

# Climate Change – Sri Lankan Perspective

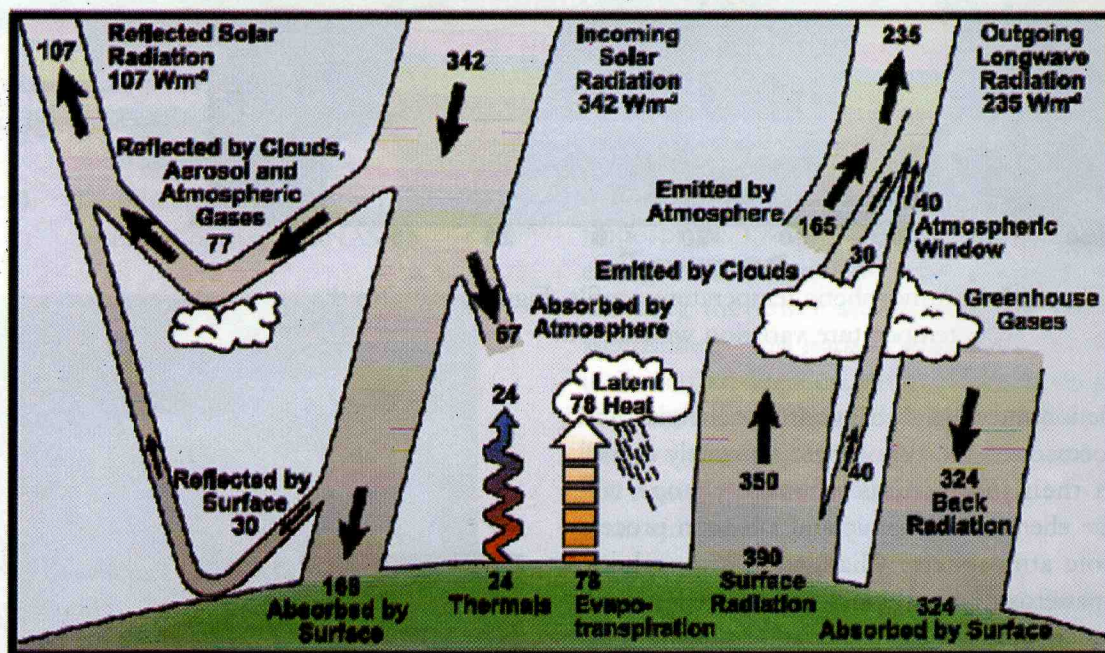
*G.H.P Dharmaratna*

## 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

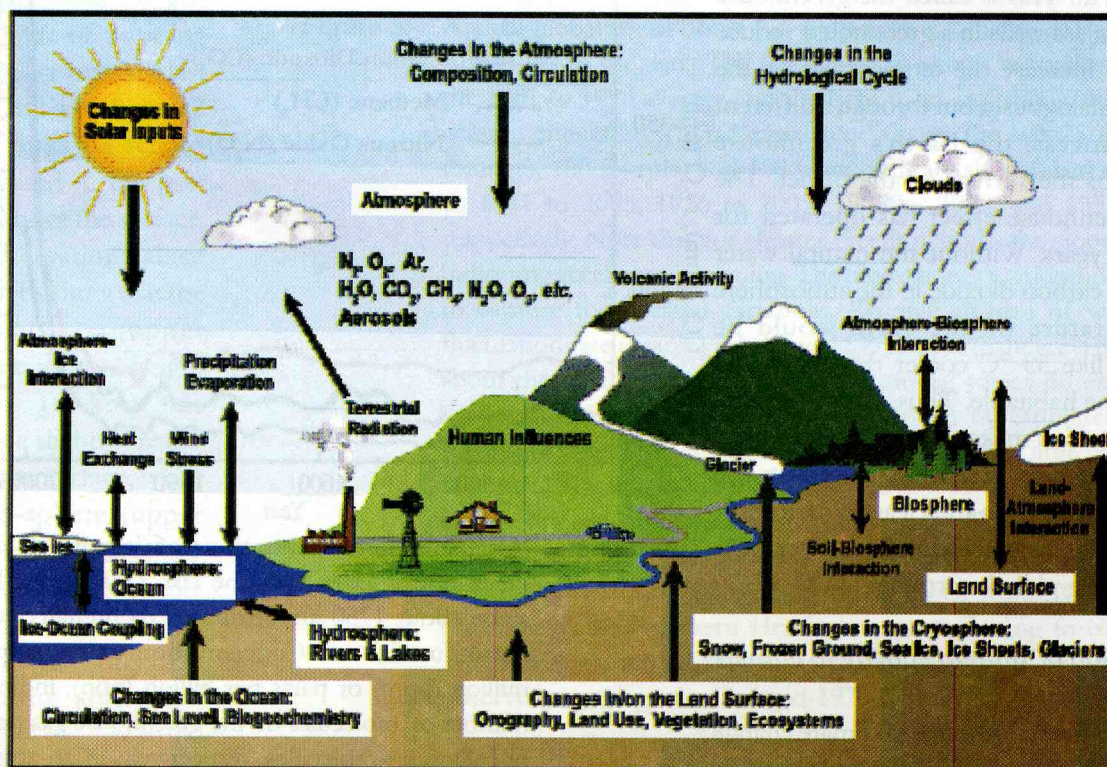


Figure 2: Schematic view of the components of the climate system, their processes and interactions

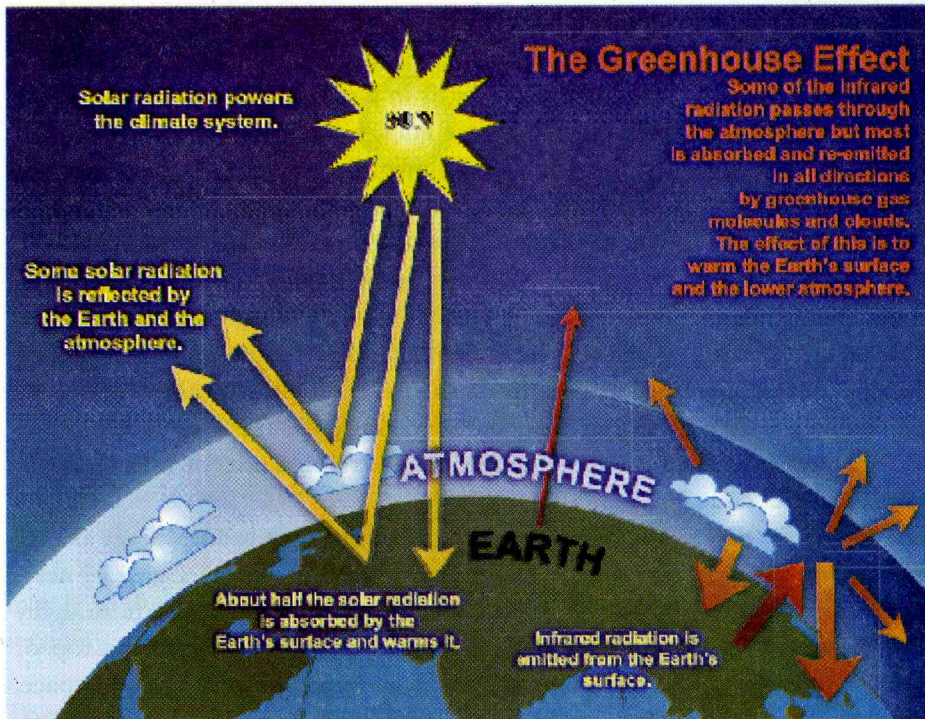


Figure 3: An idealised model of the natural greenhouse effect

spectrum. Much of this thermal radiation emitted by the eruptions.

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

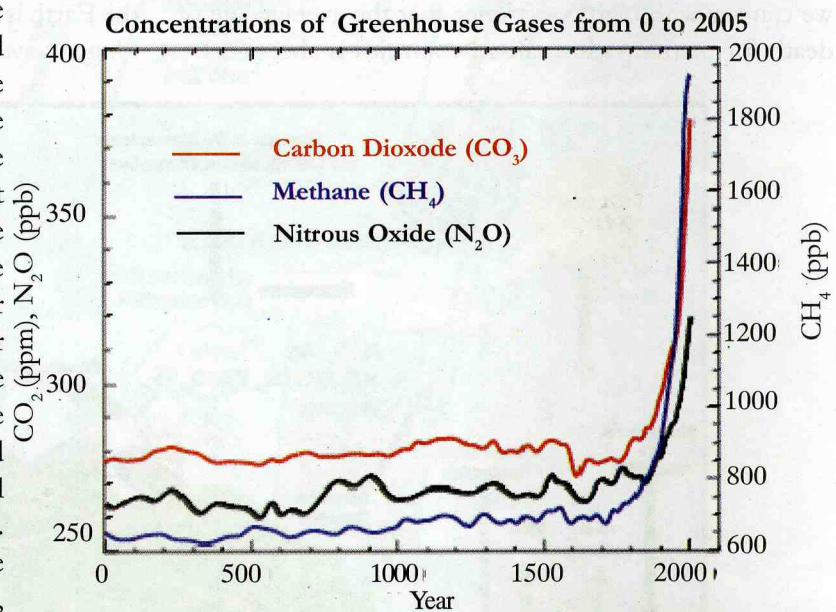


Figure 4: Atmospheric concentrations of important long-lived greenhouse gases over the last 2,000 years. Increases since about 1750 are attributed to human activities in the industrial era. Concentration units are parts per million (ppm) or parts per billion (ppb), indicating the number of molecules 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<sub>2</sub>), Methane (CH<sub>4</sub>), Nitrous Oxide (N<sub>2</sub>O) 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.

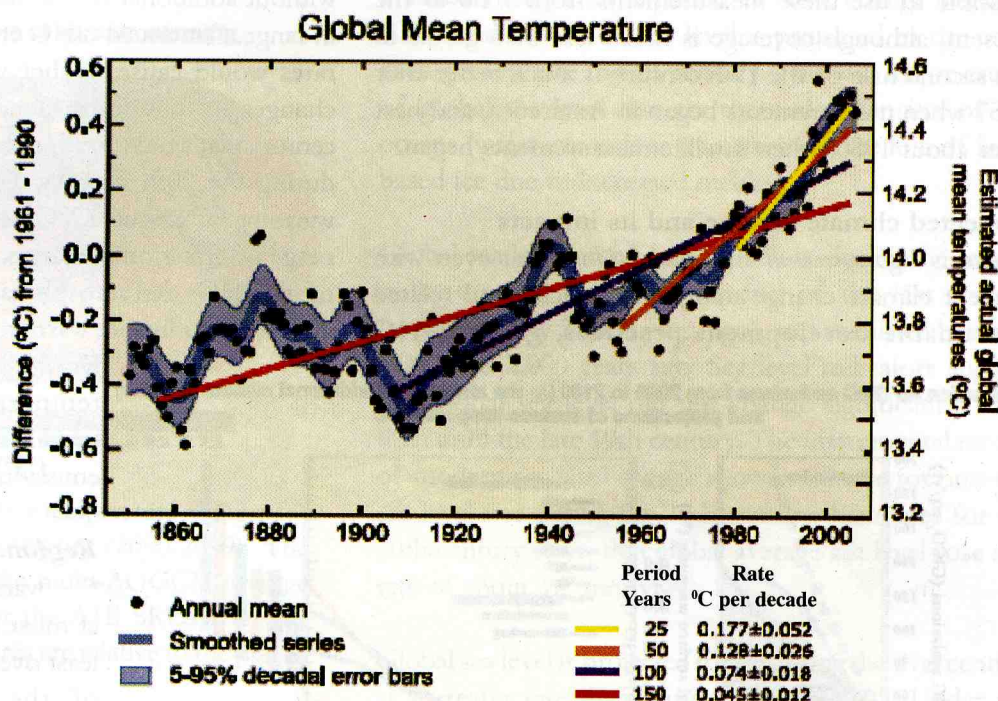
**Monitoring the change**

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



**Figure 5:** Annual global mean observed temperatures (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.

stations over the land areas of the world are combined with thousands more measurements of sea surface

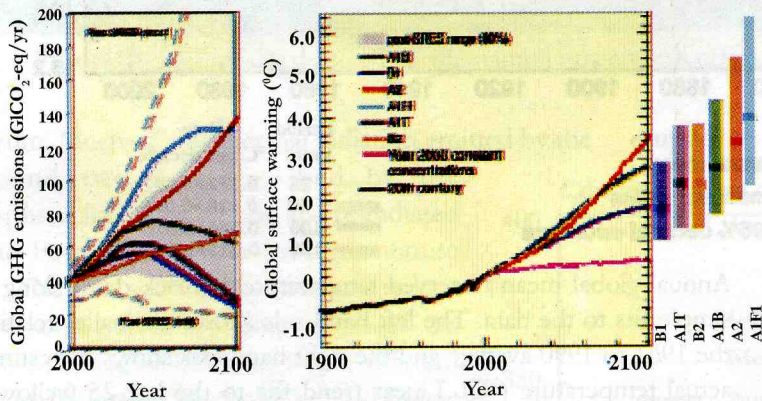
temperature taken from ships moving over the oceans, to produce an estimate of global average temperature every month. To obtain consistent changes over time, the main analysis is actually of anomalies (departures from the climatological mean at each site) as these are more robust to changes in data 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% (CO<sub>2</sub>-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.

### Scenarios for GHG emissions from 2000 to 2100 (In the absence of additional climate policies) and projections of surface temperatures



**Figure 6:** Left Panel: Global GHG emissions (in CO<sub>2</sub>-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 CO<sub>2</sub>, CH<sub>4</sub>, N<sub>2</sub>O, 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

southern Africa and northeast Brazil) will suffer a decrease in water resources due to climate change.

**Impact on sea level**

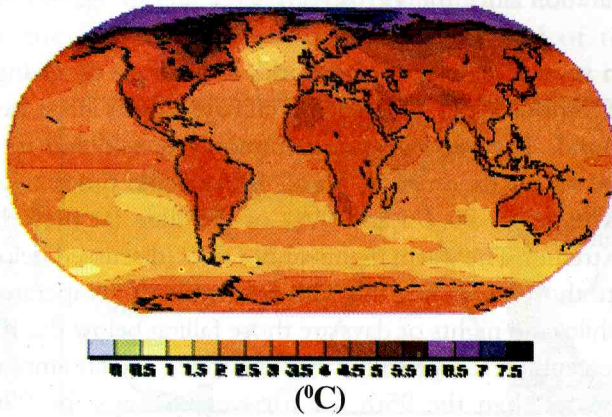
There is strong evidence that global sea level gradually rose in the 20th century and is currently rising at an increased rate, after a period of little change between AD 0 and AD 1900. Sea level is projected to rise at an even greater rate in this century. The two major causes of global sea level rise 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<sup>-1</sup>.

Global sea level is projected to rise during the 21st century at a greater rate than during 1961 to 2003. Under the

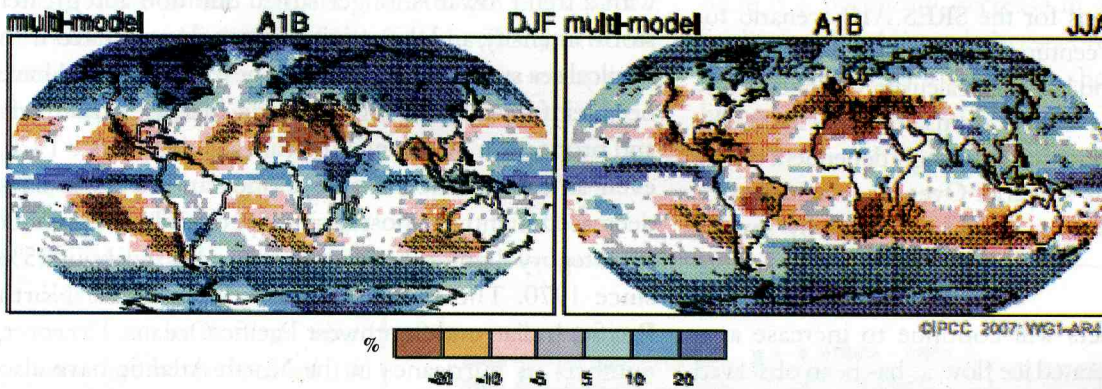
IPCC Special Report on Emission Scenarios (SRES) A1B scenario by the mid-2090s, for instance, global sea level reaches 0.22 to 0.44 m above 1990 levels, and is rising at about 4 mm yr<sup>-1</sup>. As in the past, sea level change in the future will not be geographically uniform, with regional sea level change varying

**Geographical pattern of surface warming**



**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.

**Projected patterns of precipitation changes**

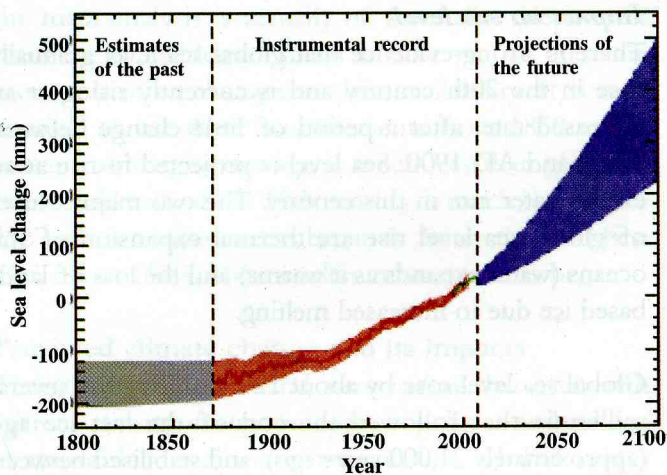


**Figure 8:** Relative changes in precipitation (in percent) for the period 2090–2099, relative to 1980–1999. Values are multi-model averages based on the SRES A1B scenario for December to February (left) and June to August (right). White areas are where less than 66% of the models agree in the sign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

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



**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.

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.

#### ***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 evaporation has increased due to warmer conditions. Generally, numbers of heavy daily precipitation events that lead to flooding have increased, 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.

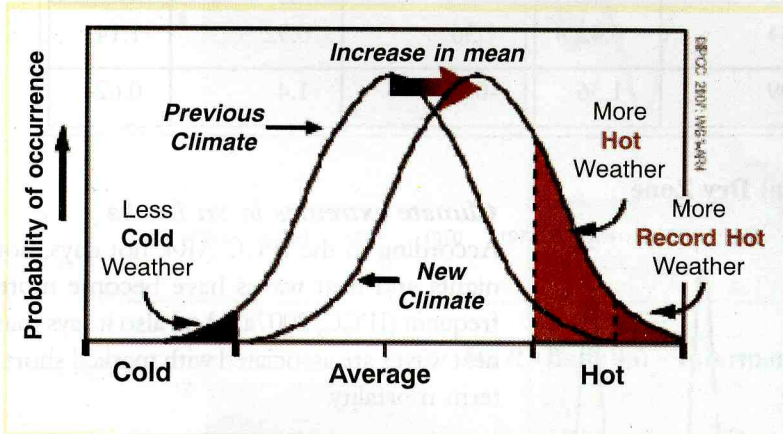
Changes in tropical storm and hurricane frequency and intensity are masked by large natural variability. The El Niño-Southern Oscillation greatly affects the location and activity of tropical storms around the world. Globally, estimates of the potential destructiveness of hurricanes show a substantial 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

- 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**



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

**Observed change in climate in Sri Lanka**

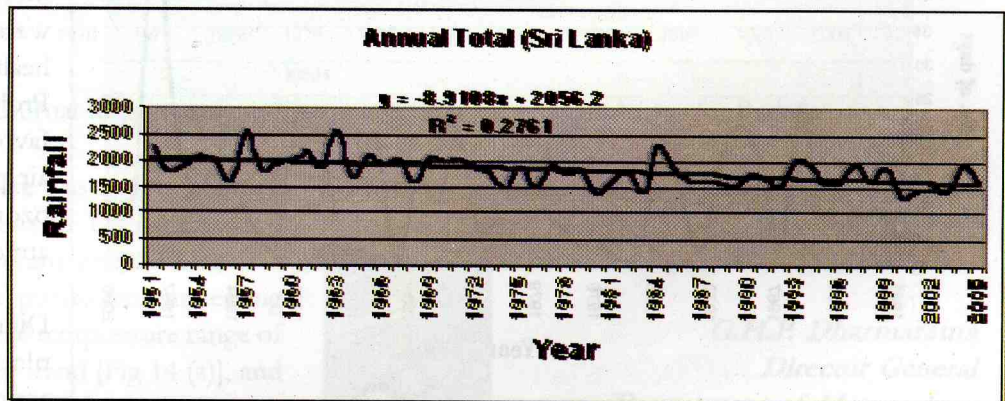
In recent studies it has been shown that the surface air temperature over Sri Lanka has been rising and there is an increasing trend in both the minimum and maximum temperatures. Almost all the stations show significant increase of Maximum temperature except the station at Nuwara Eliya (elevation 1894 m). However, the increasing trend of minimum temperature at this station is the highest and the rate is 0.02°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.

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.

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.

**Projected impacts on Asia**

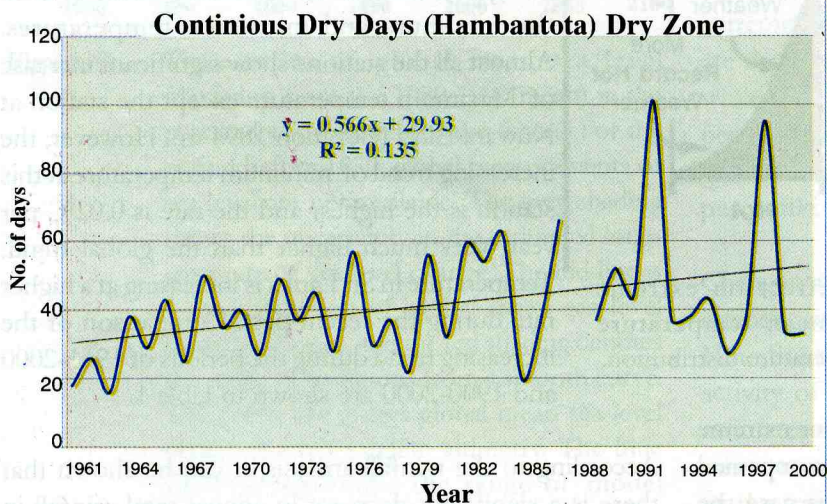
- By the 2050s, freshwater availability in Central, South, East and South-East Asia, particularly in large river basins, is projected to decrease
- Coastal areas, especially heavily-populated megadelta regions in South, East and South-East Asia, will be at greatest risk due to increased flooding from the sea and, in some megadeltas, flooding from the rivers



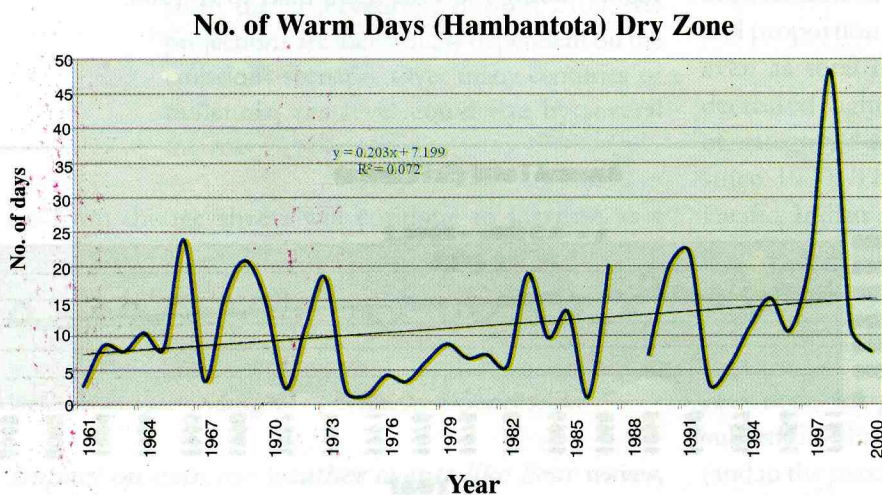
**Fig 11:** Decreasing annual total rainfall in Sri Lanka (1951-2005)

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

Station	1900-2000			1961-2000		
	Minimum	Maximum	Mean	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

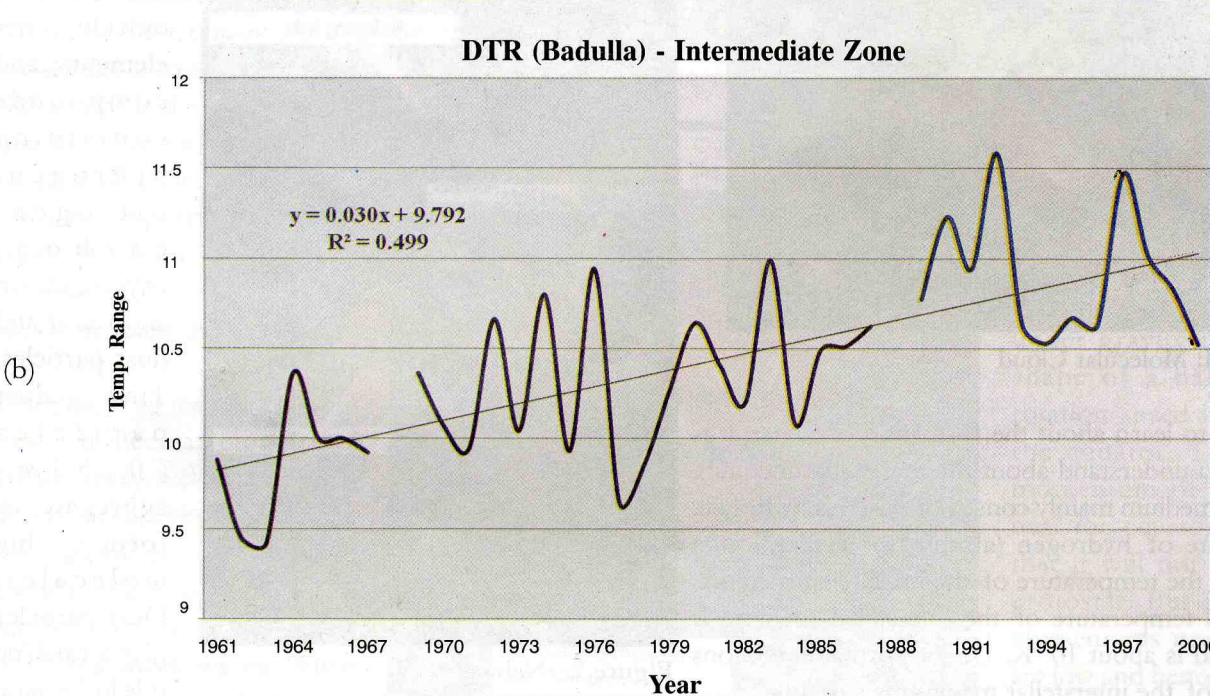
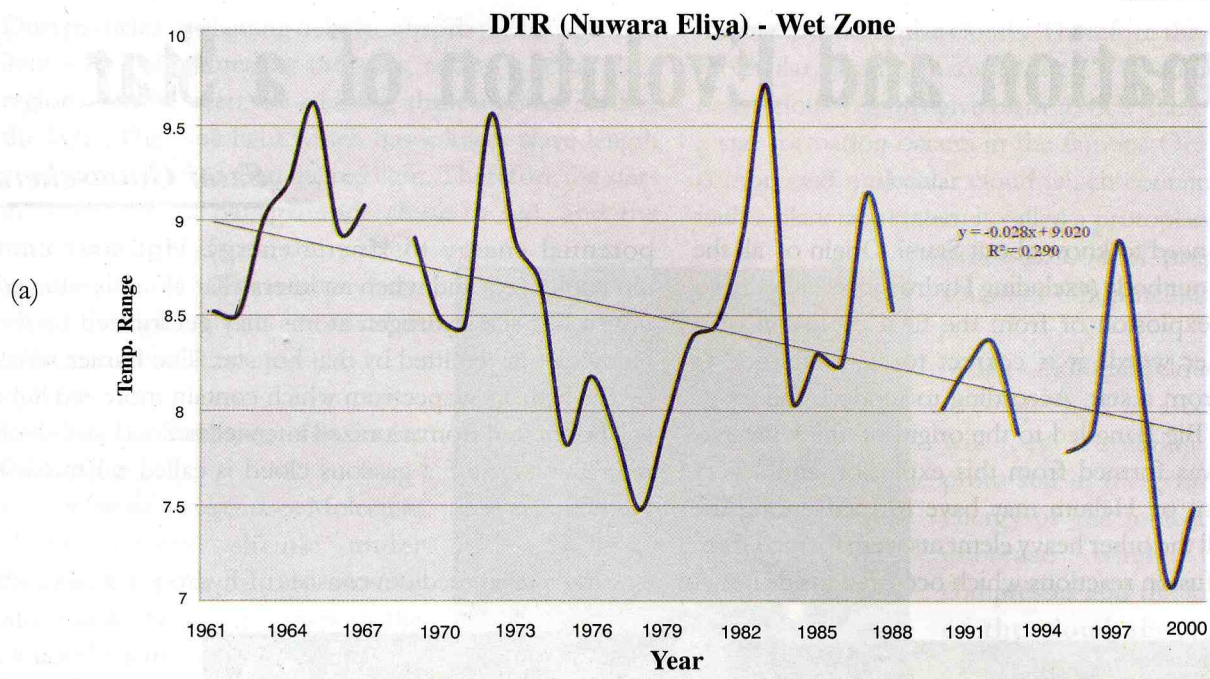
**Climate extremes in Sri Lanka**

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)].



**G.H.P. Dharmaratna**  
*Director General*  
*Department of Meteorology*