UGC NET - GEOGRAPHY

SAMPLE THEORY

PAPER - III

ATMOSPHERIC STABILITY AND INSTABILITY

- *INTRODUCTION*
- *VARIOUS STABILITIES AND INSTABILITIES*
- *AIR MASSESS (AM)*
- *TYPES OF AIR MASSES*
- *WEATHER EFFECTIVITIES INDUCED BY THE AIR MASSES*
- *TEST YOUR KNOWLEDGE*

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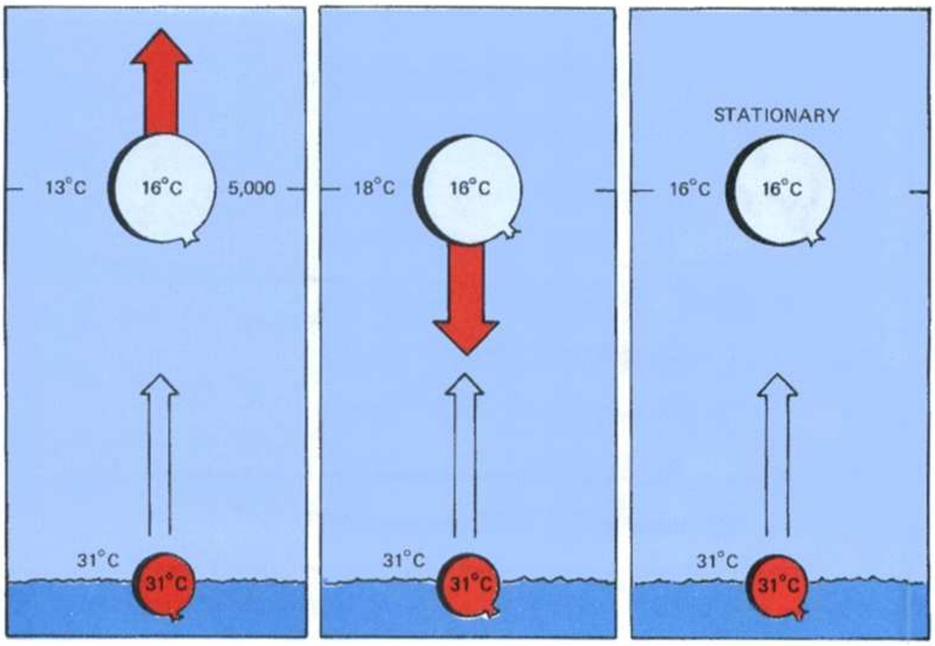
STABILITY AND INSTABILITY

Let's use a balloon to demonstrate stability and instability. In figure 42 we have, for three situations, filled a balloon at sea level with air at 31° C-the same as the ambient temperature. We have carried the balloon to 5,000 feet. In each situation, the air in the balloon expanded and cooled at the dry adiabatic rate of 3° C for each 1,000 feet to a temperature of 16° C at 5,000 feet.



Stability related to temperatures aloft and adiabatic cooling. In each situation, the balloon is filled at sea level with air at 31° C, carried manually to 5,000 feet, and released. In each case, air in the balloon expands and cools to 16° C (at the dry adiabatic rate of 3° C per 1,000 feet). But, the temperature of the surrounding air aloft in each situation is different. The balloon on the left will rise. Even though it cooled adiabatically, the balloon remains warmer and lighter than the surrounding cold air; when released, it will continue upward spontaneously. The air is unstable; it favors vertical motion. In the center, the surrounding air is warmer. The cold balloon will sink. It resists our forced lifting and cannot rue spontaneously. The air is stable-it resists upward motion. On the right, surrounding air and the balloon are at the same temperature. The balloon remains at rest since no density difference exists to displace it vertically. The air is neutrally stable, i.e., it neither favors nor resists vertical motion. A mass of air in which the temperature decreases rapidly with height favors instability; but, air tends to be stable if the temperature changes little or not at all with altitude.

Stable Or Unstable Process

Stability runs the gamut from absolutely stable to absolutely unstable, and the atmosphere usually is in a delicate balance somewhere in between. A change in ambient temperature lapse rate of an air mass can tip this balance. For example, surface heating or cooling aloft can make the air more unstable; on the other hand, surface cooling or warming aloft often tips the balance toward greater stability.

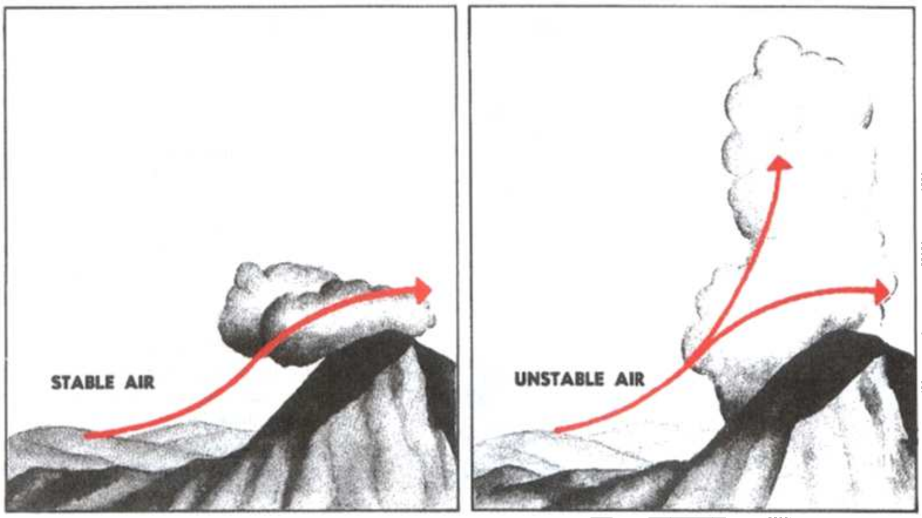
Air may be stable or unstable in layers. A stable layer may overlie and cap unstable air; or, conversely, air near the surface may be stable with unstable layers above.

Stratiform Clouds

Since stable air resists convection, clouds in stable air form in horizontal, sheet-like layers or "strata." Thus, within a stable layer, clouds are stratiform. Adiabatic cooling may be by upslope flow ; by lifting over cold, more dense air; or by converging winds. Cooling by an underlying cold surface is a stabilizing process and may produce fog. If clouds are to remain stratiform, the layer must remain in stable after condensation occurs.

Cumuliform Clouds

Unstable air favors convection. A "cumulus" cloud, meaning "heap," forms in a convective updraft and builds upward. Thus, within an unstable layer, clouds are cumuliform; and the vertical extent of the cloud depends on the depth of the unstable layer.



FIGURE

When stable air (left) is forced upward, the air tends to retain horizontal flow, and any cloudiness is flat and stratified. When unstable air is forced upward, the disturbance grows, and any resulting cloudiness shows extensive vertical development.

We can estimate height of cumuliform cloud bases using surface temperature-dew point spread. Unsaturated air in a convective current cools at about 5.4° F (3.0° C) per 1,000 feet; dew point decreases at about 1° F (5/9° C). Thus, in a convective current, temperature and dew point converge at about 4.4° F (2.5° C) per 1,000 feet as illustrated in figure 44. We can get a quick estimate of a convective cloud base in thousands of feet by rounding these values and dividing into the spread or by multiplying the spread by their reciprocals. When using Fahrenheit, divide by 4 or multiply by .25; when using Celsius, divide by 2.2 or multiply by .45. This method of estimating is reliable only with instability clouds and during the warmer part of the day.

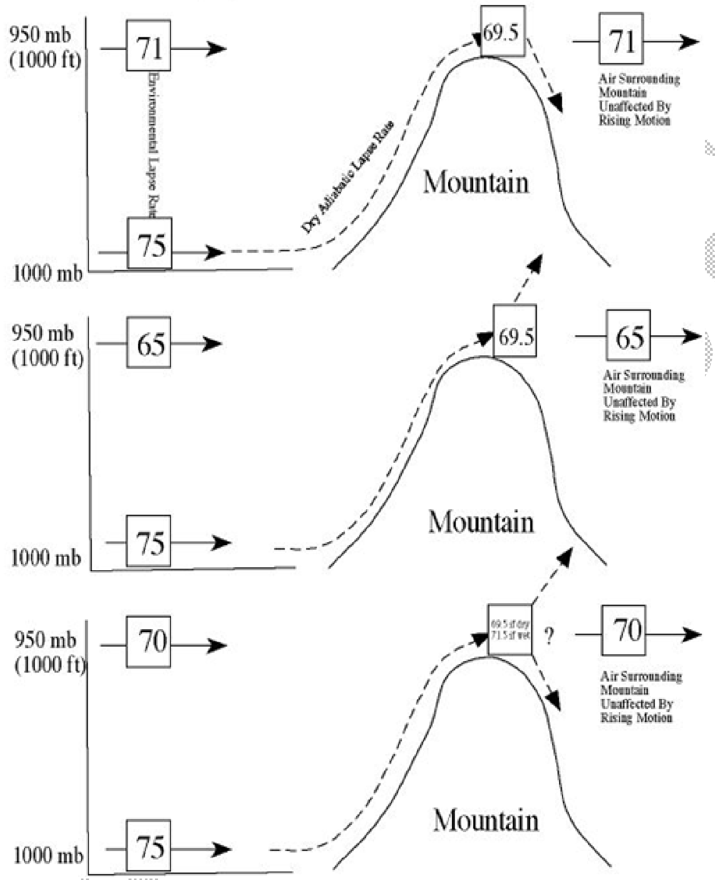
FIGURE

Cloud base determination. Temperature and dew point in upward moving air converge at a rate of about 4° F or 2.2° C per 1,000 feet.

Merging Stratiform and Cumuliform

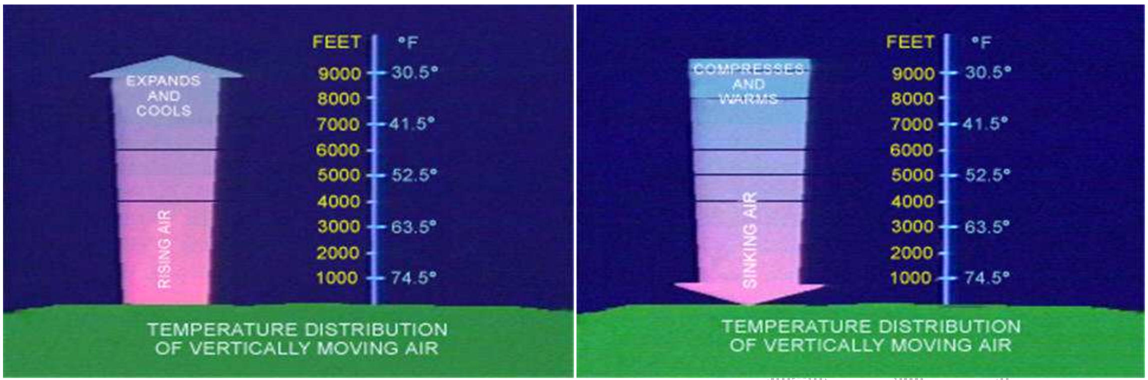
A layer of stratiform clouds may sometimes form in a mildly stable layer while a few ambitious convective clouds penetrate the layer thus merging stratiform with cumuliform. Convective clouds may be almost or entirely embedded in a massive stratiform layer and pose an unseen threat to instrument flight.

Instability -- the state in which an air parcel finds itself warmer than the air surrounding it at the same pressure (elevation). The air parcel is buoyant. Which of the following represents such a state?



Temperature distribution of vertically moving air

The term "adiabatic process" simply means warming by compression, or cooling by expansion, without a transfer of heat or mass into a system. As air moves up or down within the atmosphere, it is affected by this process. This temperature difference will be 5-1/2 degree decrease per 1,000 feet increase in altitude. This is also termed the dry adiabatic lapse rate. The atmosphere may or may not have a temperature distribution that fits the dry adiabatic lapse rate. Usually it does not.



Unstable air encourages vertical movement of air and decreases fire activity.

The actual lapse rate may be greater or less than the dry adiabatic lapse rate and may change by levels in the atmosphere. This variation from the dry adiabatic lapse rate is what determines whether the air is stable or unstable. If the air is unstable, the vertical movement of air is encouraged, and this tends to increase fire activity. If the air is stable, vertical movement of air is discouraged, and this usually decreases or holds down fire activity. The importance of this atmospheric property will become evident by the time you have completed this unit.

Dry Lapse Rates

The actual temperature lapse rate in a given portion of the atmosphere could range from a plus 15° per 1,000 feet to a minus 15° per 1,000 feet. These would represent the extremes of very stable air to very unstable air.

AIR MASSES AND FRONTS

The purpose of this module is to introduce air masses, where they originate from and how they are modified. Clashing air masses in the middle latitudes spark interesting weather events and the boundaries separating these air masses are known as fronts. This module examines fronts, with detailed explanations about cold fronts and warm fronts. Finally, different types of advection are introduced; temperature, moisture and voriticity advection. The Air Masses and Fronts module has been organized into the following sections:

Air Masses

Air masses that commonly influence weather in the United States.

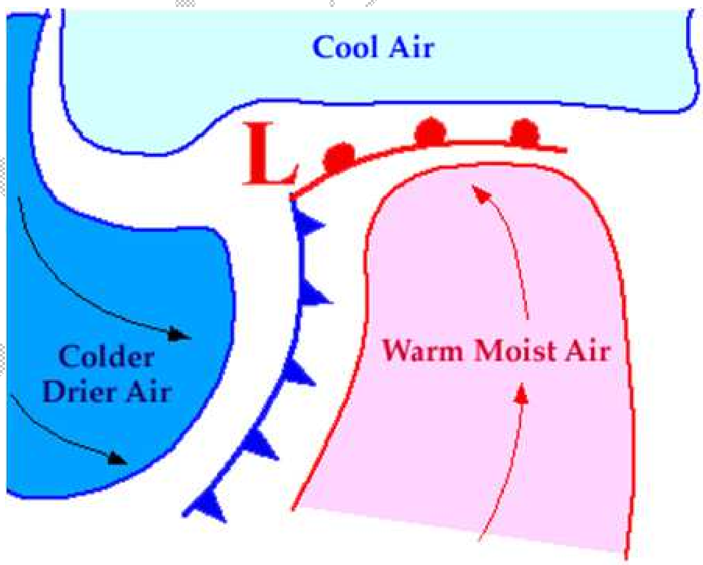
Fronts

Boundaries separating air masses. Includes warm fronts, cold fronts, occluded and stationary fronts and dry lines.

Continental Polar Air Masses

cold temperatures and little moisture

Those who live in northern portions of the United States expect cold weather during the winter months. These conditions usually result from the invasion of cold arctic air masses that originate from the snow covered regions of northern Canada. Because of the long winter nights and strong radiational cooling found in these regions, the overlying air becomes very cold and very stable. The longer this process continues, the colder the developing air mass becomes, until changing weather patterns transport the arctic air mass southward.



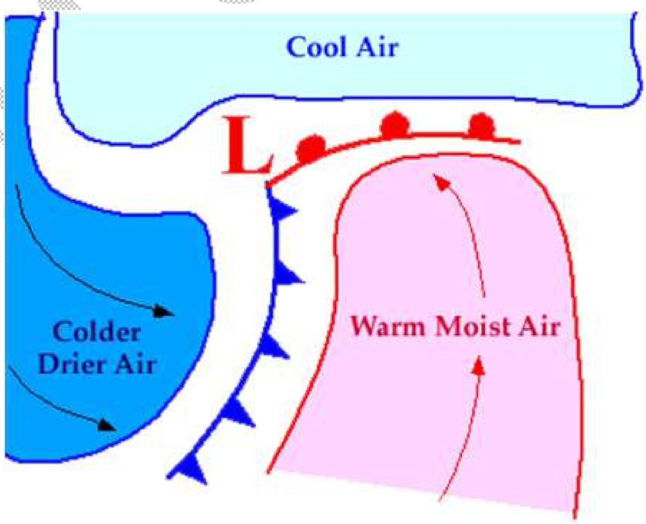
Below is a map of surface observations and the leading edge of a large arctic air mass blanketing much of the United States has been highlighted by the blue line. The center of this air mass is a high pressure center located in northern Montana (indicated by the blue "H").

From these reports, we see that most stations in the arctic air mass generally exhibit relatively colder temperatures, with lower dew point temperatures, and winds generally out of the north. Notice that on the other side of the blue boundary, outside of this air mass, surface conditions are much different, which indicates the presence of an entirely different air mass.

Maritime Tropical Air Masses

warm temperatures and rich in moisture

Maritime tropical air masses originate over the warm waters of the tropics and Gulf of Mexico, where heat and moisture are transferred to the overlying air from the waters below. The northward movement of tropical air masses transports warm moist air into the United States, increasing the potential for precipitation.



Below is a map of surface observations and the leading edge of a tropical air mass surging northward into the Ohio Valley has been highlighted in red. Southerly winds behind the boundary signify the continued northward transport of warm moist air.

From these reports, we see that most stations in the tropical air mass generally exhibit relatively warmer temperatures, with higher dew point temperatures, and winds generally out of the south. Notice that on the other side of the red boundary, outside of this air mass, surface conditions are much different, which indicates the presence of an entirely different air mass.

Air masses and their sources

Fahrenheit while a short distance behind the front, the temperature decreased to 38 degrees. An abrupt temperature change over a short distance is a good indicator that a front is located somewhere in between.

THE HYDROLOGICAL CYCLE

(also known as the water cycle) is the journey water takes as it circulates from the land to the sky and back again.

The sun's heat provides energy to evaporate water from the earth's surface (oceans, lakes, etc.). Plants also lose water to the air - this is called transpiration. The water vapour eventually condenses, forming tiny droplets in clouds.

When the clouds meet cool air over land, precipitation (rain, sleet, or snow) is triggered, and water returns to the land (or sea). Some of the precipitation soaks into the ground. Some of the underground water is trapped between rock or clay layers - this is called groundwater. But most of the water flows downhill as runoff (above ground or underground), eventually returning to the seas as slightly salty water.

Earth's water

Water is the most widespread substance to be found in the natural environment and it is the source of all life on earth. Water covers 70% of the earth's surface but it is difficult to comprehend the total amount of water when we only see a small portion of it. The distribution of water throughout the earth is not uniform. Some places have far more rainfall than others.

The Water Cycle

To assess the total water storage on the earth reliably is a complicated problem because water is so very dynamic. It is in permanent motion, constantly changing from liquid to solid or gaseous phase, and back again. The quantity of water found in the hydrosphere is the usual way of estimating the earth's water. This is all the free water existing in liquid, solid or gaseous state in the atmosphere, on the Earth's surface and in the crust down to a depth of 2000 metres. Current estimates are that the earth's hydrosphere contains a huge amount of water - about 1386 million cubic kilometres. However, 97.5% of this amount exists as saline waters and only 2.5% as fresh water.

Hydrological Cycle work

The stages of the cycle are:

- Evaporation
- Transport
- Condensation
- Precipitation
- Groundwater
- Run-off

Evaporation

Water is transferred from the surface to the atmosphere through evaporation, the process by which water changes from a liquid to a gas. The sun's heat provides energy to evaporate water from the earth's surface. Land, lakes, rivers and oceans send up a steady stream of water vapour and plants also lose water to the air (transpiration).

Approximately 80% of all evaporation is from the oceans, with the remaining 20% coming from inland water and vegetation.

Transport

The movement of water through the atmosphere, specifically from over the oceans to over land, is called transport. Some of the earth's moisture transport is visible as clouds, which themselves consist of ice crystals and/or tiny water droplets.

Clouds are propelled from one place to another by either the jet stream, surface-based circulations like land and sea breezes or other mechanisms. However, a typical cloud 1 km thick contains only enough water for a millimetre of rainfall, whereas the amount of moisture in the atmosphere is usually 10-50 times greater than this.

Most water is transported in the form of water vapour, which is actually the third most abundant gas in the atmosphere. Water vapour may be invisible to us, but not to satellites which are capable of collecting data about moisture patterns in the atmosphere.

Condensation

The transported water vapour eventually condenses, forming tiny droplets in clouds.

Precipitation

The primary mechanism for transporting water from the atmosphere to the surface of the earth is precipitation.

When the clouds meet cool air over land, precipitation, in the form of rain, sleet or snow, is triggered and water returns to the land (or sea). A proportion of atmospheric precipitation evaporates.

Groundwater

Some of the precipitation soaks into the ground and this is the main source of the formation of the waters found on land - rivers, lakes, groundwater and glaciers.

Some of the underground water is trapped between rock or clay layers - this is called groundwater. Water that infiltrates the soil flows downward until it encounters impermeable rock and then travels laterally. The locations where water moves laterally are called 'aquifers'. Groundwater returns to the surface through these aquifers, which empty into lakes, rivers and the oceans.

Under special circumstances, groundwater can even flow upward in artesian wells. The flow of groundwater is much slower than run-off with speeds usually measured in centimetres per day, metres per year or even centimeters per year.

Run-off

Most of the water which returns to land flows downhill as run-off. Some of it penetrates and charges groundwater while the rest, as river flow, returns to the oceans where it evaporates. As the amount of groundwater increases or decreases, the water table rises or falls accordingly. When the entire area below the ground is saturated, flooding occurs because all subsequent precipitation is forced to remain on the surface.

Different surfaces hold different amounts of water and absorbwater at different rates. As a surface becomes less permeable, an increasing amount of water remains on the surface, creating a greater potential for flooding. Flooding is very common during winter and early spring because frozen ground has no permeability, causing most rainwater and meltwater to become run-off.

GLOBAL WARMING

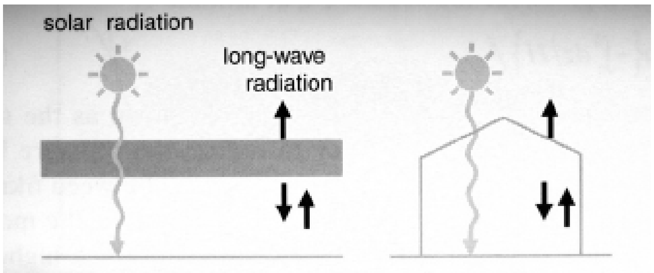
Global warming has become familiar to many people as one of the most important environmental issues of our day. This review will describe the basic science of global warming, its likely impacts both on human communities and on natural ecosystems and the actions that can be taken to mitigate or to adapt to it. As commonly understood, global warming refers to the effect on the climate of human activities, in particular the burning of fossil fuels (coal, oil and gas) and large-scale deforestation—activities that have grown enormously since the industrial revolution, and are currently leading to the release of about 7 billion tonnes of carbon as carbon dioxide into the atmosphere each year together with substantial quantities of methane, nitrous oxide and chlorofluorocarbons (CFCs). These gases are known as greenhouse gases.

The basic principle of global warming can be understood by considering the radiation energy from the sun that warms the Earth's surface and the thermal radiation from the Earth and the atmosphere that is radiated out to space. On average, these two radiation streams must balance. The greenhouse effect arises because of the presence of greenhouse gases in the atmosphere that absorb thermal radiation emitted by the Earth's surface and, therefore, act as a blanket over the surface . It is known as the greenhouse effect because the glass in a greenhouse possesses similar properties to the greenhouse gases in that it absorbs infrared radiation while being transparent to radiation in the visible part of the spectrum. If the amounts of greenhouse gases increase due to human activities, the basic radiation balance is altered.

Because of the long life time in the atmosphere of many greenhouse gases such as carbon dioxide, their effects impact on everyone in the world. Global pollution can only be countered by global solutions.

The following sections will address the basic science of the greenhouse effect

- climate variability evidenced by past records
- sources and sinks of greenhouse gases
- the concept of radiative forcing and how it is used
- climate models and how well they simulate past and current climate
- projections of climate change over the 21st century
- impacts of climate change especially those on human communities
- international policy and action regarding



Figure

A greenhouse has a similar effect to the atmosphere on the incoming solar radiation and the emitted thermal radiation.

climate change, including the work of the IPCC

- stabilization of climate
- mitigation of climate change and implications for technology and
- the future challenge

The enhanced greenhouse effect

After our excursion to Mars and Venus, let us return to Earth! To what extent are the greenhouse gases in the Earth's atmosphere influenced by human activity? The amount of water vapour depends mostly on the temperature of the surface of the oceans; most of it originates through evaporation from the ocean surface and is not influenced directly by human activity. Carbon dioxide is different. Its amount has increased substantially—by over 30 per cent—since the Industrial Revolution, due to human industry and also because of the removal of forests . Future projections are that, in the absence of controlling factors, its rate of increase will accelerate and its atmospheric concentration will double from its pre-industrial value within the next hundred years .

This increased CO2 is leading to global warming of the Earth's surface through its enhanced greenhouse effect. Let us imagine, for instance, that the amount of CO_2 in the atmosphere suddenly doubled, everything else remaining the same . The solar radiation budget would not be affected. But the thermal radiation emitted from CO_2 in the atmosphere will originate on average from a higher and colder level than before . The thermal radiation budget will, therefore, be reduced, the amount of reduction being about 4W m^{-2}. To restore the radiation balance the surface and lower atmosphere will warm. If nothing changes apart from their temperature—in other words, clouds, water vapour, ice and snow cover and so on, are all the same as before—a radiative transfer calculation indicates that the temperature change would be about 1.2°C.

In reality, of course, many of these other factors will change, some of them in ways that add to the warming (positive feedbacks), others in ways that reduce the warming (negative feedbacks). The situation is, therefore, much more complicated than this simple calculation;

it will be considered in more detail in section 6. Suffice it to say here, that the best estimate, at the present time, of the increased average temperature of the Earth's surface if CO_2 levels were to be doubled is about twice that of the simple calculation: 2.5°C. As the next section will illustrate, for the global average temperature this is a large change.

Sea-level rise resulting from global warming will, therefore, lag behind temperature change at the surface. During the following centuries, as the rest of the oceans gradually warm, sea level will continue to rise at about the same rate, even if the average temperature at the surface were to be stabilized.

What about the major ice sheets; will their contribution continue to be small in the future?

For both ice-sheets there are two competing effects. In a warmer world, there is more water vapour in the atmosphere that leads to more snowfall. But there is also more ablation (erosion by melting) of the ice around the boundaries of the ice-sheets and calving of icebergs during summer months. For Antarctica, the present estimates are that accumulation is greater than ablation, leading to a small net growth. However, it is possible that larger changes in the ice sheets may begin to occur. The Greenland ice sheet is probably the more vulnerable; its complete melting will cause a sea-level rise of about 7m. Model studies of the ice sheet show that, with a rise in summer temperature in the region of Greenland of more than 3°C—likely to be realized within a few decades—ablation will significantly overtake accumulation and melt down of the ice cap will begin. Such melt down is likely to be irreversible. If the temperature continued to rise to say 8°C or more, much of the melt down would occur during the next 1000 years. Turning to the Antarctic ice-sheet, the part that is of most concern is in the west of Antarctica (around 90°W longitude); its disintegration would result in about 6m of sea-level rise. Because a large portion of it is grounded well below sea level it has been suggested that rapid ice discharge could occur if the surrounding ice shelves are weakened.

In the absence of such rapid change, about which studies at present are inconclusive [89], the contribution of the West Antarctic Ice Sheet to sea-level rise over the next millennium will be less than 3m.

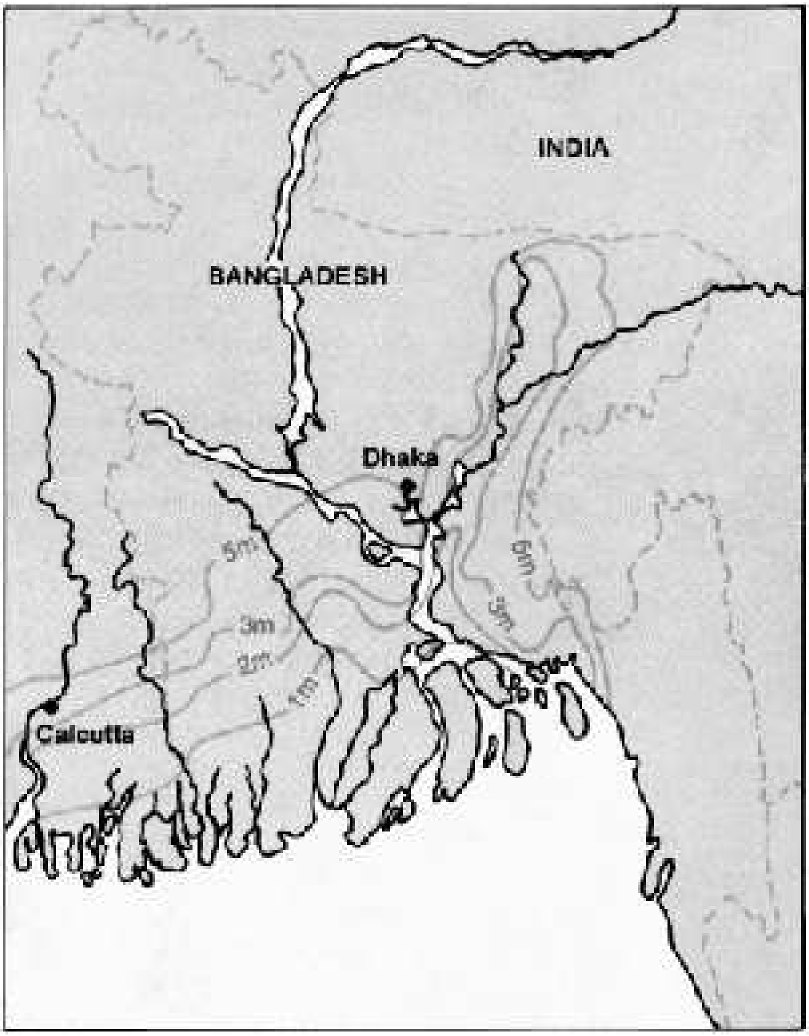
A rise in average sea level of 10 cm by 2030 and about half a metre by the end of the 21st century may not seem a great deal. Many people live sufficiently above the level of high water not to be directly affected. However, half of humanity inhabits the coastal zones around the world. Within these, the lowest lying are some of the most fertile and densely populated. To people living in these areas, even a fraction of a metre increase in sea level can add enormously to their problems. Some of the areas that are especially vulnerable are first, large river delta areas, for instance Bangladesh, second, areas very close to sea level where sea defences are already in place, for instance the Netherlands and third, small low-lying islands in the Pacific and other oceans. Here, we just consider the example of Bangladesh.

Bangladesh is a densely populated country of about 120 million people located in the complex delta region of the Ganges, Brahmaputra and Meghna Rivers About 10% of the country's habitable land (with about 6 million population) would be lost with half a metre of sea-level rise and about 20% (with about 15 million population) would be lost with a 1m rise. Estimates of the sea-level rise are of about 1m by 2050 (compounded by 70 cm due to subsidence because of land movements and removal of groundwater and 30 cm from the effects of global warming) and nearly 2m by 2100 (1.2m due to subsidence and 70 cm from global warming)—although there is a large uncertainty in these estimates.

Further exacerbation of the impact will arise through the combination of sea-level rise with likely increases in the intensity of storm surges in that region. Further, increased salt water intrusion into ground water will occur in many low lying regions. Similar situations to that in Bangladesh exist in other parts of south-east Asia, the Nile delta region of Egypt and delta regions in other parts of Africa and the Americas.

It is not only in places where there is dense population that there will be adverse effects.

The world's wetlands and mangrove swamps currently occupy an area of about a million square kilometres, equal approximately to twice the area of France. They contain much biodiversity and their biological productivity equals or exceeds that of any other natural or agricultural system. Over two-thirds of the fish caught for human consumption, as well as many birds and animals, depend on coastal marshes and swamps for



Land affected in Bangladesh by various amounts of sea-level rise.

part of their life cycles, so they are vital to the total world ecology. These areas could not adjust to the rapid rate of sea-level rise that is likely and in many cases would be unable to extend inland. Net loss of wetland area will therefore occur.

Fresh water resources

The global water cycle is a fundamental component of the climate system. Water is cycled between the oceans, the atmosphere and the land surface. Water is also an essential resource for humans and for ecosytems. During the last 50 years water use has grown over threefold it now amounts to about 10% of the estimated global total of river and groundwater flow from land to sea. Increasingly,water is used for irrigation. In India about 75% of availablewater is so used. Water from major rivers is often shared between nations; its growing scarcity is a potential source of conflict. In many areas, groundwater extraction greatly exceeds its replenishment—a situation that cannot continue indefinitely.

With global warming, there will be substantial changes in water availability, quality and flow. On average, some areas will become wetter and others drier. Substantial changes in variations of flow during the year will also occur as glaciers and snow cover diminishes leading to less spring melt. Much of these changes will exacerbate the current vulnerability regarding water availability and use. Especially vulnerable will be continental areas where decreased summer rainfall and increased temperature result in a substantial loss in soil moisture and increased likelihood of drought.

Even greater impact is likely to occur because of increased frequency and intensity of extremes, especially floods and droughts. Such disasters are the most damaging disasters the world experiences; on average they cause more deaths, misery and economic loss than other disasters. They are especially damaging to developing countries where, in general, they are more likely to occur and where there is inadequate infrastructure to cope with them. Impacts of climate change on fresh water resources are likely to be exacerbated by other pressures, e.g. population growth, land-use change, pollution and economic growth.

Agriculture and food supply

Climate change would affect agriculture and food supply through its impact on crops, soils, insects, weeds, diseases and livestock. Three factors are particularly important; changes in water availability changes in temperature and the effect of increased CO_2 on plant growth. Higher CO_2 concentrations stimulate photosynthesis, enabling some plants (e.g. wheat, rice and soya bean) to fix carbon at a higher rate. This is why in glasshouses additional CO_2 may be introduced artificially to increase productivity. Under ideal conditions it can be a large effect (for doubled CO_2 up to an average of +30% [100]). However, under real conditions on the large scale, where water and nutrient availability are also important factors, increases tend to be substantially less than what is potentially possible. For instance, for cereal crops in mid-latitudes, potential yields are projected to increase for small increases in temperature (2–3°C) but decrease for larger temperature increases.

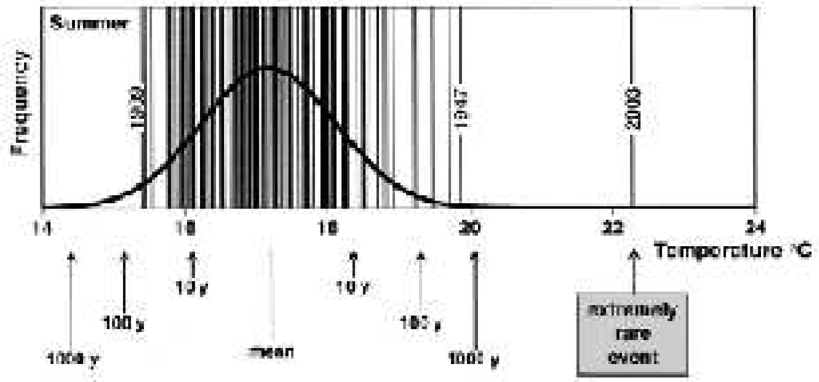
In a world influenced by global warming, crop patterns will change. But the changes will be complex; economic and other factors will take their place alongside climate change in the decision-making process. To estimate the effect of climate change on world food supply, elaborate modelling studies have been carried out. These start with climate change scenarios for different locations and times that are inserted into crop models that then produce projected changes in crop yields. Included also are farm level adaptations (e.g. planting date shifts, more climatically adapted varieties, irrigation and fertilizer application). These yield changes are then employed as inputs to a world food trade model that includes assumptions about global parameters, such as population growth and economic factors. The outputs from the total process provide information projected up to the 2080s on food production, food prices and the number of people at risk of hunger.

Ecosystems

About 10% of the world's land area is under cultivation. The rest is to a greater or lesser extent unmanaged by humans. Of this about 30% is natural forest. Within this area climate is the dominant factor determining the distribution of biomes. Large changes in this distribution have occurred during the relatively slow climate changes in the past. It is the very rapid rate of change of climate that will cause excessive stress on many systems. How much it matters depends on the species and the degree of climate change (e.g. temperature increase or water availability). Two particularly vulnerable types of species are trees and coral. The viability of some large areas of tropical forests under climate change is of especial concern. Many corals are already suffering from bleaching caused by increased ocean temperatures. Further, as large quantities of extra carbon dioxide are dissolved in the oceans, their acidity increases posing a serious threat to living systems in the oceans especially to corals.

Human health

Human health will be affected by many of the impacts described in previous paragraphs such as deteriorating water availability, food shortages and more intense and more frequent floods and droughts. Increased spread of insect-borne diseases, such as malaria, is also likely in a warmer world. The main direct effect of climate change on humans themselves will be that of heat stress in the extreme high temperatures that will become more frequent and more widespread especially in urban populations. Studies using data from large cities where heat



Distribution of average summer temperatures (June, July, August) in Switzerland from 1864 to 2003 showing a fitted Gaussian probability distribution—standard deviation 0.94°C . The 2003 value is 5.4 standard deviations from the mean showing it to be an extremely rare event. Also shown are return periods calculated from conventional statistics assuming no warming trend.

waves commonly occur show death rates that can be doubled or tripled during days of unusually high temperatures. On the positive side, mortality due to periods of severe cold in winter will be reduced.

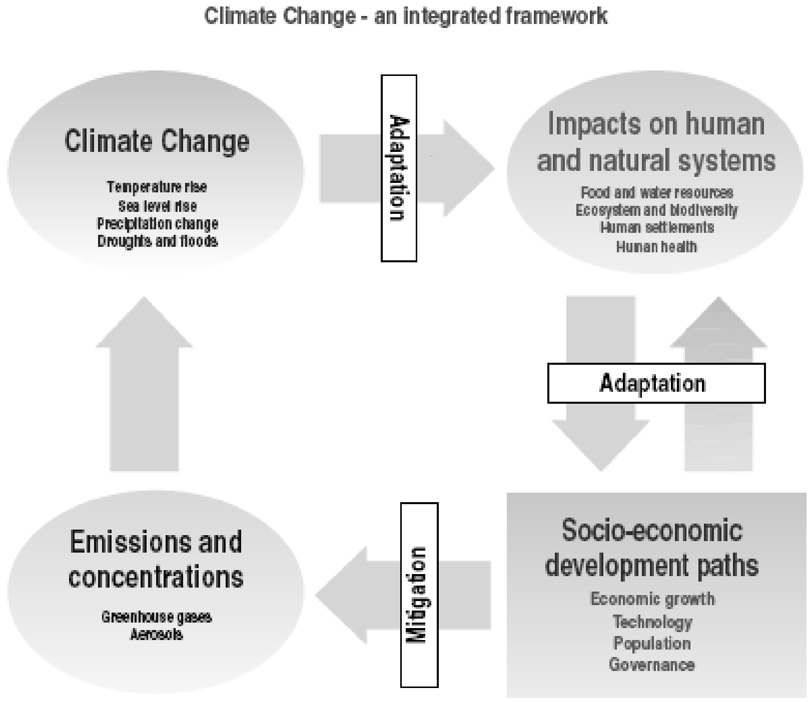
An example of record extreme high temperatures is the heat wave in Europe during June, July and August, 2003. At many locations temperatures rose above 40°C. In France, Italy, the Netherlands, Portugal and Spain over 20 000 additional deaths were attributed to the unrelenting heat. The figure illustrates the extreme rarity of this event. Studies show that it is very likely that a large part of its cause is due to the increase in greenhouse gases, that by

2050 such a summer would be likely to be the norm and by 2100 would likely be a cool summer.

Adaptation and mitigation

There are two kinds of action that can be taken—adaptation to reduce the impacts of climate change as it occurs and mitigation to reduce emissions of greenhouse gases that in turn will reduce the amount of climate change. Some of the impacts of anthropogenic climate change are already becoming apparent and a degree of adaptation is already a necessity. Many adaptation options have already been identified that can reduce the adverse impacts of climate change and can also produce ancillary benefits, but they cannot prevent all damages. Of particular importance is the requirement for adaptation to extreme events and disasters such as floods, droughts and severe storms . Vulnerability to such events can be substantially reduced by more adequate preparation.

It is associated with both the science and the impacts of climate change are considerable uncertainties—. Politicians and others making decisions are, therefore, faced with the need to weigh all aspects of uncertainty against the desirability and the cost of the various actions that can be taken in response to the threat of climate change.



Climate change—an integrating framework. A complete cycle of cause and effect is shown beginning with economic activity (lower right-hand corner) that results in emissions of greenhouse gases (of which CO_2 is the most important) and aerosols. These emissions lead to changes in atmospheric composition and hence to changes in climate that impact both humans and natural ecosystems and affect human livelihood, health and development. An anticlockwise arrow represents other effects of development on human communities and natural systems, for instance changes in land use that lead to deforestation and loss of biodiversity.

Costing the impacts

Probably the largest impact of climate change will be that of the increased number and intensity of extreme events. We noted in section 3 the recent increase in extreme events and the interest of insurance companies who have tracked increasing damage from them in recent decades. Not that insured losses are a good guide to total loss. For instance, the insured losses for Hurricane Mitch that hit Central America in 1998 were small. However, 9000 people died and the losses in Honduras and Nicaragua, respectively, amounted to about 70% and 45% of their annual gross national product (GNP) . China is a country particularly prone to natural disasters; from 1989 to 1996 they resulted in an average annual loss equivalent to nearly 4% of GDP.

International policy and action

As observational and modelling tools for studying the climate advanced during the 1970s and 1980s, the attention of scientists became increasingly directed towards the effects on the climate of human activities. A scientific conference in 1985 organized by the Scientific Committee on Problems of the Environment (SCOPE) a committee of the International Council of Scientific Unions led to an important publication that described the adverse effects that could result from continued and increased anthropogenic emissions of CO_2. That in turn led to increasing awareness amongst politicians of the scale of the potential problem. Two important international bodies were created, one in 1988 concerned with science (the IPCC) and one in 1992 with policy (the Framework Convention on Climate Change (FCCC)). These will be introduced briefly in turn.

The Intergovernmental Panel on Climate Change (IPCC)

The IPCC was formed jointly by two United Nations bodies, the World Meteorological Organization (WMO) and the United Nations Environment Programme (UNEP) with a remit to prepare thorough assessments of climate change, its causes and effects. The Panel established three working groups, one to deal with the science of climate change, one with impacts and a third with policy responses. The IPCC has produced three main comprehensive reports, in 1990, 1995 and 2001 together with a number of special reports covering particular issues.