perspective

Observed change in climate in Sri Lanka

In recent studies it has been shown that the surface air temperature over Sri Lanka has been rising and there is an increasing trend in both the minimum and maximum temperatures. Almost all the stations show significant increase of Maximum temperature except the station at Nuwara Eliya (elevation 1894 m). However, the increasing trend of minimum temperature at this station is the highest and the rate is 0.02^{0}C per year, very much higher than the global trend. Temperature in Sri Lanka is increasing at a higher rate during the recent past. Comparison of the increasing trend during the periods of 1961-2000 and 1900-2000 are shown in table 1.

According to the rainfall analysis, it can be shown that there is a significant decrease in annual total rainfall in Sri Lanka (Fig 11), and also according to the analysis of rainfall variability, it has been shown that variability is higher during the 1961-1990 than 1931-1960.

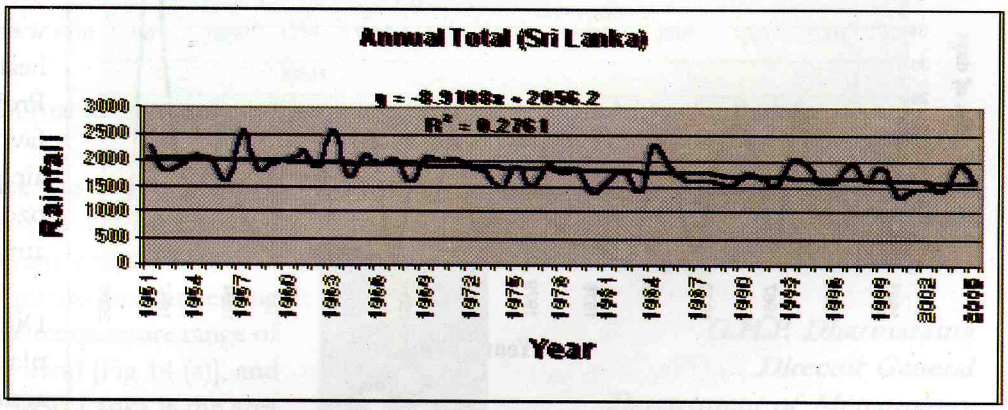


Fig 11: Decreasing annual total rainfall in Sri Lanka (1951-2005)

Table 1: Increasing trend of temperatures in different stations of 1900-2000 and 1961-2000

Station	1900-2000 Minimum	Maximum	Mean	1961-2000 Minimum	Maximum	Mean
Nuwara Eliya	2.00	-0.04	0.98	1.8	-1.12	0.34
Anuradhapura	1.35	0.73	1.04	1.64	2.53	2.09
Ratnapura	0.69	0.31	0.5	1.6	0.28	0.94
Kurunegala	1.26	1	1.13	0.4	1.48	0.94
Colombo	0.5	0.34	0.42	1.36	0.92	1.14
Puttalam	0.63	2.09	1.36	-0.16	1.4	0.62

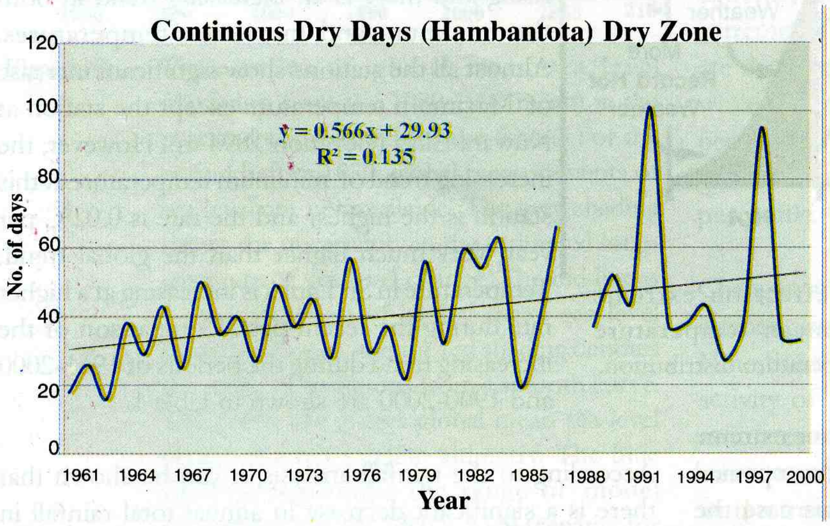


Figure 12: Continuous dry days at Hambantota from 1961-2000

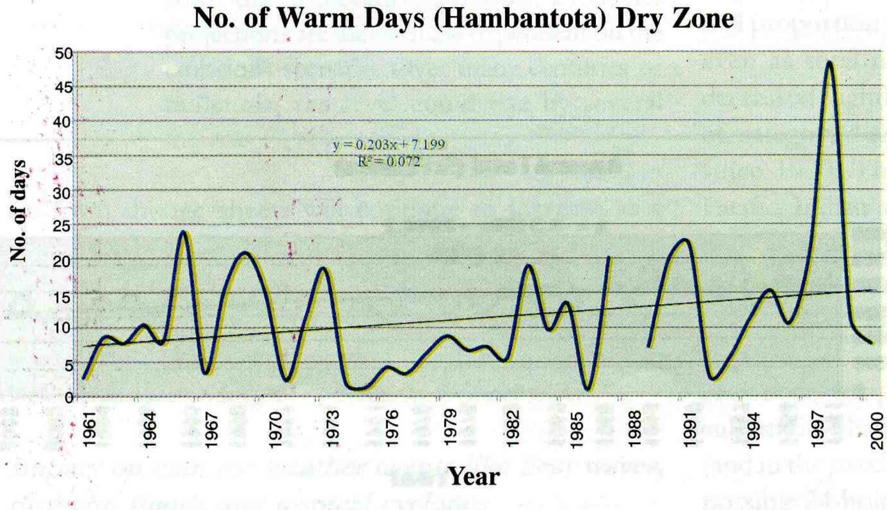


Figure13: Number of warm days in Hambantota

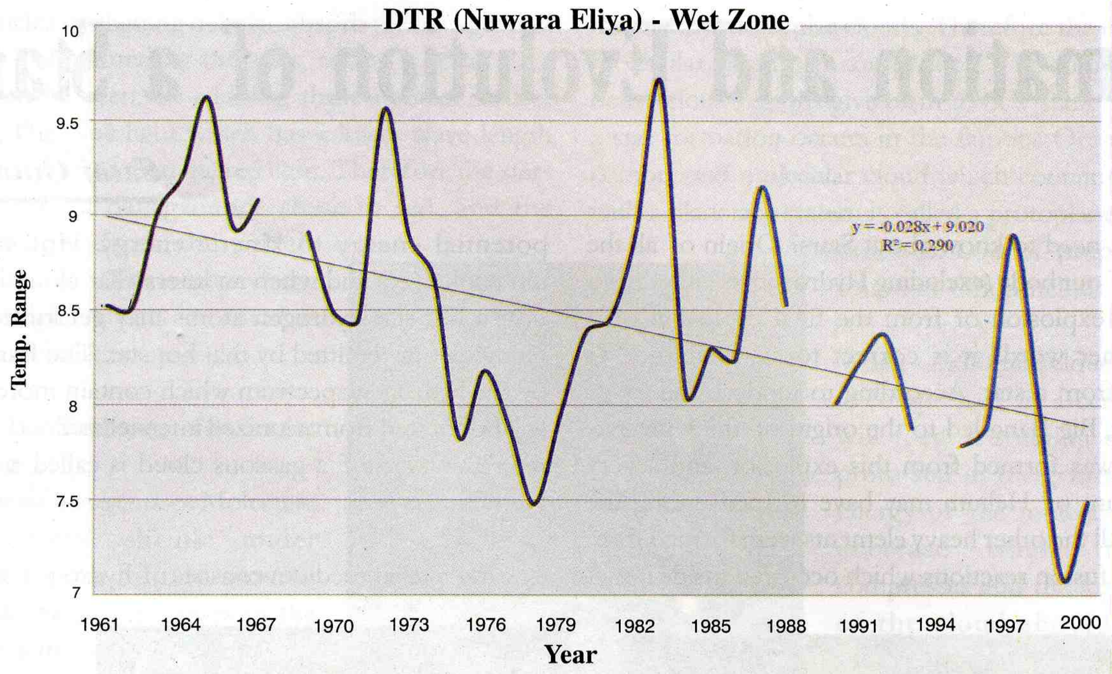
Climate extremes in Sri Lanka

According to the IPCC AR4, hot days, hot nights and heat waves have become more frequent (IPCC, 2007a). And also it says that heat waves are associated with marked short-term mortality.

According to a recent analysis, an increasing trend of continuous dry days has been observed (Fig 12) in all the meteorological stations in Sri Lanka. The trend is high in the Dry zone (Annual Rainfall <1750mm). It implies that the dry zone is more vulnerable for drought hazards in Sri Lanka. Higher percentage of local rice production is grown in the dry zone.

Number of warm days and warm nights (Fig 13) also show an increasing trend. This may affect water resources, agriculture and health sectors in Sri Lanka negatively. Prolonged warm days are very much favorable for vector borne diseases, air pollutants and also increase of ozone concentration of the lower atmosphere.

Diurnal Temperature Range (DTR) plays an important role for agriculture. In several rice and maize growing regions, including the two



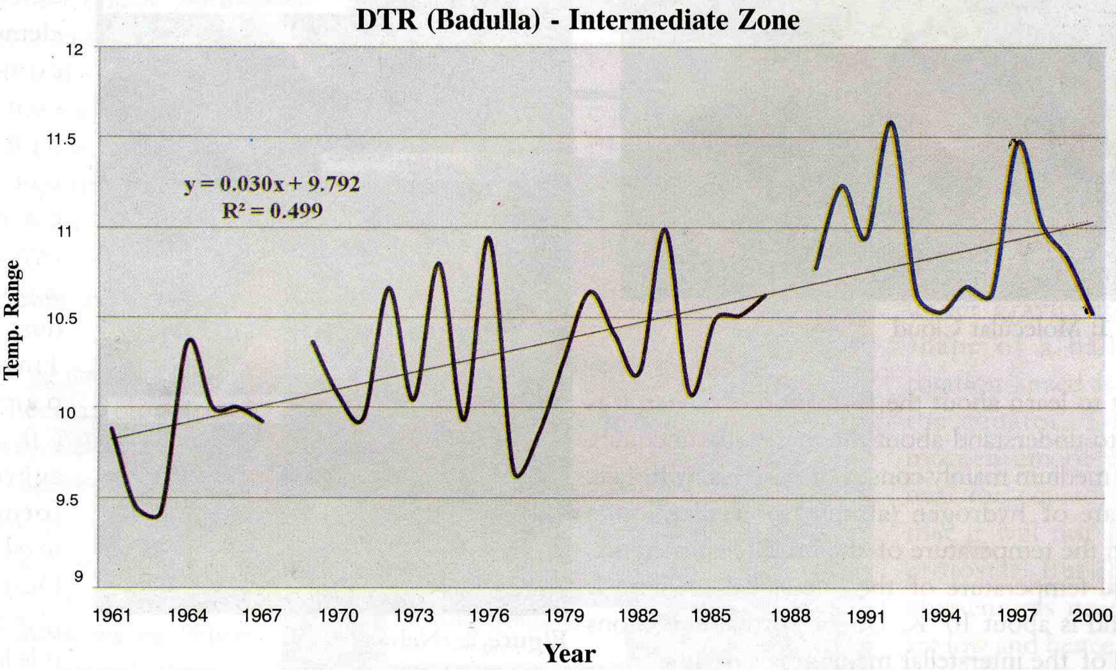


Figure 14: Diurnal temperature at different stations (a) Nuwara Eliya (b) Badulla

major nations for each crop, there was a clear negative response of yields to increased DTR. Diurnal temperature range affect to potato crop. There is a positive trend for the growth of potato with increasing diurnal temperature range. Diurnal temperature range of Nuwara Eliya shows a decreasing trend [Fig 14 (a)], and the main potato cultivation area in Sri Lanka is the area around Nuwara Eliya. According to the data analyses, DTR of other stations show increasing trends [Fig 14 (b)].

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Formation and Evolution of a Star

Saraj Gunasekera

Why do we need to know about Stars? Origin of all the elements of our body (excluding Hydrogen) is either from an internal explosion or from the final explosion of a star. In other words it is correct to say that the life originated from a star. According to modern theory of Astronomy, Big Bang led to the origin of the Universe. Hydrogen was formed from this explosion and a very small amount of Helium may have formed during the Big Bang. All the other heavy elements were formed from the nuclear fusion reactions which occurred inside a star.

Figure 1: Molecular Cloud

If we want to learn about the formation of a star, it is important to understand about the interstellar medium. Interstellar medium mainly consist of gaseous hydrogen, and the state of hydrogen (atomic/molecular/ionic) depends on the temperature of the interstellar medium. The normal temperature of the interstellar medium is very low and is about 10 ^{0}K. Under normal conditions the density of the interstellar medium is very low.

To identify hydrogen gasses, radio waves with a wave length of 21cm can be used, which is emited during the transitions between the energy states. These radio waves can be observed through a radio telescope.

In some instances the temperature of an interstellar medium is high enough to ionize hydrogen atoms in it. When an interstellar medium shrinks under gravitational forces, temperature may rise due to the conversion of potential energy to kinetic energy. Hot stars emit ultraviolet rays and when an interstellar cloud is situated near a hot star hydrogen atoms may get ionized by the ultraviolet ray emitted by that hot star. The Bamer series of the hydrogen spectrum which contain more red light will be emitted from a ionized interstellar cloud and shine red. This kind of a gaseous cloud is called a Emission Nebula.

The interstellar medium consists of hydrogen; gases such as ammonia, methane, carbon dioxide; other elements; and compounds containing hydrogen, nitrogen, carbon, oxygen, silicon and sulfur and dust particles. Tiny dust particles (0.5 *ìm*) aggregate to form big molecules. Dust particles play a catalytic role in forming big molecules, also play a role in protecting the big molecules from been destroyed by UV rays.

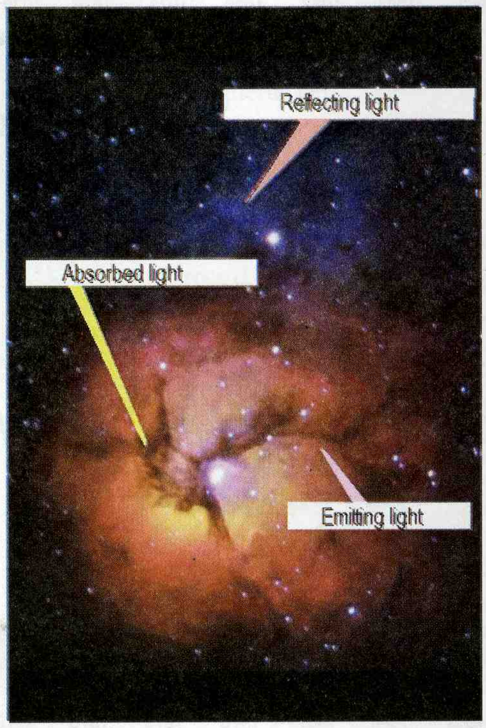

Figure 2: Nebula

Gravitational and electrostatic forces among the small molecules are not large enough to attract each other. However, such forces in between complex and big molecules are strong enough to shrink the molecular cloud. The release of enormous heat and the pressure developed during this shrinking process initiate the nuclear fusion to form new stars.

Dust particles containing nebulae absorb the background light which is emitted by the stars, and as a result dark regions can be seen. In addition these nebulae scatter the light. The blue light which has a lower wave length gets more scattered than the red light. Therefore the stars in those nebula backgrounds shine in red, and the reflected light from the nebula appears in blue. The region from which the light reflects is named as reflection nebulae.

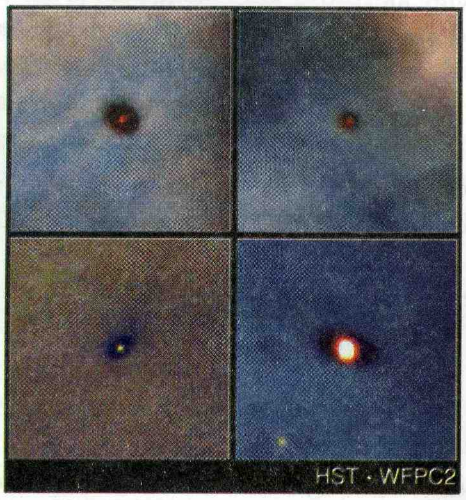

Figure 3: Protoplanetary disks

Essential factors for star formation

Low and medium weight stars: Molecular cloud should shrink under gravitational force to form stars. In this case pressure of gasses in the cloud act as the opposing forces and if the mass of the cloud can withstand these opposing forces the clouds starts to shrink. In addition, the centrifugal force and the magnetic force (due to the motion of charged particles) too act as opposing forces. The stars formed only with gravitation forces like our sun, are of medium weight.

Heavy weight big stars: High dense heavy molecular clouds can create heavy weight big stars. There are several ways for formation of high dense clouds. Big explosions (like Super nova) in the universe generates shock waves. When this shock wave travels through a galaxy, it creates a dense cloud. When molecular clouds colloid with each other they get disturbed. Even when a nearby star emits hot hydrogen during an explosion it can increase the density of a molecular cloud.

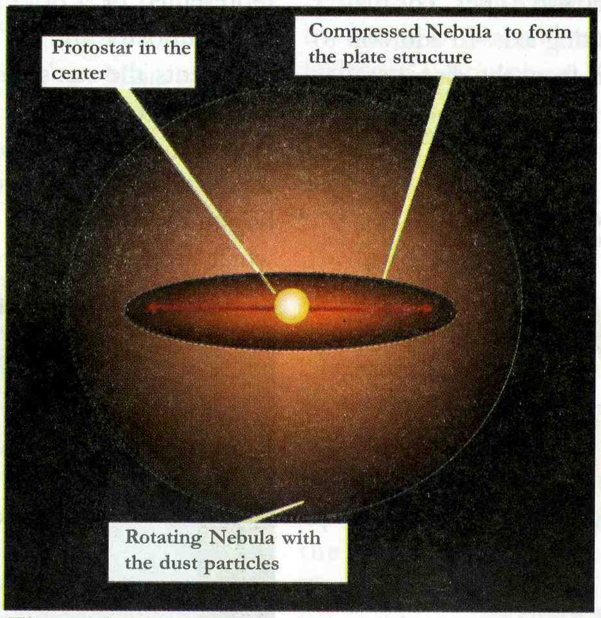

Figure 4: Compressing Nebula

Stellar wind (contains mainly ionized hydrogen and other elements, wind speed is around hundreds of kilometers per second) from the newly formed star tends to push the nearby molecular clouds. Therefore the edges of the molecular clouds get compressed. The compressed high dense cloud regions give birth to new stars. This type of a star formation occurs in the famous Orion nebula. A compressed molecular cloud which contains a new star with a planetary system is called a protoplanetary disk or proplyds. Lots of proplyds can be found in Orion nebula.

When a molecular cloud or a nebula is compressed to a certain level it will form a rotating disk with a proto star in the center. Potential energy of the molecular star will decrease when the cloud compresses and the kinetic energy of the cloud should increase according to the law of energy conservation. This happens by the increase of the angular momentum of the cloud/nebula, and the direction of rotation will remain the same as that of the cloud as when it was rotating previously.

When a nebula is compressed under gravity it takes the shape of a ball, and the rotation speed is high near the equator. The angular momentum of the nebula near the equator is so high that it will not fall on the protostar. But the angular momentums near the poles are low and hence the matter in this area will fall on the protostar, and accordingly the middle of the nebula will get the shape of a round plate. The nebula which gets compressed under these conditions will have high temperature and pressure. These conditions can lead to nuclear reactions at any moment. Then we can say that a Young Stellar Object has formed.

The nuclear reaction is as follows.

$6\,^1H^+ \rightarrow \,^4He^{++} + 2e^+ + 2\nu + 2\gamma + 2\,^1H^+$

$4\,^1H^+ \rightarrow \,^4He^{++} + 2e^+ + 2\nu + 2\gamma \longrightarrow$ (A)

(A) Weight of reactants(left side of the reaction)
$= 6.693X10^{-27}Kg$

(A) Weight of products (right side of the reaction)
$= 6.645X10^{-27}Kg$

Weight difference of the reaction
$= 6.645X10^{-27} - 6.693X10^{-27} = 0.048X10^{-27}$ Kg

According to $E = mc^2$

Energy corresponding to the weight difference

$E = 0.048X10^{-27}$ Kg X 3 X 10^8 ms^{-1}

$E = 0.43X10^{-11}$ Js^{-1}

When the nuclear reactions begin we cannot see the star because the temperature of surrounding dust and air is not hot enough to emit visible light. But these can be seen under the electro-magnetic range, and hence visible through a radio telescope.

Star driven wind and star jet:

A large magnetic field is created due to the motion of the charged particles in the star. This field is strong near the poles of the star. Ionized hydrogen gushes out from the star as a jet along the magnetic force lines. The matter in the core drives along the rotating axis. In addition to gasses, dust and rays are emitted from the disc.

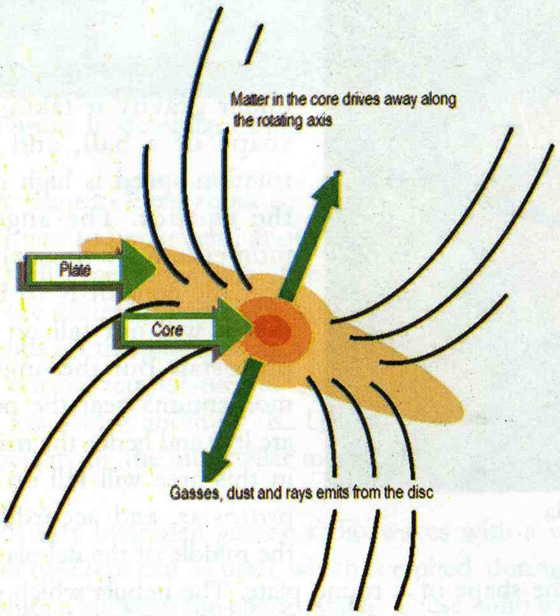

Figure 5: Star driven wind and star jet

Spectroscopy series , luminosity and the size of a star

According to the spectrum of the star, astronomers have categorized the stars. Initially they categorized the stars according to the hydrogen absorption spectrum. They name them as A,B,C,D,E,F,G,H,I,J,K,L,M,N,O, and P according to the strength of the spectrum lines. Later this was modified considering the relative strengths of all spectrum lines, and the stars were categorized as O,B,A,F,G,K,M. Further for fine categorizing, sub groups were included by introducing 1-9 for each group. Warmest stars were categorized as O. The warmest stars are blue in colour while cold stars are red in colour. Luminosity (total amount of emitted light) was also used to categorized the stars using the magnitude scale. This can be expressed as follows:

$$m_1 - m_2 = -2.5\log\left(\frac{f_1}{f_2}\right) \quad \text{where m= magnitude}$$

Magnitude of the star named Vega is considered to be zero. According to this scale brighter stars have a lower magnitude while less bright stars have a higher magnitude.

Hertzsprung-Russell diagram

In the Hertzsprung-Russell (HR) Diagram, each star is represented by a dot. The position of each dot shows its luminosity and its temperature. The vertical axis represents the star's luminosity which is technically the amount of energy a star radiates in one second. **Luminosity** is a common term, as is **absolute magnitude**. Absolute magnitude is the intrinsic brightness of a star. In either case, it is a "ratio scale" in which stars are compared against a reference (our sun).

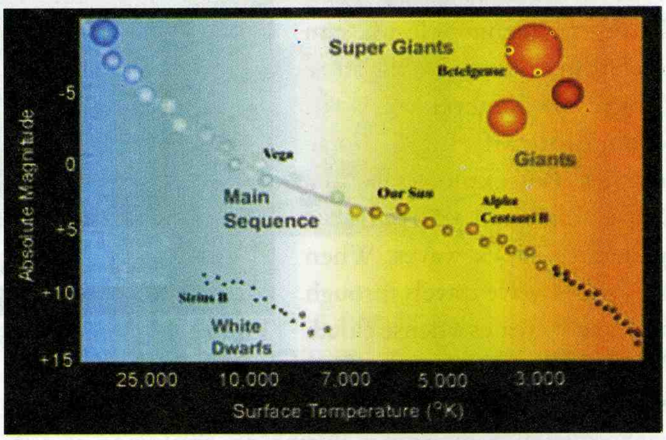

Figure 6: Hertzsprung-Russell diagram

The horizontal axis represents the star's surface temperature not the star's core temperature. Usually this is labeled using the Kelvin temperature scale. *But notice*: In most graphs and diagrams, zero (or the smaller numbers) exists to the left on the diagram. *This is not the case here.* In this diagram the higher (hotter) temperatures are on the left and the lower (cooler) temperatures are on the right. Some HR diagrams include the color of stars which is also a "ratio scale."

So how can one read the HR diagram? A star in the upper left corner of the diagram would be hot and bright while a star in the upper right would be cool and bright. The Sun rests approximately in the middle of the diagram, and can be used for comparison. A star in the lower left corner would be hot and dim, while a star in the lower right corner would be cold and dim.

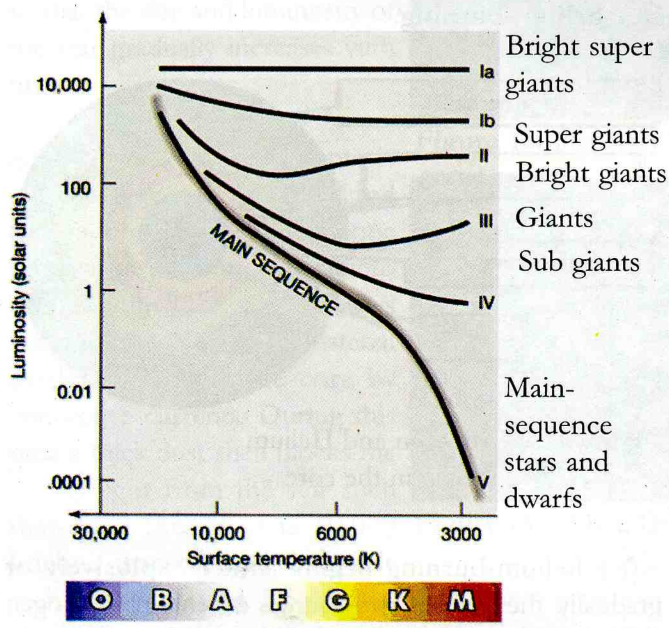

Figure 7: Luminosity Series

Deviations from H-R diagram main sequence line: Protostars which are 0.08 times less in mass than our sun will never start a nuclear reaction. It is not hot enough and dense enough for fusion. These objects are called brown dwarf stars which are not real stars that can reach the main sequence line of the H-R diagram.

Temperature of the core of the stars with higher mass than the sun (100 times) have very high temperatures, and the radian pressure that originates from the nuclear reactions are very high. This leads to instability of the star releasing hot gasses and dust with an explosion. Eta Carian is an example of a star with heavy mass that cannot reach the main sequence line of the H-R diagram.

Time taken to reach the main sequence line of the H-R diagram;
A young protostar becomes hot enough (2,000 to 3,000 K) to glow red, but is obscured by a thick cocoon of gas and dust that allows only infrared and microwaves to pass through. At some point, the central temperature of the protostar climbs high enough for deuterium, to undergo fusion, which temporarily halts the object's gravitational contraction. When deuterium is used up, the embryonic star continues its gravitational infall as a pre-main-sequence object, until its core temperature reaches the point at which normal hydrogen burning can take place, and the star joins the main sequence.

Mass	Time(Years)
0.5 M_Q	$100X10^6$
1.0 M_Q	$30X10^6$
2 M_Q	$8X10^6$
5 M_Q	$0.7X10^6$
15 M_Q	$0.16X10^6$

A star arrives on the main sequence after it starts hydrogen burning in its core and remains there throughout its core-hydrogen-fusion phase. A star's position and length of stay on the main sequence depends critically on mass. Length of stay on the main sequence $\propto 1/$ (mass of the star)^3

The most massive stars – the hot, blue-white,O stars and B stars – stand at the upper left and have main-sequence lifetimes of only a few million, or tens of millions years. The least massive hydrogen-burning stars, the red dwarfs, sit to the lower right and may remain on the main sequence for hundreds of billions of years. When a star remains on the main sequence, it stays in a hydrostatic equilibrium. That is the gravitational force towards and the outward radiation pressure is in equilibrium. Therefore the star remains unchanged. Here it remains in a stable condition for about 90% of its lifetime.

Mass (relative to the Sun's mass)	**Spectral Class**	**Length of stay on the main sequence (years)**
0.4	M	$200,000 X10^6$
1	G2	$10,000 X10^6$
3,3	A	$500 X10^6$
40	05	$1 X10^6$

Nuclear reactions in the core of a star:
Nuclear fusion reactions depend on the temperature of the core.

Nuclear reaction		Temperature
I.	Proton-Proton chain	8 X10^6 °K
II.	Carbon-Nitrogen Oxygen Chain	20X10^6 °K
III.	Triple-alpha process	100X10^6 °K
IV.	Carbon burning	600X10^6 °K

When the star exhausts its central hydrogen supply, the core deprived of outward radiation pressure, begins to shrink; meanwhile fusion starts in a shell around the core. This phase is relatively rapid and sees the star's outer layers swell and cool through the sub-giant stage to yield a red giant, or in the case of a very massive star, a red super-giant.

A star's subsequent career continues to hinge on its mass. For stars heavier than one solar mass, the hydrogen-burning shell eats its way outward leaving more and more helium behind. As the helium piles up the core becomes massive, and so it contracts becoming denser and hotter. Eventually, the core becomes so dense that the electrons inside it enter the state of an electron degenerate gas – a condition in which they resist further contraction or expansion(A form of degenerate matter in which the weight of overlying material tries to force all of the electrons surrounding the atomic nucleus into the lowest energy quantum state. The electrons resist because of the Paul Exclusion Principle, and so exert a pressure known as degenerate electron pressure or *electron degeneracy pressure*, that halts further collapse.).

Helium flash
The helium flash happens in the hydrogen-exhausted core of a star that has become a red giant. When gravitational pressure has raised the temperature of the dormant helium core to a temperature of about 100 million K, the helium nuclei undergo thermonuclear reactions. Once the helium burning has started, the temperature climbs rapidly and the extreme sensitivity of the nuclear reaction rate to temperature causes the helium-burning process to accelerate. This in turn raises the temperature, which further accelerates the helium burning, until a point is reached at which the thermal pressure expands the core and thereby limits the flash. The helium flash can only occur when the helium core is less than the 1.4-solar-mass Chandrasekhar limit, and thus it is restricted to fairly low-mass stars.

Helium flash lasts only a few minutes, and the star generates energy at 100 times the rate of the rest of the Galaxy put together. However, this huge surge of energy never reaches the surface, but instead goes into removing the degeneracy of the electrons and expanding the core. For stars more than 2 solar masses, the triple-alpha process starts before the electrons become degenerate, and so there is no helium flash – just a gradual shift to a core-**helium-burning**.

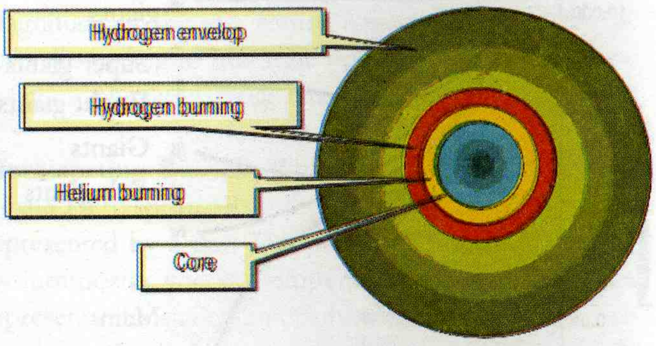

Figure 11: Hydrogen and Helium burning in the core

After helium-burning begins either explosively or gradually, the star has two sources of energy: hydrogen fusion in a shell around the core and helium fusion in the core itself. Helium fuses to give carbon, and some of this carbon combines with helium to yield oxygen. At the same time as the core of the star becomes rich in carbon and oxygen nuclei, the surface temperature climbs until the star reaches a part of the HR diagram known as the horizontal branch. Stars with masses greater than or equal to one solar mass, become smaller and hotter at a constant luminosity. They evolve to the horizontal branch by moving across the HR diagram at constant brightness – low mass stars at about 10 L_{sun}, high mass stars (10 M_{sun}) at about 200 L_{sun}.

After existing as horizontal branch stars for a few million years, the helium in the core of the star is exhausted (now being mostly carbon and oxygen nuclei) and a helium burning shell develops below the hydrogen burning shell. The electrons and nuclei in the core again become degenerate and the star expands and cools to become an **asymptotic giant branch star (AGB stars).** Most of the energy comes from the hydrogen burning shell; the helium burning shell is small at this time. However, the hydrogen shell dumps helium ash onto the helium shell. After some time, enough helium is built up so that the helium shell undergoes an explosive event called a ***thermal pulse.*** Although this pulse is barely noticed at the surface of the star, it serves to increase the mass of the carbon/oxygen core, so that the size and luminosity of the star gradually increases with time.

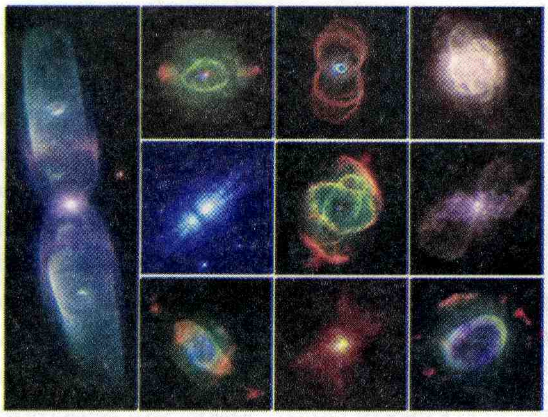

Figure 12: Planetary Nebulae

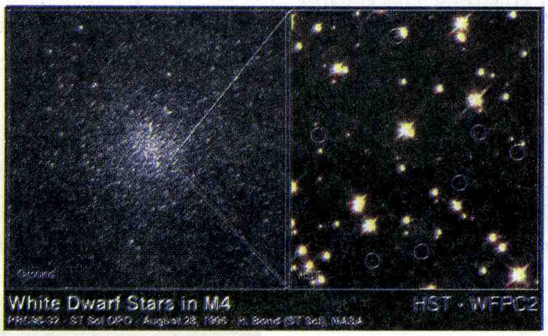

Figure 13: White Dwarf stars

As the star climbs the asymptotic giant branch, a stellar wind develops in the star's envelope that blows the outer layers into space. In this wind, dust particles are formed from carbon material dredged up from the core by convective currents. During this time a thick dust shell blocks the visible light from the star such that even though it is 10,000 brighter than the Sun, it is only seen in the infrared. The stellar wind causes mass loss for AGB stars. This loss is around 10^{-4} solar mass per year, which means that in 10,000 years the typical star will dissolve leaving the central hot core (the central star in a planetary nebula). If the star is larger than 8 solar masses, then the core continues to heat. Carbon and oxygen fuse to form neon, then magnesium, and then silicon. Silicon will fuse to form an iron ash core. Iron is extremely stable and resistant to fusion. The temperature of an iron core can reach 3 billion degrees. When the iron core reaches a critical mass, it collapses suddenly to become a **neutron star** or possibly even a **black hole,** while the outer layers are violently expelled in a supernova explosion.

End of a star, planetary nebulae and white dwarf:
A planetary nebula forms when a star can no longer support itself by fusion reactions in its center. The gravity from the material in the outer part of the star takes its inevitable toll on the structure of the star, and forces the inner parts to condense and heat up. The high temperature in central regions drive the outer half of the star away in a brisk stellar wind, lasting a few thousand years. When the process is complete the remaining core remnant is uncovered and heats the now distant gases and causes them to glow. Despite the name, these objects are totally unrelated to "planets". It is commonly thought that they may represent the final episode of the Sun's existence as a star. This concept has been questioned recently, wherein evidence from globular cluster stars indicates that stars must be about 20% heavier than the Sun to form a Planetary nebula. Planetary nebulae have a lot of shapes. It is believed that the environment of the dying star, distribution of the envelop of the star, and the rotating speed of the star would be the effective factors to determine the shape of the stars.

For stellar masses less than about 1.44 solar masses, the energy from the gravitational collapse is not sufficient to produce the neutrons of a neutron star, so the collapse is halted by electron degeneracy to form white dwarfs. This maximum mass for a white dwarf is called the Chandrasekhar limit. As the star contracts all the lowest electron energy levels are filled and the electrons are forced into higher and higher energy levels, filling the lowest unoccupied energy levels. This creates an effective pressure which prevents further gravitational collapse.

When the white draft does not have the energy source it will become a black dwarf.

Evolution of stars with different masses:

$<0.07\ M_Q$ - Not enough mass for hydrogen burning
0.07-0.5 M_Q - Hydrogen burning occurs in this star and it will come to the giant branch. Not enough mass for helium burning.
0.5-2.2 M_Q - Star will lie on the main sequence and later it will become a white dwarf.

2.2 – 8.0 M_Q - No helium degeneracy and therefore no helium flushing. But later carbon degeneracy may occur. If the core gets burnt it will end-up with a Super Nova. But so far there is no evidence for such explosions. Astronomers believed that these stars would form star winds but temperature and pressures are not high enough for carbon fusions. Some of the stars end up as planetary nebulae.

8.0 – 10 M_Q - Not enough mass to burn the carbon core. No carbon degeneracy, therefore no explosions. Carbon fuse to form oxygen. But temperature and pressures are not high enough for oxygen fusion.

10- 15 M_Q - Can fuse oxygen and has the oxygen degeneracy. Therefore eventually the star dies in a Super Nova.

15-100 M_Q - Very soon (perhaps 150 million years), helium runs out in the core. The core collapses. This time the mass and gravity are high enough for further nuclear reactions to begin. Carbon can be changed to oxygen and silicon. The carbon in the core runs out after perhaps 40 million years. The core collapses again. Higher core temperatures are reached. More nuclear reactions occur, this time using oxygen. Each time a nuclear fuel runs out in the core, the core collapses. This collapse raises the temperature, which in turn triggers off more nuclear reactions. Each subsequent set of reactions lasts for a shorter period than the previous. This can continue through the elements until iron is reached. Iron nuclei cannot react to produce energy. When the core is made up totally of Iron, gravity finally takes over. The core collapses again. Any nuclear reactions that occur now consume energy so that gravity cannot be held at bay. The core collapses catastrophically. In an instant it shrinks uncontrollably to almost nothing. The huge amount of shrinking heats up the core so dramatically that the power produced blows the outer layers of the star away in a huge explosion.

Supernovae come in two main types: Type I, which lack hydrogen lines in their spectra, and type II, which have hydrogen lines. These types are further subdivided. Types Ia, Ib, and Ic are distinguished by other details of their spectra. Types II-L and II-P are distinguished on the basis of their light curves: type II-Ls showing a linear ("L") decline, while type II-Ps remains on a plateau ("P") for a few weeks before falling off. Type Ia supernovae are the brightest of all, reaching a maximum absolute magnitude of -19. Types Ib and Ic tend to be a couple of magnitudes fainter, while Type II supernovae vary widely in their peak output. Type Ia supernovae occur in older populations of stars, such as those making up elliptical galaxies and the halos of spiral galaxies. Types Ib, Ic, and II are largely confined to the younger populations of stars found in the disks of spirals.

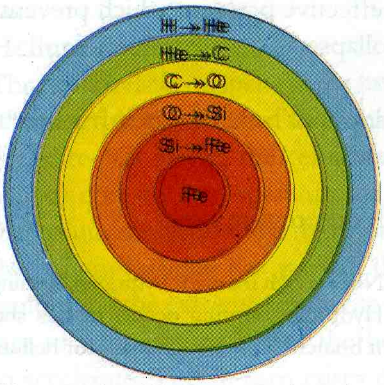

Figure 14: Nuclear reactions in a high dense star

In terms of the underlying mechanism of the explosion, types Ib, Ic, and II have more in common with each other than they do with type Ia. The latter is thought to occur exclusively in binary systems in which a white dwarf has acquired a large amount of material from its companion. When the white dwarf's mass exceeds the Chandrasekhar limit of about 1.4 solar masses, runaway carbon burning is triggered, which results in the incineration of the dwarf and the violent disruption of its contents. The other varieties of supernova are all thought to be due to the core collapse of massive stars. Types Ia and Ib involve stars that have lost their hydrogen envelopes, either through a powerful stellar wind or the transfer of material to a companion. Wolf-Rayet stars are considered likely progenitors of these kinds of supernovae, the slight chemical differences between types Ia and Ib arising from different degrees of stripping of the Wolf-Rayet's outer layers prior to the explosion.

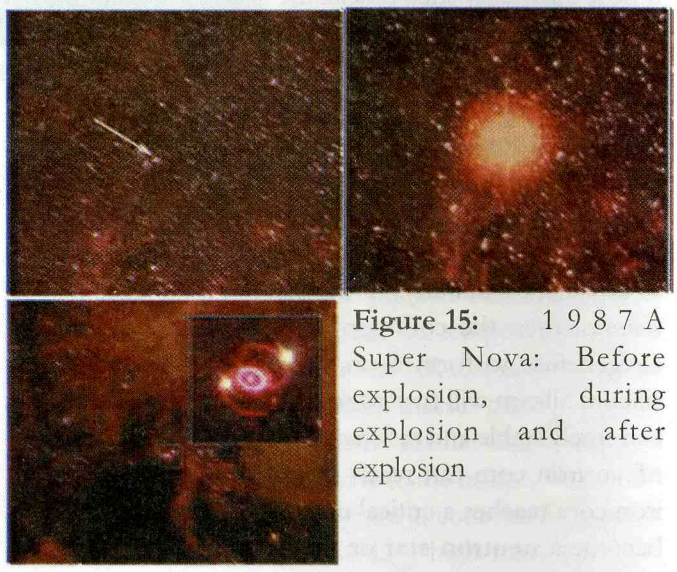

Figure 15: 1987A Super Nova: Before explosion, during explosion and after explosion

Stars come to life, they live over a very long period of time - and finally they die. The life of the stars can vary; the same applies to their death.

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Mathematical Modeling and its Applications in Day-to-Day life

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A couple of decades ago, Mathematics meant some sort of introduction to mathematical reasoning courses, in which we were supposed to learn how to prove mathematical theorems. During that time the answers to questions like, **"What is this good for?"**; **"After these the structures of logical arguments?"**; **"Is it a technique we can use to prove many theorems?"**; **"Is it a cool argument/result?"**; or **"Are we going to use it to prove something else?"**. Later many mathematicians would say that this is what mathematicians do, and that mathematics is about-proving theorems.

Today mathematics is at the other extreme. Our goal is to learn how to use mathematics to understand/explain/describe/predict aspects of the real world. This is what scientists and engineers do, they use mathematics as a language that is more precise, clearer, and more useful for their purposes than 'natural' language. Despite the judgement asserted at the end of the previous paragraph, this is the context in which the bulk of mathematical language is used.

There is perhaps an analogy with natural language: A small fraction is used for literary purposes, e.g., poetry, where a substantial emphasis is on language for language's sake, while by far the majority of language is more utilitarian, e.g., conversation, or newspaper writing. Just as many mathematicians would emphasize the importance of proofs, many more literature professors study and teach poetry than newspaper articles.

Applications drove the early creation of mathematics: counting, measuring land, navigation, etc., and pure mathematics continues to develop in tandem with applications: low-dimensional topology and gauge theory, algebraic geometry and string theory, graph theory and analysis of the Internet, etc.

That is what mathematicians do in modern times; they try to describe and analyze some real world phenomena mathematically, which may require learning some new mathematics, and even proving a few theorems along the way. This process is called Mathematical Modeling. Keeping this idea in mind, let us move to get experience about mathematical modeling.

What is Mathematical Modeling?

Mathematical Modeling is the process of creating a mathematical representation of some phenomenon in order to gain a better understanding of that phenomenon. It is a process that attempts to match observation with symbolic statement. During the process of building a mathematical model, the modeler will decide what factors are relevant to the problem and what factors can be de-emphasized. Once a model has been developed and used to answer questions, it should be critically examined and often modified to obtain a more accurate reflection of the observed reality of that phenomenon. In this way, mathematical modeling is an evolving process; as new insight is gained, the process begins again as additional factors are considered.

Building a mathematical model

Building a mathematical model for real world problems can be challenging, yet an interesting task. A thorough understanding of the underlying scientific concepts is necessary and a mentor with expertise in problem topic is invaluable. It is also best to work as part of a team to provide more brainstorming power. In industry and engineering, it is common practice for a team of people to work together in building a model, with the individual team members bringing different areas of expertise to the problem.

Although problems may require very different methods of solution, the following steps outline a general approach to the mathematical modeling process:

- **Identify the problem**, define the terms in your problem, and **draw diagrams** where appropriate.

- Begin with a **simple** model, **stating the assumptions** that you make as you focus on particular aspects of the phenomenon.
- **Identify important variables and constants** and determine how they relate to each other.
- **Develop the equation(s)** that express the relationships between the variables and constants.

Verifying and refining a model

Once the model has been developed and applied to the problem, our resulting model solution must be analyzed and interpreted with respect to the problem. The interpretations and conclusions should be checked for accuracy by answering the following questions:

- Is the information produced reasonable?
- Are the assumptions made while developing the model reasonable?
- Are there any factors that were not considered that could affect the outcome?
- How do the results compare with real data, if available?

In answering these questions, we may need to modify our model. **This refining process should continue until we obtain a model that agrees as closely as possible with the real world observations of the phenomenon that we have set out to model.**

Variables and parameters

Mathematical models typically contain three distinct types of quantities: *output variables, input variables, and parameters* (constants). Output variables give the model solution. The choice of what to specify as input variables and what to specify as parameters is somewhat arbitrary and often model dependent. Input variables characterize a single physical problem while parameters determine the context or setting of the physical problem. For example, in modeling the decay of a single radioactive material, the initial amount of material and the time interval allowed for decay could be input variables, while the decay constant for the material could be a parameter. The output variable for this model is the amount of material remaining after the specified time interval.

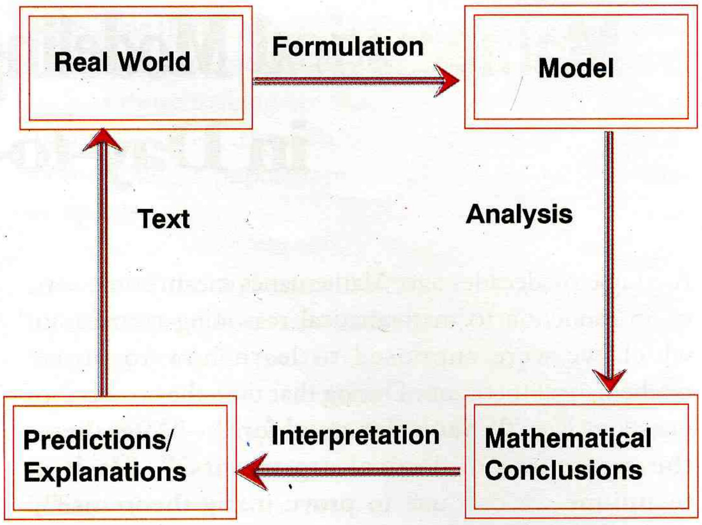

Figure 1: Process of Mathematical Modeling

With this brief idea about mathematical modeling, let us try to understand what kind of fields can be described using mathematical models. Any kind of real world problems can be described using mathematical models, but the following fields can be listed due to the importance of these in day-to-day life.

- Engineering
- Finance
- Economics
- Industry
- Biology
- Medicine
- Ecology
- Physiology
- Chemical processes
- Environmental problems
- Sports
- Wild life Management
- Management

Now we would like to outline a few real world phenomenon in which we are practising mathematics.

Tsunami prediction

How does mathematical models help us to understand the behaviour of a physical phenomenon like a **tsunami**? We can talk about equations that describing this phenomenon. This means the equations provide a relationship between variables such as wave speed or wavelength and physical parameters such as gravity and ocean depth. Such a relationship can be used to approximate the future behaviour of the wave itself.

For example, the usual approximation for wave speed in the open ocean is based on the formula, speed is proportional to the square root of the force of gravity times the ocean depth. ***Such a quantifiable relationships allows scientists to generate warnings of approaching tsunamis, with predictions of both arrival times and wave size, so that costal communities may be called for evacuations.***

Figure 2: Tsunami waves

Airplane boarding

When boarding an aircraft we often hear the announcement - "Now passengers boarding rows 15 to 18, …now boarding rows 20 and up." We have all heard this monotonous call as we patiently wait to board a plane. When your row finally win this airplane boarding lottery, you hurriedly walk down the gangway only to wait on the aisle while your fellow passengers stow their luggage, and also allow more time for those in aisle seats to get up to allow the window and middle-seat passengers to slide into their cramped, coach-class quarters. The whole process seems to go on forever. Why cannot this process be done faster and more efficiently?

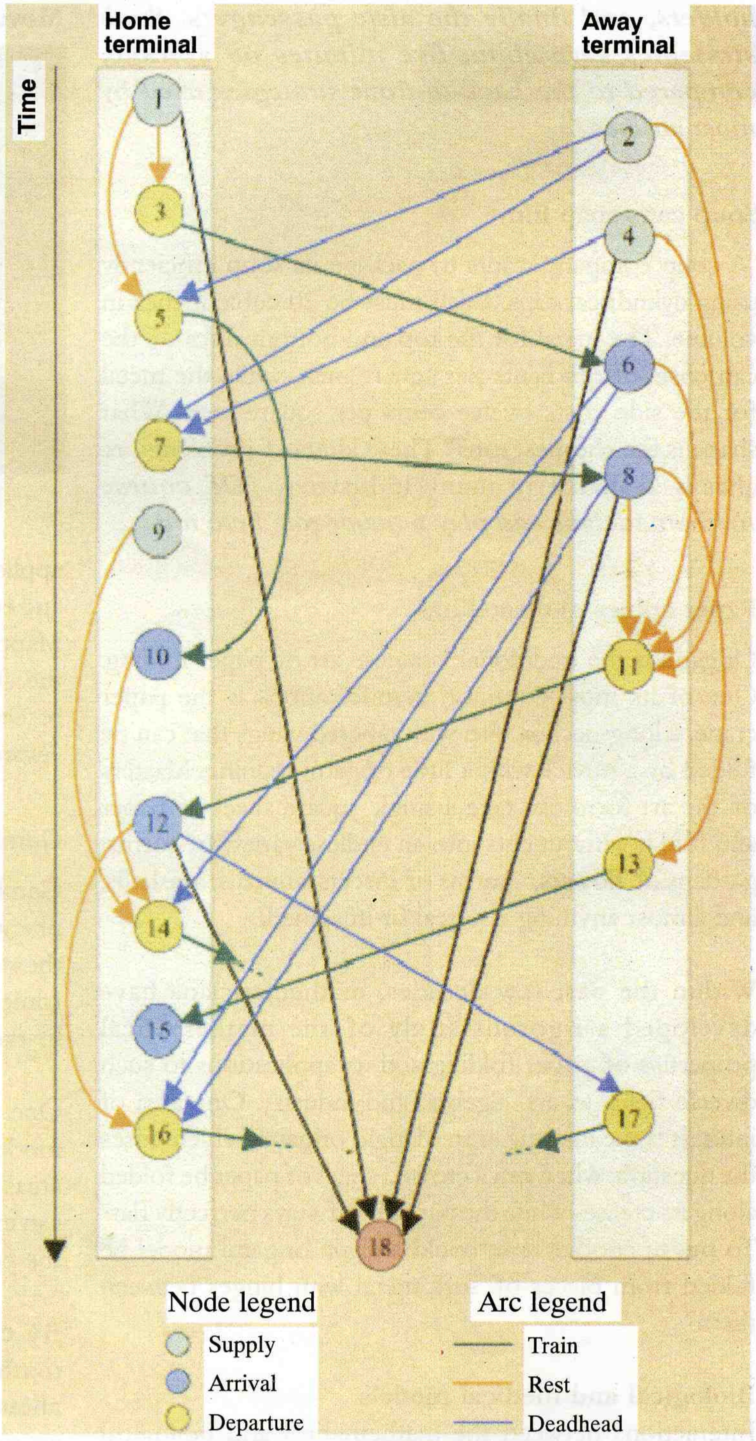

Figure 3: Network model for the scheduling problem

Using a mathematical model and a computer simulation, we compared a variety of boarding strategies. By putting passengers in a random order within their boarding group and running a large number of simulations (3,000 for each strategy), we determined the mean, best, and worst-case boarding times. The results were surprising, given our experiences with the supposedly efficiency-conscious airline industry.

The quickest way to get passengers onto a plane is to board them from the outside in, starting with the window passengers, then the unlucky middle-seat

holders, and finally the aisle passengers. Such strategies save about five minutes on average, compared to the back-to-front strategies used by most airlines.

Soup cans soap film

"A soup company wants to package its soup efficiently using cylindrical cans. Each must be 20 cubic inches in volume. The metal for the top and bottom discs of the can costs fifteen cents per square inch, while the metal for the side costs twelve cents per square inch. What shape is the cheapest can?" These kinds of problems are always available in many industries. ***Of course mathematicians can play a major role here too.***

Paper cranes and satellites

Origami is the traditional Japanese art of paper folding. One of its most common manifestations is the paper crane, a long-necked bird with tapered wings that can be folded by a novice with a little origami training. Masters of the art form can take a single square sheet of paper and fold it without cuts into an endless variety of forms: gardens of flowers, swarms of insects, animals, seashells, and almost anything else real or imagined.

Within the past few decades, mathematicians have developed a rigorous study of the mathematical properties of paper folding and its applications to such diverse fields as art, algebra, and industry. One area of interest is the investigation of rigid origami, which poses the question: when can a creased sheet of paper be folded along its creases while the paper itself stays perfectly flat? To put in another way, could a given origami model be folded from pieces of stiff metal with hinges between them?

Biological and medical models

Interactions between the mathematical and biological sciences have been increasing rapidly in recent years. Both traditional topics, such as population and disease modeling (especially cancer modeling), and new ones such as those in genomics arising from the accumulation of DNA sequence data, have made biomathematics an exciting field. The best predictions of numerous individuals and committees have suggested that the area will continue to be one of great growth.

Move industry

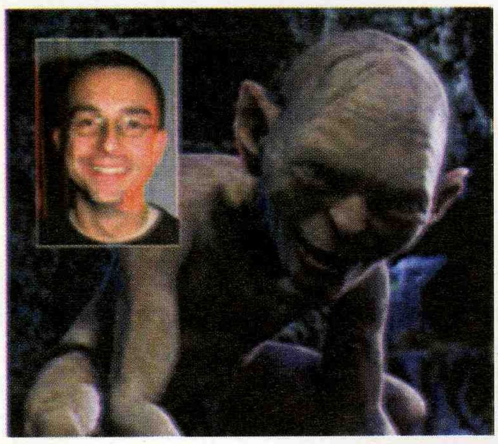

Figure 4: Lord of the Rings

Today, people use mathematical modeling techniques in the move industry too. Image modeling is a research field, which is rapidly growing and which can be applied in countless ways to the industry, medical science and entertainment. Henrik Wann Jensen invented Photon Mapping at DTU, the technique that was used to simulate the skin on Gollum in "**Lord of the Rings**". For his research Henrik Wann Jensen received an Academy Award at the Oscar ceremony.

Gambling games

Gambling games like roulette are good models for many phenomena involving chance, for example, investing in the stock market. It is easier to analyse games involving a roulette wheel than investments involving the stock market but the same ideas are involved.

One can give thousands of examples for mathematical models in various different fields. The above kinds of areas are good examples of the kinds of questions we can examine if we have a good model, and these illustrate the power of modeling.

By considering all these facts, one can think of mathematical modeling as an activity or process that allows a mathematician to be a chemist, an ecologist, an economist, a physiologist, a biologist ...etc.

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