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Potential health effects of climatic change

Report of a WHO Task Group

This report contains the collective views of an international group of experts and does not necessarily represent the decisions or the stated policy of the World Health Organization

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Preface

The initial draft of this report was prepared by a Working Group that met in Geneva in June 1989. Following the incorporation of the comments from selected WHO focal points, the revised draft was finalized by a WHO Task Group that met in Geneva in April 1990. The participants in the two groups are listed in Annex 1.

WHO would like to thank all the participants for giving so unstintingly of their time and expertise to produce a valuable report.

In addition, gratitude is expressed to the World Meteorological Organization (WMO), the Food and Agriculture Organization of the United Nations (FAO), the Scientific Committee on Problems in the Environment (SCOPE), and the US National Institutes of Environmental Health Sciences (NIEHS) for their substantial contributions to the text.

This report formed the basis of the World Health Organization's contribution to the health section of the report of the Intergovernmental Panel on Climate Change (IPCC) to the Second World Climate Conference in November 1990.

Introduction

This document is designed to assist decision-makers and public health planners in determining the potential health problems that may arise in their region from global climatic changes caused by an increase in "greenhouse gases" and a decrease in the ozone layer. Not all regions will be confronted with the same health problems and only general guidance can be provided. National health authorities need to decide which of the health effects described are most likely to occur in their region, and to take the most appropriate planning action to mitigate these effects.

This publication is not an exhaustive treatise for the expert. It is hoped that the style in which it is written will have a wide appeal and be easily understood, while still retaining technical accuracy.

Human activities have influenced the environment since the first settlements were built and the land cultivated. At that time, the changes were relatively small and were absorbed by the resilience of the environment. Today, however, it is clear that the effects of the unlimited growth of the human population, and of recent unrestricted technological advances, have had a much greater impact on the environment and may well exceed it's capacity to absorb them. The human race is the sole protector of the environment, with the capability to plan wisely, to conserve providently, and to develop prudently. Conversely, it is also capable of polluting or even destroying the environment through greed, ignorance, or indifference.

Emissions of "greenhouse gases" into the atmosphere have been increasing ever since the beginning of the industrial revolution. Today the levels are such that, if continued over the next decades, they could lead to a rise in mean global temperature greater than any experienced in human history. Besides the changes in global climate and climate distribution that this would induce, the global environment would also be affected by an increase in ultraviolet radiation (UVR), due to a decrease in stratospheric ozone caused by the accumulation of chlorofluorocarbon gases (CFCs) and other man-made compounds in the atmosphere.

The extent and distribution of these changes are not well understood, at present, but a number of possible scenarios were developed at meetings held at Villach and Bellagio at the end of 1987 (WMO/UNEP, 1988). Refinements of the models and predictions have been incorporated into the report of the Intergovernmental Panel on Climate Change (IPCC, 1990). Starting from these projections, the following predictions can be used as a basis for discussion on the potential consequences for human health:

- the average global surface temperature could increase by 3 °C (Celsius) by the year 2030 (range: 1.5–4.5 °C);
- this increase would be most marked in the high latitudes of the Northern hemisphere, where it could amount to as much as 8–10 °C; in the equatorial regions and low latitudes, the increase would be closer to the global average, or at the lower end of the range;
- the sea level could rise by 0.10–0.32 m by the middle of the next century; this would be largely due to expansion resulting from the increase in ocean temperature and possibly from the melting of the polar ice-caps;
- the occurrence of extreme climatic events (e.g., heatwaves, monsoons, droughts) might have a more profound impact than the overall average changes, and might be quantitatively more important, especially if overall changes in the average temperature were small;
- the amplitude of climatic variation occurring over the year could increase, leading, in some cases, to more extreme low temperatures in the winter months;
- no valid predictions can be made for another 10 years on the potential regional changes in rainfall or wind patterns; tropical cyclones might become less frequent, but of higher intensity;
- significant changes are unlikely to be seen for at least one decade;

- ultraviolet radiation, mainly UV-B, is expected to increase by a maximum of 20–25% by the year 2050, but this will vary somewhat with latitude.

As no detailed region-specific scenarios are available, predictions on the potential living conditions of human communities and the health effects of the climatic changes have to remain very general and speculative; except in the case of a few diseases and life expectancy, there are insufficient data for the production of any kind of quantitative projection.

Nevertheless, when discussing the various health effects potentially related to climatic change, it is necessary to put them in a population context: many of the conditions discussed hereafter have quite specific distribution patterns in the population with regard to their occurrence and/or effects. Age, level of hygiene and socioeconomic status, skin pigmentation, and health status will all be determinants of the net effects of climatic change. Some examples of the health effects associated with these determinants are shown below.

Age	infant mortality from diarrhoeal diseases, undernutrition
Hygiene, socioeconomic status	waterborne diseases, undernutrition
Skin pigmentation	risk of skin cancer
Health status	susceptibility of cardiovascular system to heat

Similarly, geographical factors will determine the populations at risk from certain conditions or events (e.g., the risk of flooding of low-lying coastal regions as a result of a rise in the sea level) and from the ensuing effects on the maintenance of traditional agriculture, and, for that matter, on nutrition and socioeconomic status.

Precise estimations cannot be made. However, from the relative size of the subpopulations at risk and the severity of the conditions considered, it should be possible, even at this stage, for the governments of countries or larger geographical areas to identify a number of priorities, if only for the timely establishment of appropriate surveillance and monitoring systems.

The distribution of the human population over an extremely wide range of environmental temperature conditions (+55 °C to -60 °C), is testimony to the adaptive capacity of the human species. This typically human potential is the result of evolution, with an extraordinarily high capacity for individual physiological, intellectual, and social adaptability being uniformly distributed among all populations of the world (Weihe, 1979).

Furthermore, environmental factors can induce specific, acquired adaptations in individuals, either morphological (e.g., the barrel-shaped thorax of people living their lives at high altitude) or functional. Social and cultural adaptive measures, such as hygiene practices, clothing, housing, and medical and agricultural traditions, support the reversible adaptation of human beings to a particular environment. The viability of a sociocultural adaptation is determined, among other things, by the strength of the economy, the quality and coverage of medical services, and the integrity of the environment. Societies with robust economic adaptive mechanisms will suffer less severe effects from changes in the environment than cultures where adaptations are precariously maintained, with no reserve resources to call upon in an emergency. It is among these poor societies, representing nearly three-quarters of the world's population, that adverse climatic effects are likely to have a major and lasting impact. Similarly, at the individual level within the population, the less resilient, such as the poor, the disabled, and the sick, are at a higher risk, because they are less able to adapt to adverse climatic conditions.

Climatic changes will develop gradually over several decades. Some of them, such as heatwaves, will have a direct effect on human health (causing heat illness, for example), but many of the changes will have mainly indirect effects by changing natural ecosystems, affecting such aspects as food production, vector-borne diseases, and a number of other infectious and non-infectious diseases. These phenomena are likely to precipitate migration from one rural region to another, and from rural to urban areas. Where, for example, urban areas are threatened by rising sea levels, the flow of migration may be towards rural areas.

If, however, the slow climatic changes are also accompanied, as is feared, by an increase, at least in intensity, of some natural disasters, such as cyclones and floods, immediate effects on human health become more likely. Moreover, these catastrophes can generate large refugee and population movements, with a need for resettlement in what may already be densely populated areas.

Most of the problems discussed in the following sections will not be universally applicable, but health authorities in Member States will be able to identify problems that might eventually be of special relevance to their own situation.

Chapter 1.

Mechanisms of climatic change

Greenhouse effect

About half of the solar energy incident upon the upper level of the atmosphere reaches the earth's surface. The bulk of the remainder is reflected back, with a small amount being absorbed directly by some of the gases and clouds in the atmosphere.

Most of the solar radiation that penetrates the atmosphere is not absorbed by the so-called minor constituents of the atmosphere, namely, water vapour, carbon dioxide, and ozone, and the earth's surface is warmed when it absorbs the radiation. The surface of the earth re-radiates some of the absorbed energy, but this radiation is in the infrared region of the electromagnetic spectrum. This back-radiation has a longer wavelength, and consequently is partly absorbed by the water vapour, carbon dioxide, and ozone in the atmosphere and, in turn, re-radiated back to the earth. Thus, part of the energy re-radiated by the earth's surface, returns to it as a result of the action of the minor constituents, and the earth's surface is maintained at a warmer temperature than would be the case if gases such as water vapour, carbon dioxide, and ozone were not present in the atmosphere. The warming effect of these constituents is known as the "greenhouse" effect and such gases are referred to as the "greenhouse" gases (GHGs). There are other greenhouse gases in addition to the three mentioned.

Causes of climatic change

Changes in the following factors can cause changes in climate: solar output, the earth's orbit, atmospheric composition, the reflecting properties – or albedo – of the earth–atmosphere system, including those due to volcanic eruptions and changes in cloud cover. The effects of these factors could be individual or additive, or they could annul one another or any effects produced by the greenhouse gases.

Changes in the composition of the atmosphere resulting from increases in the concentrations of the greenhouse gases, are now accepted as being the causal factors in a possible warming of the climate on a time scale that may range from decades to a century; the extent of the warming will depend on the magnitude of the increase in concentrations. In comparison, the effects of volcanic eruptions are on a shorter time scale (generally 1 or 2 years) while changes in the earth's orbit are on a glacial/interglacial time-scale.

Calculations of climatic warming

Climatic warming calculations are generally based on the assumption of a doubling of the atmospheric concentration of carbon dioxide over its pre-industrial value. The latter is generally accepted to be 275 ± 10 ppmv (parts per million by volume) (Bolin et al., 1986). These calculations indicate a possible increase in the global average temperature in the range of 1.5–4.5 ^{o}C. Such warming would be of greater magnitude than any encountered in human history (UNEP/WMO/ICSU, 1985). An increase in greenhouse gases other than CO_2 will add to this warming trend.

Thus, the term "equivalent doubling of CO2" has come to be widely used. This is defined as the temperature effect that would result from increases in the concentrations of all GHGs that would be of the same magnitude as the temperature effect resulting from the doubling of the concentration of CO_2 alone, over its pre-industrial value. The timing of such equivalent doubling would obviously depend on future trends in the concentrations of GHGs. Much of the currently observed increase in the GHGs is attributed to power generation, agriculture, animal husbandry, changes in land use, and industrial expansion. Thus, the timing of the equivalent doubling would depend on the future course of these and similar human activities.

There are a number of feedback mechanisms that may exacerbate or moderate the effects of increasing levels of GHGs. These include: the increases in humidity that accompany warming, with subsequent changes in cloudiness; the amount and distribution of ice; and the thermal inertia of the oceans. It should be noted that the calculated range of 1.5–4.5 ^{o}C warming for the equivalent doubling of CO_2 is thought to encompass the effects of these modifying mechanisms

(NAS, 1983). Climatic warming will affect ecosystems. The latter can have a feedback effect on the former. While this is thought to be a positive feedback, there is no generally accepted assessment of it (IPCC, 1990).

The geographical distribution of the climatic warming is still an area of active scientific inquiry. While the computer models agree on the magnitude of average global warming, there is no agreement on regional changes. Changes in precipitation are difficult to predict, even on a global scale. The regional changes are important for analyses of impacts, including those on living conditions and human health.

An important effect of global warming is the thermal expansion of the oceans due to the warming and possible melting of land ice. The resulting rise in sea level would depend on the rate of increase in GHG concentrations. For example, if the equivalent doubling of CO_2 should occur by the year 2030, it has been calculated that the rise in sea level would be in the range of 10–32 cm by that year, with a best estimate of 20 cm. Even if the greenhouse gases were to stop increasing at that time, the sea level would still rise by an additional 23 cm by the year 2100, owing to lags in climate, ocean, and ice mass responses (IPCC, 1990).

In the following sections, the trends observed in the atmospheric concentrations of the principal greenhouse gases will be discussed. The question of ozone change will be included, where it is relevant to changes in climate and to health impacts.

Greenhouse gases of concern

The primary GHGs of concern today are carbon dioxide (CO_2), chlorofluorocarbons (CFCs) and halons, methane (CH_4), nitrous oxide (N_2O), and ozone (O_3). These contribute directly to the greenhouse effect through their thermodynamic properties. There are other gases that, while not having a direct thermal effect, contribute indirectly through their chemical reactions with the GHGs, thus affecting the concentrations of the latter. Examples of such gases are nitric oxide (NO) and carbon monoxide (CO). Some of the GHGs, such as ozone (O_3) and methane (CH_4), have both direct and indirect effects. There are a number of other gases that would be important if their concentrations were to increase dramatically (WMO, 1983).

The effectiveness of any given GHG will depend on the magnitude of the increase in its concentration, its lifetime in the atmosphere, and the wavelengths of radiation that it absorbs. The chlorofluorocarbons (CFCs) are highly effective, because of their absorption characteristics and their long atmospheric lifetimes. One molecule of CFC 11 or 12 has the effect of 10 000 molecules of CO_2 (WMO, 1985). However, carbon dioxide produces the major greenhouse effect today, because of its abundance. The longer the lifetime of a GHG molecule, the longer it will take for the earth–atmosphere system to recover from any change brought about by that GHG.

Carbon dioxide

Carbon dioxide concentrations have been measured in the atmosphere and recorded since 1957, and long and precise time-series are available for different latitudes (Fig. 1 and 2).

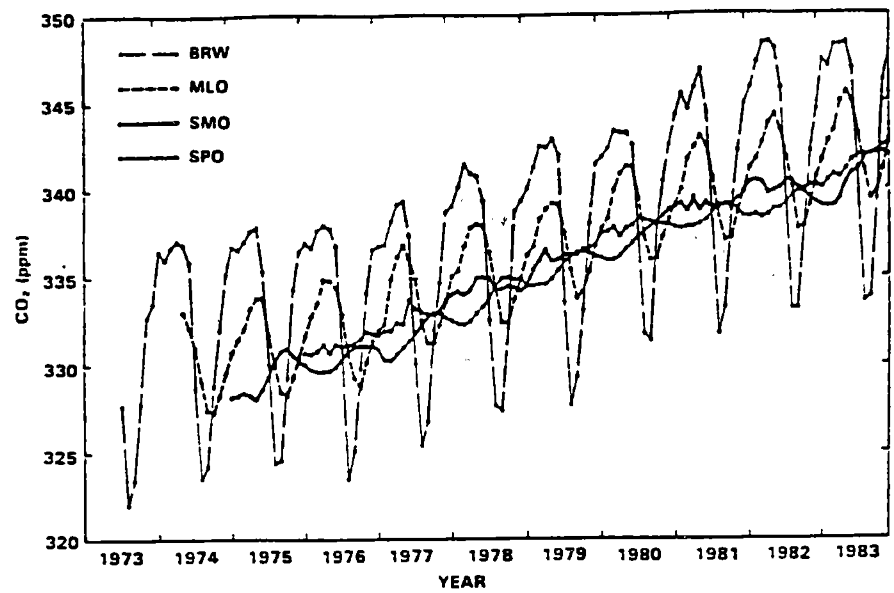


Fig. 1. Selected monthly mean carbon dioxide concentrations from continuous measurements (Barrow, Alaska (BRW); Mauna Loa, Hawaii (MLO); American Samoa (SMO); South Pole (SPO). From: WMO, 1985.

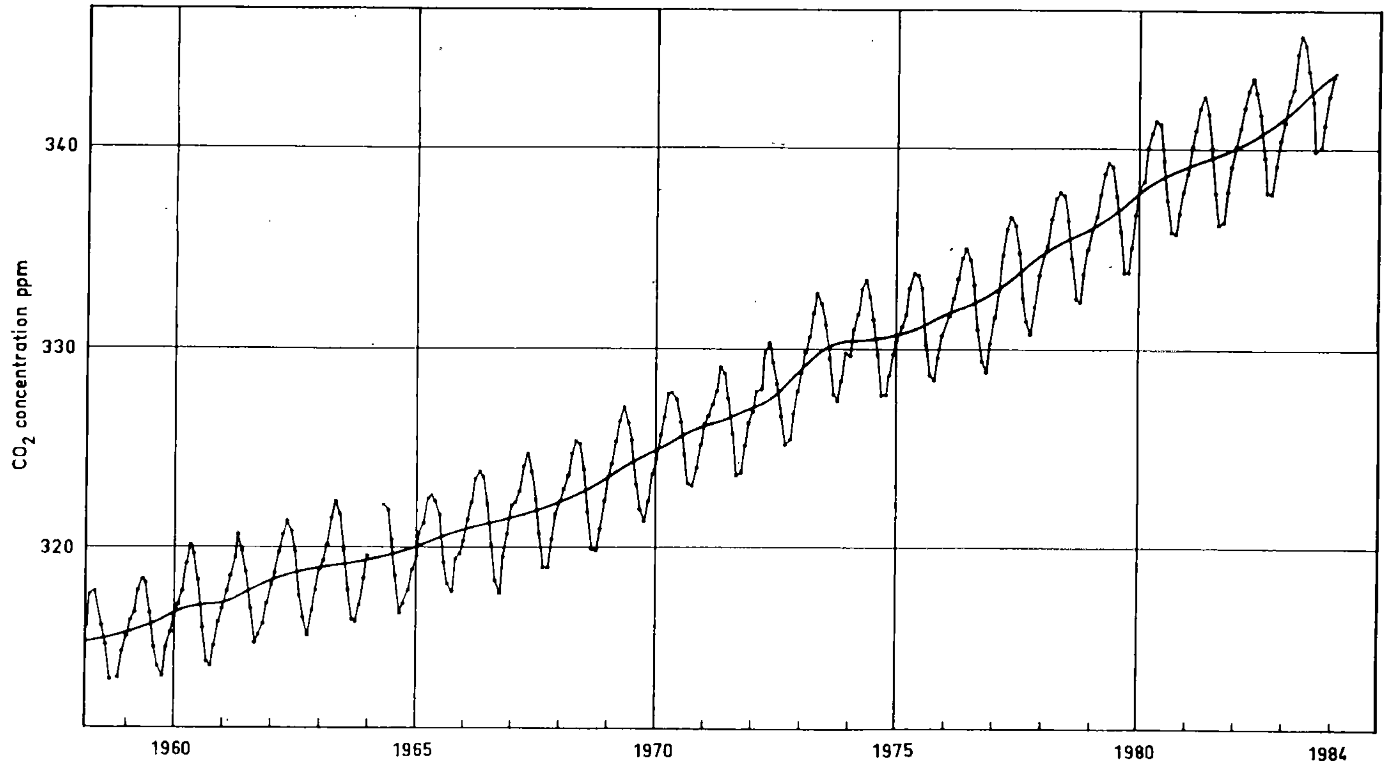


Fig. 2. Concentration of atmospheric carbon dioxide at Mauna Loa Observatory, Hawaii, derived from monthly avarages of continuous measurements. Reproduced from: Bolin et al., 1986.

The seasonal amplitude of CO_2 concentration depends on the latitude, being higher in the northern latitudes. According to measurements of carbon dioxide trapped in the Vostock ice core, the average atmospheric concentration in 1989 was 354 ppmv higher than at any time in, at least, the last 160 000 years. It is rising at about 1.6 ppmv, or about 0.5%, annually. The time taken for atmospheric CO_2 to adjust to changes in sources or sinks is 20–500 years (IPCC, 1990).

About 70% of the total CO_2 emissions today comes from fossil fuel combustion (oil, gas, and coal), while the rest comes from deforestation and changing land use.

The emissions can be linked to atmospheric concentrations in a simple way, using the concept of airborne fraction, i.e., the ratio of the increase in CO_2 concentrations in the atmosphere to total emissions of CO_2 into the atmosphere. The commonly accepted figure today for the airborne fraction is $43 \pm 10\%$ (Bolin et al., 1986), while the remainder finds its way into the various reservoirs, including the oceans.

Chlorofluorocarbons (CFCs)

This class of compounds is purely man-made in origin. It includes CFC-11 ($CFCl_3$), CFC-12 (CCl_2F_2), CFC-113 ($C_2Cl_3F_3$), and CCl_4. These compounds have been used for many years as solvents, refrigeration fluids, spray-can propellants, and, more recently, as blowers in foam-making. Their concentrations have been measured in the atmosphere since 1978 (WMO, 1985). The annual growth rates for atmospheric concentrations have been 5% for CFC-11 (Fig.3) and CFC-12, and 1% for CCl_4. The 1983 concentrations of CFC-11 and CFC-12 were 200 pptv (parts per trillion by volume) and 320 pptv, respectively. The measured concentration of CFC-113 was 32 pptv in January 1985 and that of CCl_4 was 140 pptv in 1979. The 1990 concentrations are about 280, 484, 60, and 146 pptv for CFC-11, CFC-12, CFC-113 and CCl_4, respectively (IPCC, 1990). Much attention has been focused on these compounds, because they are the primary agents causing the destruction of stratospheric ozone. They have long atmospheric lifetimes (75, 111, and about 50 years for CFC-11, CFC-12, and CCl_4, respectively) (Wuebbles & Edmonds, 1988).

Although the concentrations of CFCs have been observed to be higher in the Northern than in the Southern hemisphere, the observed rates of increase are larger in the Southern hemisphere.

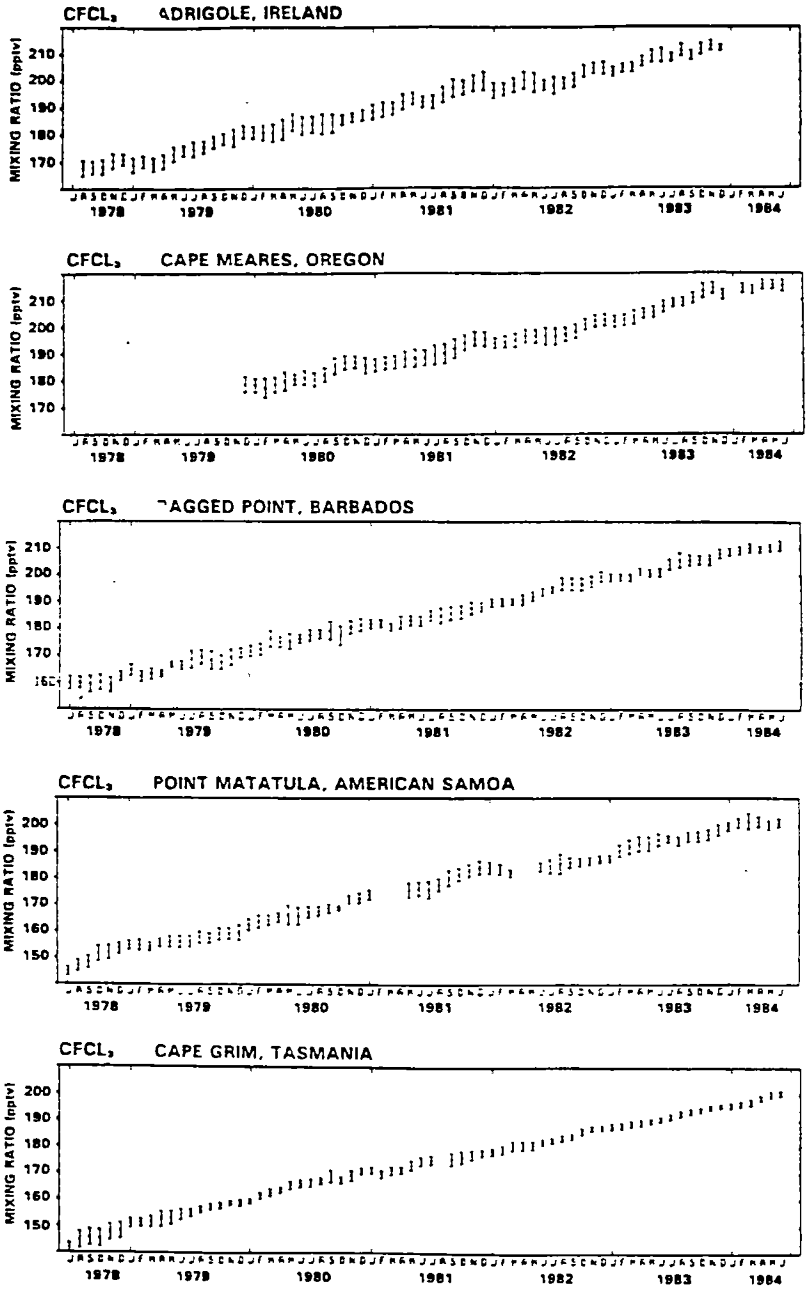


Fig. 3. Mixing ratios for CFC-11 (1978-83), showing measured annual trends of 4.6, 4.3, and 5.2%, respectively, at five stations. From: WMO, 1985.

Halons

Two of these brominated compounds, halon 1301 ($CBrF_3$) and halon 1211 ($CBrClF_2$), have been increasingly used in fire-extinguishers for high technology, aircraft, and military applications. These compounds can also destroy ozone. Their atmospheric concentrations in 1984 were about 1 pptv and 1.2 pptv, respectively (WMO, 1985), and in 1990, about 2 and 1.7 pptv (IPCC, 1990). Halon 1301 is known to have the properties of a greenhouse gas and its atmospheric lifetime is 110 years. The lifetime of halon 1211 is 12–15 years (Wuebbles & Edmonds, 1988).

Methane

Methane (CH_4) is produced by microbial activity in anaerobic environments. The major sources are: wetlands (including wet tundra and sedge), floodplains, peatlands and associated open-water areas, wild fires, rice paddies, termites, and enteric fermentation in ruminants; it is also released in activities such as the exploitation of natural gas, biomass burning, and coal mining. The apportionment among these different sources is highly uncertain.

Fig. 4 shows the global average concentrations of CH_4 from 1977 to 1985 (WMO, 1985). The 1985 average concentrations were 1.7 ppmv in the Northern hemisphere and 1.6 ppmv in the Southern hemisphere, compared with a pre-industrial value of about 0.8 ppmv (IPCC, 1990). The observed increase is about 1% per year. The lifetime of methane in the atmosphere is 11 years (WMO, 1985).

Nitrous oxide

The concentrations of nitrous oxide (N_2O) in the atmosphere are well documented (WMO, 1985). The average global concentration in 1985 was 310 ppbv (parts per billion by volume), with little geographical variation. Its atmospheric lifetime is 150 years. The current annual increase is 0.2–0.3%. A major natural source is thought to be nitrification in soil and water. There are two significant sources that can be ascribed to human activity, namely, the burning of fossil fuel and biomass, and the use of nitrogenous fertilizers.

Carbon monoxide

Carbon monoxide (CO) is not itself a greenhouse gas. In the atmosphere it is chemically coupled to CH_4 and exerts an indirect greenhouse effect. The atmospheric concentrations of CO are higher in

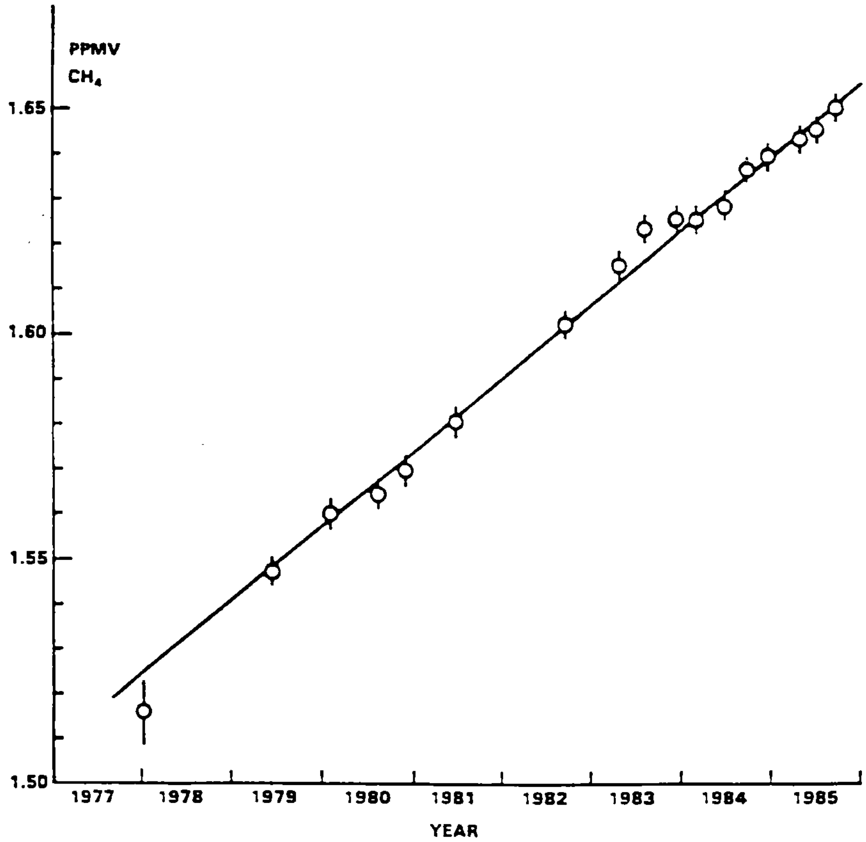


Fig. 4. Global average concentrations of methane from 1977 to 1985.
From: NASA, 1986.

the Northern hemisphere than in the Southern hemisphere and higher in winter than in summer. The major sources of CO are combustion (including biomass burning) and hydrocarbon oxidation. Its atmospheric lifetime is short (2–3 months) with the result that CO concentrations show much variability in time and space. For this reason, the determination of any trend in concentration would be difficult. An annual increase of 1–2% seems likely in the Northern hemisphere, while evidence for the increase in the Southern hemisphere is ambiguous (IPCC, 1990).

Ozone

Much of the ozone (O_3) in the atmosphere (about 90%) resides in the stratosphere, at an altitude of between 15 and 30 km (WMO, 1985). Ozone, while having greenhouse gas properties, also directly absorbs much of the shorter wavelength ultraviolet radiation (UVR) from the sun. Such direct absorption is responsible for the temperature structure of the stratosphere (which is either isothermal or an inversion). This also prevents much of the shorter wavelength, biologically active UVR from reaching the ground.

Ozone is formed by the recombination of an oxygen molecule and an oxygen atom in a three-body reaction. The oxygen atom may originate either from the photolysis of an oxygen molecule (as happens in the upper atmosphere) or the photolysis of NO_2 (as is the case in polluted urban atmospheres). Ozone is also destroyed by photolysis, contact with the earth's surface, and catalytic removal mechanisms, such as those involving the removal of chlorine from CFCs. This removal process has become of great significance, since human activities that release CFCs are now held responsible for such phenomena as the Antarctic ozone "hole".

Selected CFCs and halons are now subject to the provisions of the Montreal Protocol on substances that deplete the ozone layer.

The climatic effects of changing ozone concentrations are strongly dependent on whether the ozone change occurs in the stratosphere or in the troposphere. When stratospheric ozone is lost, the greenhouse effect is diminished, since some of the ozone is no longer there to absorb and re-radiate the earth's infrared radiation. On the other hand, the direct solar UVR that is normally absorbed by it will reach lower levels in the atmosphere, and some will reach the earth's surface. This will have two effects: (i) if the solar radiation reaches the earth's surface then there will be a warming of the surface, in addition to direct adverse biological effects due to UVR; (ii) the ozone-generating process will be more effective at these lower levels. The increasing ozone at the lower levels can still be effective as a greenhouse gas; in fact, on a per molecule basis, ozone in the troposphere, especially in the upper part of it, is a more effective greenhouse gas than ozone in the stratosphere (WMO, 1983). Model calculations indicate that an increase of 50% in tropospheric ozone would lead to a surface warming of about 0.3 °C (Wuebbles & Edmonds, 1988). Thus, it is hard to generalize about the resulting climatic effects of stratospheric ozone loss.

Ozone concentrations have been recorded systematically since 1957 with ground-based and balloon sensors, and since 1978 with satellite sensors.

Ground-based data showed decreases of 3.4–5.1% at latitudes of between 30 and 60 degrees North for December–March between 1969 and 1988, the upper end of the range occurring at the higher latitudes; no statistically significant trend was found in other months. In the rest of the world, with the exception of Antarctica, trends cannot be determined conclusively on the basis of the observed data (IPCC, 1990).

Ground-based data support positive trends in ozone concentrations of about 1% per year below 8 km (troposphere) in the Northern hemisphere. At 40 km (upper stratosphere), satellite data indicated decreases in concentrations of $3 \pm 2\%$ between 1979 and 1982 and between 1984 and 1988. There is also evidence that ozone concentrations have decreased in the lower stratosphere (ca. 25 km) by a few percent globally (IPCC, 1990).

Chapter 2

Direct effects

Climatic stress and adaptation

Human beings can cope with wide extremes in environmental conditions much better than any other species, and can live in virtually every climate on earth. Changing climatic conditions exert stress on the body, requiring regulation of bodily functions to re-establish internal balance. The stress resulting from a change in climatic conditions, in turn, produces a strain within the body to establish the physiological autonomic response and to determine conscious behavioural regulation.

Minor changes within daily life or diurnal climatic variations, which may necessitate adjustment of regulation, go unnoticed without amounting to stress. They do not tax the adaptive capacities of the individual. Unlike plants and animals, human beings have the adaptive ability to contemplate the future and adopt appropriate strategies for protection. The human race has the freedom to alleviate or avoid a climatic stress and, in this way, to protect the body; in addition, an individual can use will-power to modify needs and desires. Climatic stress can be aggravated by inappropriate behaviour or, conversely, can be ameliorated by the use of more adaptive capacities, as awareness of the effects of climate increases. This takes place empirically and is manifested in habits, customs, and cultures that develop through a continuous interaction between human beings and their environment.

If there were a local climatic change to which the native population was not accustomed, the impact of the stress would greatly depend on the ability and willingness of the population to accept the change. Even major, man-made climatic changes are unlikely to be out of the range of climatic variations that have been experienced historically and against which adaptive strategies have been developed. The total number and kind of environmental adjustments needed may be vast; they may also be expensive and may require many sacrifices in life-style and well-being to re-establish and maintain the basic needs. The costs would involve adjustments in: housing, clothing, nutrition, mobility, education, and health services, and the restructuring of production, and involve much of the established infrastructure.

A distinction should be made between the climatic stress for a population and that for an individual. Populations are looked upon as expressing an average adaptive capacity. There is no evidence that there are other than minor differences among different human populations in the capacity to adapt to changes in the thermal climate. Within any population, the individuals with a low adaptive capacity will suffer first and foremost from climatic stress of any magnitude. The relative degree of risk associated with climatic stress is particularly high for individuals with failing functions of the cardiovascular, respiratory, renal, endocrine, or immune systems, for those with immature regulatory systems, such as infants and children, and for those with reduced adaptive regulatory functions, such as the elderly and physically handicapped. Depending on the frequency distribution of these groups of vulnerable individuals in a population, any climatic stress will be more or less effective in causing an increase in the incidence of morbidity and mortality from non-communicable diseases.

Thermal factors

Changing hygrothermal conditions can be expected to influence human health and well-being in proportion to the degree of heat stress. In healthy individuals, an efficient heat regulatory system will normally enable the human body to cope effectively with a moderate rise in ambient temperature. Thus, within certain limits of mild heat stress and physical activity, thermal comfort can be maintained by appropriate thermoregulatory behavioural responses, and physical and mental work can be pursued without detriment. Heat acclimatization will develop after several days of heat exposure and this will help to alleviate the effects of heat stress. However, severe heat stress can result in a deterioration in health including heat illness, with effects ranging from mild reversible cardiovascular disturbances to severe tissue damage and death. Of primary concern are certain high-risk groups in whom even mild heat stress may produce abnormal heat strain and heat-related disorders.

Heat disorders

Disorders due to heat most frequently occur with sudden increases in heat stress (Weiner et al., 1984). Heatwaves regularly produce an increase in the incidence of heat casualties, and few newcomers to very hot climates can afford to ignore the potential hazards of the first few days of heat exposure. Thus, acute heat illnesses are not confined to the tropics; some of the more serious outbreaks have occurred in unacclimatized urban communities in temperate zones, and these are likely to increase with global warming. Intermittent regional temperature variations will have more profound direct effects on health than long-term climatic trends to which populations become adapted.

The initial physiological adjustments to heat, involving changes in cutaneous vasodilatation and fluid balance, often produce mild swelling of the ankles or feet (heat oedema). Syncope can be precipitated by a sudden change in posture or by venous stasis in the legs during prolonged standing. Skin disorders, such as prickly heat and skin rashes, may occur when sweat is allowed to accumulate on unventilated skin. Increased fluid requirements in warmer environments make it imperative to ensure adequate supplies of potable water as a primary health objective. Even when drinking-water is freely available, sweat losses in hot environments are not usually completely replaced. This type of dehydration is best countered by providing readily available supplies of other palatable fluids.

Salt depletion under hot conditions is often manifested by muscle cramps, fatigue, and anorexia. Salt tablets rarely need be taken, except by those undertaking heavy physical work who incur large sweat losses. In some susceptible individuals, salt tablets can cause vomiting. Caution is also required with fluid and electrolyte replacement in persons with renal or cardiac disease.

In urban areas, even in heatwaves, it is unlikely that severe heat exhaustion will arise due to anhidrosis, water-deficiency, or salt-deficiency, when it is possible to restrict physical activity outdoors, to seek shelter, and to have ready access to fluids. However, at present, there are large urban areas of the world where water supplies and cooling systems are inadequate, and where, under heatwave conditions, the availability of water will become extremely critical for human survival.

Heat exhaustion syndromes and heat intolerance can, in the extreme, lead to heat-stroke, which is characterized by hyperthermia with core temperatures of 41 °C (106 °F) or more, central nervous system disturbances leading to convulsions and coma, and often marked anhidrosis, with a hot dry skin. For the majority of unacclimatized people in cities and urban areas, and, especially for the physically unfit and vulnerable, increased cardiovascular strain is the main threat imposed by environmental heat (Schuman et al., 1964, Kilbourne et al., 1982).

Heatwaves present special problems in urban areas because of the retention of heat by buildings, if ventilation for cooling at night is inadequate (Weihe, 1985). Measurement of average hygrothermal conditions will not provide a full indication of the heat stress, as the numbers of heat casualties increase with duration of exposure. Forced air movement, using fans, is generally beneficial, but may be associated with increased thermal discomfort, when the ambient temperature exceeds 38 °C. Early behavioural signs of prolonged heat stress in densely populated areas include increasing discomfort, social intolerance, irritability, and industrial accidents. This may be particularly important where urban "heat islands" occur (WMO, 1986). Those unaccustomed to heat stress may be adversely affected by indirect effects of high ambient temperatures on sleep patterns. Health and safety regulations based on indices of heat stress may require new interpretation, and, in the tropics, industrial activity may need to be curtailed for those working near the limits of heat tolerance (NIOSH, 1986).

Although precipitation patterns cannot be predicted yet, global warming in some regions may be accompanied by an increase in relative humidity, which, in warm environments, greatly increases heat stress and thermal discomfort, because of reduced evaporative cooling from the skin surface.

In summary, the average predicted increases in global hygrothermal conditions can be expected to exert a minor deleterious thermal stress on populations, but adaptation will readily occur with prolonged and gradual warming. Extreme variations and rapid changes in thermal conditions, especially in low latitudes with existing high heat stress, and in densely populated urban areas, will carry an increased risk of heat-related disorders.

Effects of ultraviolet radiation on human beings

Current recorded measurements indicate that there has been a significant decline in the stratospheric ozone concentrations over the Northern hemisphere of the earth of 1.7–3% during the past 20 years. The decrease in total column ozone between latitudes 40° N and 52° N has been more than 5% in the winter-spring months, less than 2% in the summer months, and not significant in the autumn.

Observations in the equatorial zone and Southern hemisphere (except for Antarctica) are too sparse to be evaluated at this time (NASA, 1988). While the ozone decrease has been small, but significant, the increase in biologically effective UVR (UV-B) exposure to date has been minimal. This is due to the seasonal distribution of ozone reduction. The major effects occur in the winter months, when, because of low sun angle and therefore a long path through the atmosphere, UV-B radiation at ground level is normally low. There are also significant seasonal variations. Thus, the increases in UVR at the earth's surface over ambient levels are quantitatively very small (Dahlback et al., 1989). Estimates have been made that, for a 1% decrease in stratospheric ozone, the biologically effective UVR could increase by 1.25–1.5% (Urbach, 1989). Actual measurements of biologically effective UVR in the past 15 years have not shown any increase at ground level (Scotto et al., 1989). In fact, the increase in ozone levels in the troposphere may be responsible for the lack of increase in the UV-B measured at the earth's surface.

The changing ozone column has three different kinds of effects—one biological, due to increases in biologically effective UVR exposure, one chemical, and one related to climatic change. As previously explained, the chlorofluorocarbon gases that are implicated in the ozone layer depletion are also "greenhouse" gases, which currently contribute 10–15% of the global warming, calculated by models.

Because ozone absorbs mainly the UVR with wavelengths less than 325 nm, a reduction in the atmospheric ozone concentration will result in an increase in the 290–325 nm segment of the solar UVR spectrum. For most biological action spectra, this will result in disproportionate increases in biologically effective UVR (Sterenborg & van der Leun, 1987). However, phototoxic reactions are almost only activated by wavelengths longer than 340 nm.

The health effects, occurring largely as a result of increases in biologically effective UVR, are expected to consist of: increases in non-melanoma skin cancer (NMSC) and malignant melanoma skin cancer (MM); increases in eye diseases, primarily cataract; and possible alterations in the immune response.

Increase in skin cancer

Increases in skin cancer are among the best documented adverse human health effects arising from exposure to UVR. The most definitive evidence exists that NMSC is linked to long-term, repeated exposure to mid-range UVR (UV-B 290–320 nm) and therefore likely to increase if ozone depletion continues. Individuals differ greatly in susceptibility, primarily because of genetically determined skin pigmentation. However, the major determinant of the occurrence of skin cancer is the quantity and quality of exposure to sunlight. Races with greater constitutive pigmentation, and those capable of pigmenting easily on exposure to UVR, are minimally affected. Thus, increases in NMSC incidence are likely to affect mainly the 20% of the world's population with light coloured skin (Scotto et al., 1983).

A recent report (Glass & Hoover, 1989) shows that, in the western USA from 1960 to 1986, the incidence of squamous cell carcinoma increased 260% in men and 310% in women, and that of malignant melanoma increased 350% in men and 460% in women. However, on the basis of the most stringent assumptions, and a 3% decrease in stratospheric ozone (NASA, 1988), squamous cell carcinoma should have increased by only about 10% and malignant melanoma by 3% during this period. In addition, the increase in NMSC incidence that has taken place over the past two decades is not likely to have been due to the recently observed ozone decrease, given the long latency associated with the effects of UVR on skin (2–3 decades), but rather to changes in life-style. However, knowledge of action spectra for NMSC development and the projections for the quantity and quality of UVR changes that can be expected in the future, make reasonable estimates of the effects possible. For a 1% depletion in stratospheric ozone, NMSC can be expected to increase, at equilibrium, by about 3% (Slaper & van der Leun, 1987; Urbach, 1989). This projection does not take into account any protective measures that might be adopted.

Depending on the assumptions adopted, and on the model used for calculation of the future concentration of stratospheric ozone, the incidence of NMSC could increase between 6% and 35% after the year 2060. However, these increases may be much larger in the Southern hemisphere, where observed total ozone depletions have been larger, and tropospheric ozone may have declined outside of industrialized areas (Crutzen, 1988; UNEP, 1989).

The evidence for the role of UVR exposure in the development of malignant melanoma is less certain. There is considerable evidence that sunlight exposure plays a role, but the mechanism is certainly different from that operating in NMSC (Scotto & Fears, 1987). While it is much more difficult to estimate the magnitude of the effects, the results of epidemiological studies in the USA suggest that for a 1% reduction in ozone, the incidence of malignant melanoma might increase by 0.6% (Lee, 1989).

Possible alterations in immune responses

In recent years, evidence has accumulated in studies of animal models that exposure to high doses of UV-B radiation produces selective alterations in the immune function that are mainly seen in the form of suppression of the normal delayed type cutaneous immune responses. In animals, this immune suppression is important for the development of non-melanoma skin cancer, and may influence the development and course of infectious diseases, and possibly protect against autoimmune reactions (Kripke et al., 1977; Giannini, 1986).

The evidence that immune suppression is induced in human beings by low doses of UVR is less compelling, though an induction of suppression pathways has been noted following low exposures to sunlight (Hersey et al., 1983). The wavelengths of UVR most affected by possible depletion of the stratospheric ozone layer are those known to be most immunosuppressive in animals, and it is possible that such depletion may increase any existing effect of sunlight on human immunity.

Studies are therefore required: (i) to establish whether or not UV-B radiation can cause significant suppression of humoral immune function in human beings; (ii) to determine whether melanin pigmentation can provide protection against such suppression, and to ascertain the role of any such suppression in the pathogenesis of human skin cancer; (iv) to ascertain whether there are any effects on the development of infectious diseases and on vaccine effectiveness; and (v) to assess the capacity of the human skin to develop protective mechanisms that can limit such damage (Morison, 1989).

Effects on eye diseases

Adverse effects of UV-B radiation on the eye have long been suspected, but have only recently been quantified by human epidemiological studies. These studies became possible when methods to quantify individual ocular exposure were developed.

A consistent dose-dependent association between ocular UV-B exposure and two common types of cataract (cortical and posterior subcapsular) has been shown. Cataracts are a leading cause of blindness in many parts of the world, and an increase in UV-B exposure could increase this burden. Although suggested by experimental studies, evidence does not exist at present to link UV-B exposure with senile macular degeneration. Ocular exposure to UV-B is also associated with several corneal changes: pterygium, climatic droplet keratopathy, and acute photokeratitis (snow blindness). Significant reduction in ocular UV-B exposure results from the use of glasses and hats (Taylor, 1989).

Positive effects of ultraviolet radiation

UVR is known to have systemic effects, the best known being the conversion of 7-dehydrocholesterol to vitamin D_3 in the skin. Deficiency of vitamin D leads to rickets, a disease still frequent in children living north of latitude 60° N. There are other systemic effects, such as improvement of the body's tolerance to toxic agents, lowering of blood pressure, etc. Thus, an increase in ambient UVR could have some beneficial effects, particularly on circumpolar populations.

Adaptation of man to ultraviolet radiation

Under normal conditions, the human skin adapts to long-term UVR exposure by a thickening of the horny layer and an increase in the melanin pigmentation. These phenomena can significantly decrease acute and long-term UVR effects, but the degree of possible adaptation is greatly influenced by genetic background. However, in addition to physiological adaptation, alteration in behaviour by avoiding mid-day exposure wearing more extensive clothing, hats, and glasses will provide significant protection. Furthermore, modern chemical sunscreens have become very effective, if used properly.

It seems reasonable that these mostly minor modifications of behaviour, which are neither energy intensive nor expensive, would mitigate the risks of skin cancer from increases in UVR exposure for races with light-coloured skin.

Air pollution

The assessment of the possible effects of predicted climatic changes depends on the results of unverified models, since the resilience to change of the many terrestrial, hydrospheric, atmospheric, and stratospheric elements involved is complex and not well understood.

Atmospheric concentrations of pollutants are influenced by a variety of factors, such as topography, wind speed, wind direction, precipitation, and weather patterns. It is expected that "global warming" will cause changes in many of these factors, but it is not possible to predict with accuracy how the frequency distributions will change at a specific location. Some regions may experience more frequent and prolonged periods of atmospheric stagnation (low wind speed and thermal inversion) and others, less frequent periods. As a result, modifications may be needed to emission control implementation plans that have been designed on the basis of past air pollution and meteorological statistics.

Most man-made air pollutants come from the combustion, complete or incomplete, of fossil fuels used for the generation of heat and power. The current increase in the concentration of carbon dioxide would not have, itself, any discernible direct effects on human health. However, fossil fuels contain compounds of sulfur which, when oxidized to sulfur dioxide, sulfur trioxide, and sulfuric acid, can cause irritation of the respiratory tract, leading to adverse effects on health. The resulting acid rain is also the subject of current concern because of its effects on forests and aquatic biota. Burning of fossil fuels also causes the emission of carbon monoxide, oxides of nitrogen, polycyclic aromatic hydrocarbons, and a host of other potentially toxic, carcinogenic, and chemically active species. The net increase or decrease in these pollutants will largely depend on the trend in global fossil fuel consumption, rather than on the balance between a decreased need for industrial and domestic heating because of less cold winters, and an increased demand for air conditioning in the summer.

Global warming and depletion of the stratospheric ozone layer will have a direct effect on the production of ozone at the earth's surface. Almost all of the ozone at ground level is produced in the lower atmosphere as a result of complex photochemical reactions catalysed by sunlight, involving the oxides of nitrogen and reactive hydrocarbons, the main source of which is the motor vehicle. In addition to ozone, peroxyacetyl nitrates (PANs) are produced. Increases in incident sunlight, temperature, and oxidant reactants are expected to raise the concentrations of tropospheric ozone, thereby increasing the problem of photochemical smog.

There is little doubt that air pollution causes increased respiratory morbidity and mortality (Whittemore, 1985). Ozone, in concentrations measured in ambient air, has been shown to irritate and cause inflammatory reactions in the respiratory tract of sensitive individuals (Schneider T., 1989). However, in combination with other pollutants, such as acids, the effect can be very much greater. A number of different pollutants, e.g., pesticides, CFCs, metal aerosols, and organic carcinogens can interact in the atmosphere and produce more toxic products, and the products may be subject to long-range atmospheric transport and in this way affect distant populations. Both ozone and PAN are phytotoxic and their effects on food crops and plants are also of indirect importance to human health. The effects of increases in UVR and temperature at ground level are difficult to predict, but any increase in the concentrations of the secondary pollutants, ozone and PAN, as a result of climatic change, would be undesirable. For example, these changes may make air quality standards for ozone more difficult to meet, which, in turn, could result in serious economic consequences for countries in which control programmes for ozone are mandatory.

Apart from the effects of global climatic changes, air pollution is expected to increase throughout the world because of extending industrialization. The precise impact of global warming on air pollution and population exposures cannot be clearly defined. However, the potential exists for major changes in the concentrations, duration, and types of pollution, all of which could significantly affect air pollution-related morbidity and mortality in populations throughout the world.

Chapter 3

Indirect effects

Food and nutrition

Even in the absence of large, overall, long-term changes in the global climate, there may be an increase in the frequency and intensity of short- to medium-term climatic changes. These will modify the nutritional requirements of the exposed individuals and affect agriculture and, hence, food production and consumption. A direct effect of UVR on biota, including marine organisms and plants, could also adversely affect agriculture, food, and fisheries.

Nutritional requirements

The human body requires nutrients, minerals, vitamins, and water for growth and development, tissue maintenance, and physical and mental well-being. While the basic energy requirement, expressed as the basal metabolic rate, is the same for all people, independent of climate, the total daily energy requirement is closely related to physical activity, age, body composition, gender, and genetic make-up. Insulation of the body plays an important role in the conservation of energy, by the retention of body heat.

Energy requirements generally increase with colder conditions, higher activity levels, and reduced body insulation. They decrease with a warmer environment, reduced work rates, and reduced heat dissipation. Hence, there is an apparent relationship between latitude and human energy requirement, it being lowest in hot, humid climates and highest in cold, dry climates. This difference has been mitigated, to some extent, by the wider application of technologies for the control of the thermal environment inside dwellings and changes in life-style and industrial production, particularly in the temperate and cold climates. It is unlikely that nutritional requirements will change drastically because of a change in temperature.

Food production

Both short- and long-term variations in climate will continue to be important determinants affecting agricultural, livestock, and fish production, in the future. The adequacy of food supplies could be affected in four principal ways: (i) spatial shifts in the agroclimatic zones suited to the growth of specific crops; (ii) changes in crop yields, livestock output, and fisheries productivity; (iii) reduction in the quantity of water available for irrigation; and (iv) loss of land through sea level rise.

In zones that now have a temperate or cold climate, an increase in average temperature, solar radiation, and rainfall can, in general, be expected to give higher yields and to extend the arable area towards higher latitudes and altitudes. However, at present, little is known about possible changes in total annual rainfall, let alone about changes in its seasonal distribution. Experience in semi-arid regions includes several short-term climatic events during the 1980s (i.e., exceptional drought periods in northeastern Brazil and southern and eastern Africa, and extensive floods in Ecuador and Peru). In all cases, there was a substantial reduction in agricultural productivity, and, in extreme, but not infrequent, instances, this led to famine, increased starvation, and death (Perry et al., 1989).

A number of factors will determine whether such climatic events will result, in certain areas, in disruption of the existing food requirements/food production balance, or simply in a relative and temporary decrease in yields, without any dramatic impact on the nutritional and general health status of the population. Deficits in agricultural yield in one area are currently offset by imports from areas with a surplus.

Regions that, at present, are in a precarious agro-economic equilibrium, because of overpopulation and marginal climatic conditions, are the most vulnerable to even small changes in the frequency, seasonal timing, or length of drought periods. Drought is an important, though not the only, factor in the process of desertification, and is most often a contributing factor to other underlying problems plaguing societies that are dependent on agriculture for their livelihood and welfare (Glantz, 1986).

Altered meteorological conditions can lead to the destruction of growing crops, resulting in crop failure, which could leave the soil exposed to wind erosion. Wind-blown dust can also destroy crops in adjacent areas. Ground water availability and quality may be adversely affected through increased demand due to population shifts and higher temperatures, or through contamination and salination due to the rising sea levels.

Following a rise in sea level, inundation could result in the displacement of millions of people from large urban centres and fertile coastal regions (Brown et al., 1989). This would create not only an unmanageable number of environmental refugees but also food shortages that could easily reach famine proportions in some regions. Sea-level rise is also a threat to the food supplies of countries and communities heavily dependent on coastal acquaculture. For example, extensive shrimp and fish ponds throughout Asia could be flooded, and almost all the hatcheries for fish fry could be destroyed, since they are generally sited as close as possible to the sea and set at a level that permits tide-aided filling and draining.

In other parts of the world, where the present climatic conditions are less marginal for agricultural production, the economic resources, the sociopolitical organization, or the expertise might be insufficient to ensure a timely adaptation to changing climatic conditions. The adoption of new crops or of new agricultural or forestry techniques requires extensive economic and educational programmes, which are currently lacking in large parts of the world. However, since the main impact of climatic change is several decades away, and new measures could be developed and introduced within 10–20 years, the international community should be able to assist countries that might be affected to respond. Even in the absence of severe quantitative effects on the agriculture, climatic variations are likely to reduce the variety of crops, thereby causing a narrowing of the dietary spectrum. Under such conditions, infants, children, and pregnant women are especially at risk owing to the lack of the balanced nutrition required for healthy growth and development. As a result, large segments of the population might develop specific nutritional deficiencies (Harrison, 1990).

Changing climatic conditions may also result in a new spectrum of plant pathogens and pests that have a major effect on food production. Finally, there may be an effect on food storage and distribution, where warmer, humid conditions may enhance the growth of bacteria and moulds and their toxic products, such as aflatoxins. This would probably result in increased amounts of contaminated and spoilt food, the consumption of which has been demonstrated to have adverse health effects on man and animals.

Even in the absence of any climatic change, the number of malnourished people is projected to increase over the next 10–20 years, and in several countries it will be difficult to raise food production in line with the population increase (FAO, 1987a).

The predicted shifts in food production and availability due to climate change will exacerbate the existing detrimental effects on the health of the population. These effects are summarized in Table 1.

Table 1. Potential effects of climatic change on food availability

Primary effects	Secondary effects
Child malnutrition	-impairment of physical and intellectual development -increased morbidity and mortality
Adult malnutrition	-impairment of work capacity -deficiency syndromes -increased morbidity and mortality
Poverty	-childhood mortality and many other health problems
Famine	-morbidity, incapacity and increased mortality

Despite the population increase, an absolute, global food shortage has not yet been forecast. It is clear that the most severe effects on human health are to be expected in developing countries. In countries with greater adaptive capabilities, the climatic changes might simply result in a more or less temporary decrease in income, and intermittent food shortages.

While not strictly a health effect, another threat to the earth's resources from climatic change is a loss of biological diversity. Many animal and plant species have provided mankind with food, drugs, and other useful products. A vast number of species have not yet been investigated for potentially beneficial products; these can be regarded as a large untapped resource that could be developed by future generations. Changes in climate, destruction of the rain forests, and other interventions by mankind will disturb the ecological niche of many species of plants and animals, which could then become extinct and their existing and potential benefits lost forever.

Effects of ultraviolet radiation on biota other than man

Marine organisms

Marine organisms in the upper layers of the sea may be endangered by increased UVR resulting from a reduction in the thickness of the stratospheric ozone layer. There is strong evidence that exposure to UVR decreases algal productivity and causes damage to various forms of aquatic larvae and other organisms. Indeed, there is evidence to suggest that present levels of UVR incident on the surface of the ocean affect a number of aquatic organisms (Worrest & Caldwell, 1986; Bidigare, 1989).

A major problem in testing this hypothesis is the difficulty of quantitatively extrapolating laboratory and shipboard results to the potential effects of increased UVR on natural populations. The problem includes the natural variability of in-water radiation levels and the range of physical and biological processes influencing this variability. Adding to this difficulty are the wide range and natural variability of aquatic organisms, their developmental stages, pigment absorptive characteristics, and different sensitivities to UVR flux, mediated simply through selection of resistant types. There is also a potential for significant indirect effects, such as changes in community structure.

Thus, the estimates of the effects of increased UVR on populations of marine organisms range from insignificant to catastrophic (Calkins, 1982; Smith, 1989).

Terrestrial plants

The potential impacts of an increase in solar UVR reaching the earth's surface due to stratospheric ozone depletion, have been investigated by several research groups during the last two decades. Overall, the effects of UVR vary among both species and cultivars of a given species. Sensitive plants often exhibit reductions in growth (plant height, dry weight, leaf area, etc.), photosynthetic activity, and flowering. Competitive interactions may also be altered indirectly by differential growth responses. Photosynthetic activity may be reduced by direct effects on photosynthetic enzymes and metabolic pathways, or, indirectly, through effects on photosynthetic pigments or stomatal function. The spectral dependence of these changes has yet to be clearly demonstrated. Plants sensitive to UVR may also respond by accumulating UV-absorbing compounds in their outer tissue layers, which presumably protect sensitive targets from UVR damage. Several key enzymes in the biosynthetic pathways of these compounds have been shown to be specifically induced by UV-B radiation.

The effects of UVR on plant yield, under field conditions, have been documented in only a few studies. One of these is a six-year study on soybeans demonstrating yield reductions under a simulated ozone depletion of 25%. These effects are further modified by the prevailing microclimatic conditions. Plants tend to be less sensitive to UVR when subjected to drought or mineral deficiency, while sensitivity increases with low levels of visible light. Further studies are needed to understand the mechanisms of UV-B effects and the interactions with present stresses and future projected changes in the environment (Worrest, 1986; Coohill, 1989; Tevini & Teremura, 1989).

Communicable diseases

When discussing the impact of the projected climatic changes on communicable diseases, two basic mechanisms can be distinguished. The first mechanism operates through a modification of the ecology of vectors (mostly arthropods) of a series of diseases that are currently prevalent, mostly in tropical and subtropical regions. The second mechanism is through a direct modification of human-related risk factors, the most important of which, in this context, are the availability and quality of water for drinking, cooking, sanitation, and irrigation. Furthermore, diseases related to the soil, airborne diseases, and diseases related to human behaviour may also show changes in distribution, as a result of the socioeconomic consequences of climatic change.

Vector-borne diseases

The occurrence of vector-borne diseases is widespread, ranging from the tropics and subtropics to the temperate climate zones. With few exceptions, they do not occur in the cold climates of the world.

The occurrence of vector-borne diseases is largely determined by: (i) the abundance of vectors and intermediate and reservoir hosts; (ii) the prevalence of disease-causing parasites and pathogens suitably adapted to the vectors, the human or animal host, and the local environmental conditions, especially temperature and humidity; and (iii) the resilience and behaviour of the human population, which must be in dynamic equilibrium with the vector-borne parasites and pathogens. Climate affects each of these factors and the specific role of climate and possible effects of climatic change can best be described in epidemiological models (Fig. 5). Such a model has been

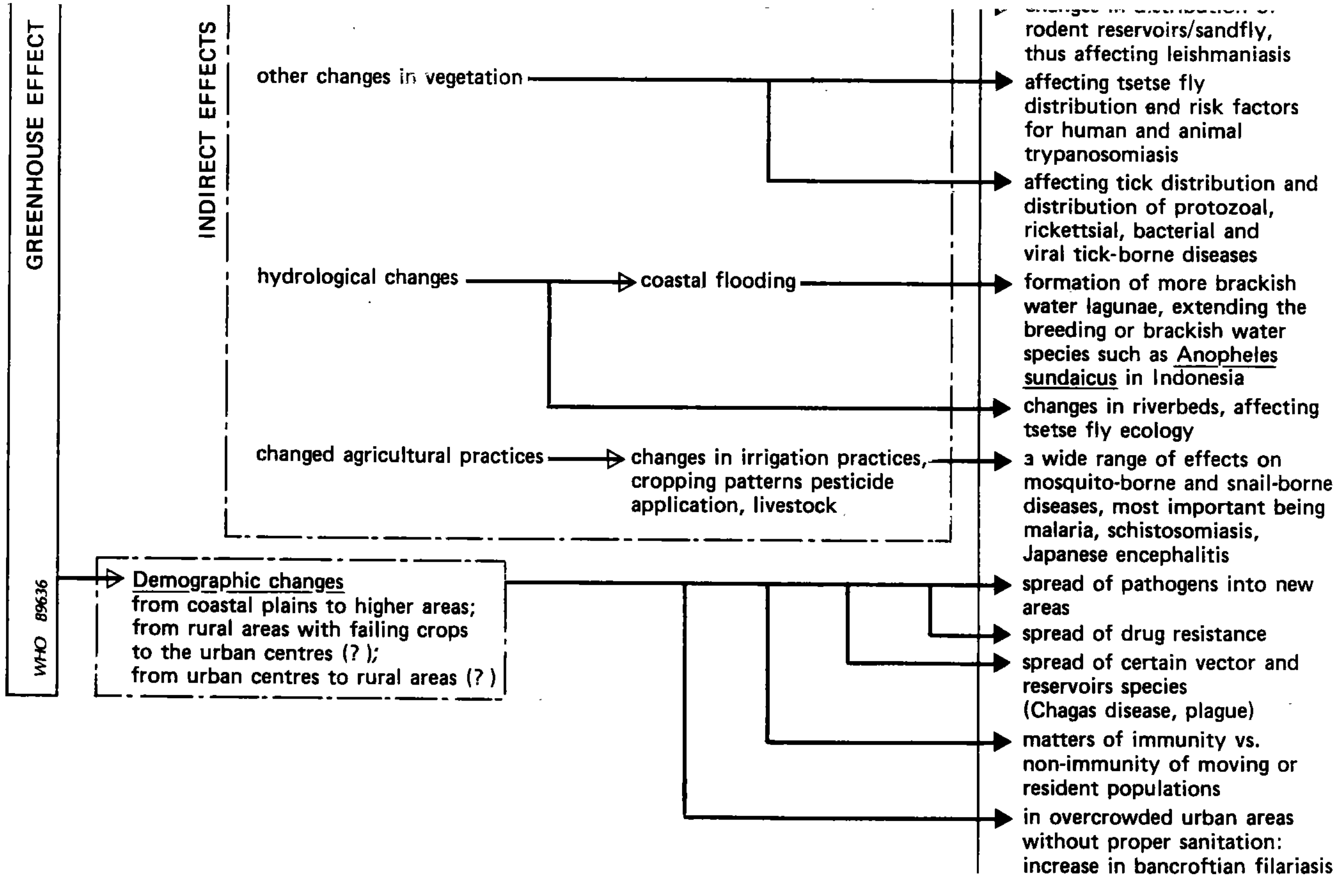
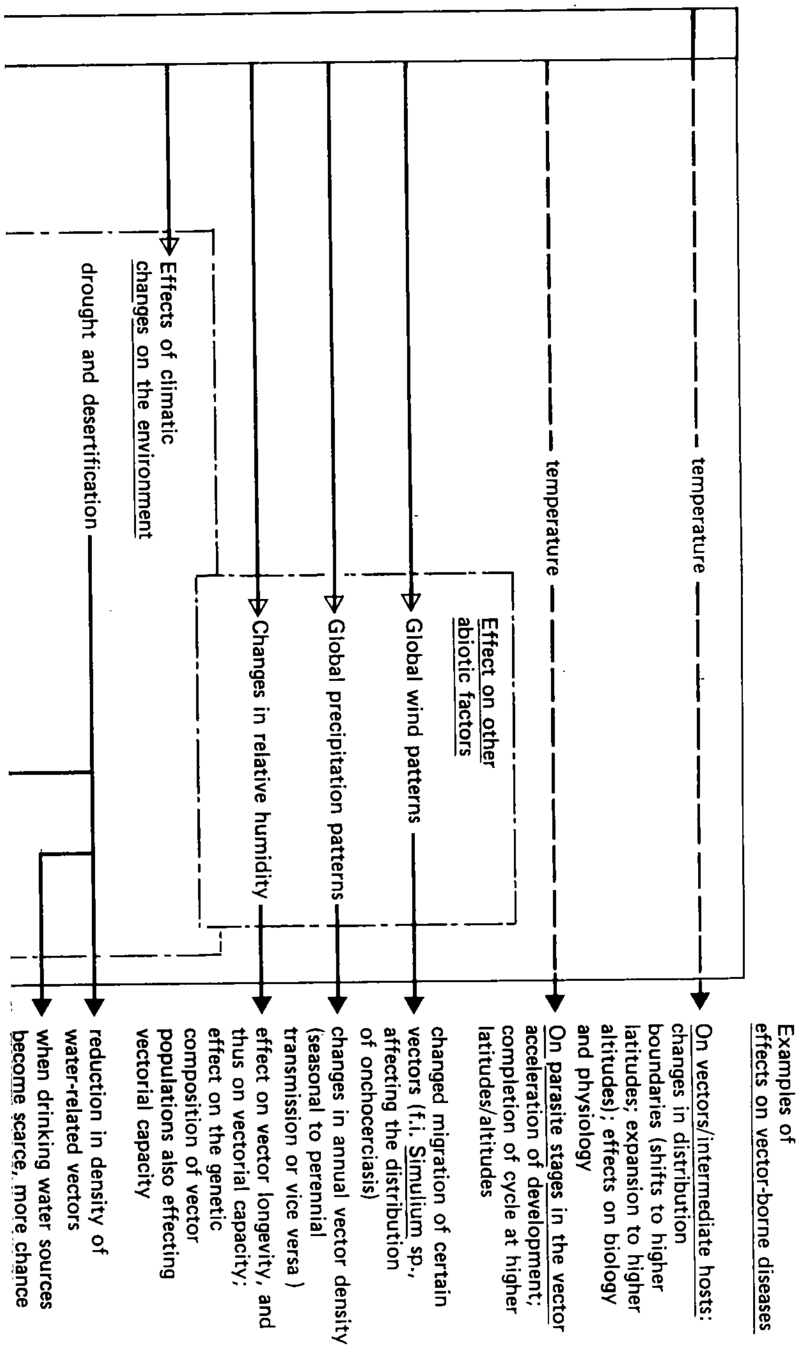


Fig. 5. Possible effects of climatic change due to the greenhouse effect on vector-borne disease epidemiology.


Examples of effects on vector-borne diseases
temperature
On vectors/intermediate hosts: changes in distribution boundaries (shifts to higher latitudes; expansion to higher altitudes); effects on biology and physiology
temperature
On parasite stages in the vector acceleration of development; completion of cycle at higher latitudes/altitudes
Effect on other abiotic factors
Global wind patterns
changed migration of certain vectors (f.i. Simulium sp., affecting the distribution of onchocerciasis)
Global precipitation patterns
changes in annual vector density (seasonal to perennial transmission or vice versa)
Changes in relative humidity
effect on vector longevity, and thus on vectorial capacity; effect on the genetic composition of vector populations also effecting vectorial capacity
Effects of climatic changes on the environment
drought and desertification
reduction in density of water-related vectors
when drinking water sources become scarce, more chance

described for malaria (Macdonald, 1957) and models of this type have been reviewed by Rogers (1988). The possible effects of climatic change on vector-borne diseases are illustrated in the figure above, and are discussed in detail below.

In the descriptive model (Fig. 5), it is suggested that climatic change may lead to a shift of risk areas, depending on the ecology of the parasite-vector complex.

The most important vector-borne diseases are listed in Table 2. From these data it is evident that a large proportion of the world's population is at risk, particularly in the tropics. It should be mentioned that, until relatively recent times, endemic malaria was widespread in Europe and parts of North America (Bruce-Chwatt & de Zulueta, 1980) and that yellow fever occasionally caused epidemics in Portugal, Spain, and the USA (Brès, 1986). Stringent control measures, possibly aided by adverse environmental conditions, and certain changes in life-style following economic progress, have led to the eradication of malaria and yellow fever in these areas. The recent accidental introduction in the USA of *Aedes albopictus*, a vector of the virus causing dengue and dengue haemorrhagic fever in South-East Asia, has given much reason for concern, especially since higher ambient temperatures caused by climatic change may enhance the vectorial capacity of this mosquito (Knudsen, 1986).

The possible changes in the distribution of vector-borne diseases (Table 2) reflect changes due to variations in abiotic factors only. Since the effects on human behaviour can only be speculative, changes caused by such responses as altering agricultural practices or demographic movements have not been considered here.

(1) *Malaria*. Rises in temperature and rainfall would most probably allow malaria vectors to survive in areas immediately surrounding their current distribution limits. How far these areas will be extended would depend on the magnitude of the change in climate. A detailed description of the relationship between the incidence of malaria and the climate is given on pages 40–42 of this book.

(2) *Lymphatic filariases*. The vectors of these diseases are tropical mosquitos, mainly associated with unplanned urbanization. Extension of the current tropical areas will probably be accompanied by a wider distribution of the vectors, but the incidence of these diseases depends largely on the local level of health infrastructure — latrines, covered sewage systems, and the management of floating vegetation — so that the risk will be determined more by the degree of socioeconomic development than by climatic factors.

Table 2. Global status of major vector-borne diseases[a]

No.[b]	Disease	Populations at risk (millions)[c]	Prevalence of infection (millions)	Present distribution	Possible change of distribution as a result of climatic change[d]
1.	Malaria	2100	270	tropics/subtropics	+ + +
2.	Lymphatic filariases	900	90.2	tropics/subtropics	+
3.	Onchocerciasis	90	17.8	Africa/L. America	+
4.	Schistosomiasis	600	200	tropics/subtropics	+ +
5.	African trypanosomiasis	50	(25 000 new cases/year)	tropical Africa	+
6.	Leishmaniases	350	12 million infected + 400 000 new-cases/year	Asia/S. Europe/ Africa/S. America	?
7.	Dracunculiasis	63	1	tropics (Africa/Asia)	o
	Arboviral diseases				
8.	Dengue	no estimates available		tropics/subtropics	+ +
9.	Yellow fever			Africa/L. America	+
10	Japanese encephalitis			E/S.E. Asia	+
11.	Other arboviral diseases				+

[a] Source: WHO 1990.
[b] The numbers refer to explanations in the text.
[c] Based on a world population estimated at 4.8 billion (1989).
[d] o = unlikely; + = likely; + + = very likely; + + + = highly likely; ? = not known.

(3) *Onchocerciasis*. The distribution of onchocerciasis is highly dependent on the presence of specific vectors, which, at present, are not invading areas that are climatically suitable for them. Possibly, small changes in distribution, due to climatic change, will occur locally, but major shifts are not expected.

(4) *Schistosomiasis*. It is assumed that distribution patterns of schistosomiasis are determined by the presence of suitable intermediate hosts, and by activities involving contact with freshwater, including labour intensive agricultural practices, which contribute to increased transmission. An increase in the climatic conditions favourable for the development of the disease, may lead to a significant expansion of risk areas, provided that the intermediate hosts invade the previously unfavourable areas and are able to compete successfully for survival. Since, in many areas, the prevalence of schistosomiasis is closely linked to irrigated agriculture, predicted increases in rice cultivation in new areas may lead to a further increase in this disease (IRRI/ PEEM, 1988).

(5) *African trypanosomiasis*. The present distribution of African trypanosomiasis is discontinuous throughout tropical Africa. In some areas, notably E. Africa, serious epidemics occur at times when all the ecological elements necessary for effective transmission are favourable. Higher rainfall in the forest belt may lead to increased breeding of the tsetse fly, the only known vector of human African trypanosomiasis. Climatic change could also affect the development of the parasite in the vector. Whatever the scenario, the changes in the environment due to climatic change will probably be slow and it should be possible to respond to changes in tsetse fly distribution in order to avoid an increase in transmission.

(6) *Leishmaniases*. The various forms of leishmaniasis occur under contrasting climatic conditions throughout the world. The effects of climatic change on the vector are unclear.

(7) *Dracunculiasis*. Distribution of the disease is determined by the presence of intermediate hosts, i.e., small crustaceans that live in wells and permanent pools of standing water. It remains to be seen whether climatic change will lead to a redistribution of these intermediate hosts.

(8-11) *Arboviral diseases*. The vectors of arboviral diseases are known to breed over a wide range of climatic zones and may invade areas that are not infested at present, if the temperature and humidity rise. Furthermore, some species can establish themselves successfully in new areas, e.g., *Aedes albopictus* in the USA. Because arboviral diseases can, under favourable environmental conditions, change from endemic to epidemic forms, caution must be exercised in predicting what might happen to these diseases as a result of climatic change. An increase in temperature, for instance, shortens the reproductive cycle and extrinsic developmental period of the pathogens, allowing transmission of several arboviral diseases, such as St Louis encephalitis, Japanese encephalitis, dengue, and Rift Valley fever (Kay et al., 1989).

Direct effects

Vectors require specific ecosystems for survival and reproduction. These ecosystems are influenced by a number of factors, which are listed in Table 3. Changes in any of these factors will affect the survival and hence the distribution of vectors (Kay et al., 1989). The projected global climatic changes discussed elsewhere in this document may, therefore, have a considerable impact on the distribution of vector-borne diseases.

Table 3. Environmental factors determining the survival of vectors of disease-causing agents

Abiotic	temperature precipitation relative humidity wind solar radiation topography fresh water ponds, rivers, lakes
Biotic	vegetation hosts (mammals, reptiles, birds) natural predators, parasites, pathogens of the vector

A permanent change in one of the abiotic factors may lead to an alteration in the equilibrium of the ecosystem, resulting in the creation of more favourable or less favourable vector habitats. At the present limits of vector distribution, the projected increase in average temperature is likely to create more favourable conditions for the vectors, which may then breed in larger numbers and invade formerly inhospitable areas. The projected increase in global temperature, coupled with an increase in rainfall, may lead to an expansion of favourable habitats for malaria vectors, whereas reduced rainfall associated with such temperature increases may create new habitats for the phlebotomine vectors of leishmaniasis. Human lymphatic filariasis transmission may be reduced if there is a decrease in ambient relative humidity.

The anticipated changes in temperature and precipitation resulting from global warming will affect vector reproduction and longevity. Hence, disease transmission that is at present seasonal may change to perennial transmission and vice-versa. In addition, changes in vectorial capacity may occur because the rate of development of the parasites and pathogens in the vector is temperature controlled. Regions at higher altitudes or latitudes may become hospitable to the vectors. Thus, disease-free highlands, such as parts of Ethiopia, Indonesia, and Kenya, may be invaded by vectors as a result of an increase in the annual temperature.

From these limited descriptions, it is apparent that major shifts in vector densities and distribution can be expected. The present distribution limits of vector-borne diseases and their vectors are fairly well known (WHO, 1989a). It is important to emphasize that vectors often occur far beyond the areas in which the disease that they transmit is prevalent (e.g., malaria, dengue), and that other factors not related to the environment (e.g., degree of socioeconomic development, hygiene, health delivery system) are important determinants of disease prevalence. For example, it will probably be possible to keep historically malarious, but currently malaria-free, countries free of disease by increased surveillance and, if necessary, reinstatement of previously successful control methods, even if the area of distribution of the vectors increases (Bruce-Chwatt & de Zulueta, 1980).

Since many of the environmental changes caused by the potential change in climate depend on the local topography of an area, any predictions on future vector-borne disease risk can only be speculative, at present. Based on models of climatic change, an alteration in the level of risk can already be predicted (Schneider S.H., 1989). It will be necessary to study these effects at an early stage in the parts of the world where areas that are currently free of vector-borne diseases border on endemic areas, and to study the impact of climatic change on vector behaviour in areas where there is perennial or seasonal transmission. Such studies are already being undertaken for agricultural pests (Farrow et al., 1989).

Vector control is considered to be the most effective way to interrupt disease transmission and many control strategies have been developed, some highly successful, others less so. Vector control programmes may be operated as separate, usually disease-specific, activities. In a number of countries, however, vector control activities have become integrated into the general health services. In recent years, it has proved increasingly difficult to meet the desired goals, partly because existing vector control measures have become inadequate, following the development of insecticide resistance, and partly because many countries do not have sufficient resources to maintain an effective control programme. For these reasons, control measures have become less effective in many parts of the world, leading to an increased prevalence of diseases, such as malaria and dengue (WHO, 1989b). In addition, currently effective control measures may become less effective because of behavioural changes induced in the vector by such climatic changes. All these factors increase the need to establish efficient vector control programmes with international, as well as national, components.

Indirect effects

A considerable amount of information is available on the impact of changed agricultural practices on the epidemiology of vector-borne diseases (FAO, 1987b). It is likely that, with shifts in rainfall patterns and temperature changes, agricultural practices will change, especially as regards irrigation, cropping patterns, livestock husbandry, and fertilizer/pesticide application. Now that predictions on agricultural change that might result from the greenhouse effect are becoming available (Perry et al., 1989), the implications of these changes for the vector-borne disease situation need to be, and can be, assessed.

Malaria, schistosomiasis, and Japanese encephalitis can be singled out as the vector-borne diseases most affected by changes in irrigation practices and in the distribution of irrigated areas. Examples of the localized nature of such effects, and the complexity of factors that may play a role, come from Africa and Asia in the form of two flooded rice irrigation schemes in Burkina Faso and in Burundi. In one (Vallée du Kou, Burkina Faso), the vector population density increased, while the transmission of malaria decreased. In the Rusisi Plains in Burundi, the transmission peak shifted to the period with the lowest mosquito density. The first phenomenon was explained by the competition between sibling species, which resulted in the establishment of a vector population with a lower vectorial capacity (Carnevale & Robert, 1987). The second phenomenon was explained by increased vector longevity, associated with a rise in relative humidity, which produced a high vectorial capacity (Coosemans, in press).

The projected rise in sea level, and the resulting coastal flooding, will affect vector breeding in many parts of the tropical belt (Schneider S.H., 1989). Wherever this leads to the extension of brackish water lagunae, *Anopheles sundaicus*, already an important malaria vector in the coastal areas of Indonesia and mainland South and South-East Asia, will be favoured. Increased salination of fresh water impoundments in coastal areas may, in fact, have a negative effect on vector breeding and thus improve the malaria situation. The changes in fast running riverbeds and in seasonal flow intensities may affect the breeding of *Simulium* species and have consequences for the transmission of onchocerciasis. Drought and desertification, including a shift in the global desert belts, are likely to have a beneficial effect on vector-borne diseases because: (i) vector breeding is generally linked to an aquatic environment, and (ii) vector longevity is related to relative humidity. Two exceptions to this rule are dracunculiasis and leishmaniasis. The incidence of the first disease may rise if drinking-water sources become scarce and people have to resort to the use of unsafe water sources that harbour the guinea worm. The prevalence of the second disease may increase in desertified areas where specific rodent reservoirs and phlebotomine vectors increase in density.

Both drought and hydrological changes will affect natural vegetation cover, thereby having an impact on the ecology of a wide range of vector species, such as the vectors of African trypanosomiasis, the vectors of arboviral diseases, the triatomine vectors of Chagas' disease and their sylvatic reservoir hosts, the ticks responsible for the transmission of a number of protozoal, bacterial, rickettsial, and viral diseases in man and animals, and the sandfly vectors of cutaneous and mucocutaneous leishmaniasis.

Possible effects on malaria and malaria vectors

Today, malaria is found in the tropics and parts of the subtropics, but its present range is considerably smaller than its potential range, characterized by the presence of mosquito vectors and specific temperature requirements for parasite development. This is the result of effective vector control measures, the identification and treatment of infected individuals, and ongoing surveillance for introduced cases in previously malarious, but presently malaria-free, areas. There is good evidence that much of the success of these antimalaria campaigns can be ascribed to improved socioeconomic conditions (Bruce-Chwatt & de Zulueta, 1980).

Although more than 400 mosquito species of the genus *Anopheles* have been described, less than one-tenth of these are of importance as malaria vectors (White 1982, 1989). Each *Anopheles* species has a restricted distribution, determined by environmental factors. In many areas, more than one species occur, each having its specific ecological niche. Climate, particularly temperature, directly influences mosquito development, the gonotrophic cycle and longevity, as well as the duration of extrinsic development of the plasmodial parasites and, indirectly affects other environmental factors, such as vegetation and breeding sites. The sexual stages of the human malaria parasite are picked up by the female *Anopheles* mosquito when taking a blood-meal. The parasite undergoes sporogonic development in the mosquito lasting 8–25 days, after which infective sporozoites are transmitted to the human host during subsequent blood-meals. The rate and success of parasite maturation in the mosquito are determined by the ambient temperature, which may vary from 16 to 35 °C, the shortest development cycle occurring at 26 °C. From these brief remarks, it is evident that the longevity of the mosquito and the duration of the sporogonic cycle of the parasite, both affected by ambient temperature, are critical factors for efficient malaria transmission. The epidemiology of malaria is usually assessed by measuring the vectorial capacity, a mathematical expression that includes vector, parasite, and human-host characteristics (Macdonald, 1957). By inserting adverse or favourable climatic conditions in this expression, distribution limits for each vector can be simulated. Such models can be very useful in assessing the effects of climatic change.

Occasional, localized epidemics caused by imported malaria parasites may develop in previously endemic, but now malaria-free, areas. Because of effective control measures, it is not expected that these regions would return to a former state of endemicity, even though climatic change may lead to increased vector breeding. However, a different situation can be expected in currently endemic areas and areas bordering on malarious countries, especially in the subtropics (e.g., China, South Africa). Increases in temperature and rainfall may lead to improved environmental conditions for the *Anopheles* vectors, and, thus, to changes in vector density and longevity. The described events may have profound effects on the incidence and prevalence of malaria in the world.

In areas where malaria is seasonal, a dramatic increase in disease prevalence occurs in all age-groups during the annual transmission season, because previously acquired immunity in the host is lost in the non-transmission season (Molineaux & Grammicia, 1980). Potential lengthening or shortening of the vector-breeding season may lead to shifts in malaria incidence and prevalence. Similarly, in areas where there is perennial transmission, an increase in malaria incidence may occur, due to improved vector-breeding conditions. Thus, it is likely that the epidemiology of malaria will be altered by the anticipated climatic changes.

Climatic change and the epidemiology of vector-borne diseases

Knowledge about the direct and indirect effects of climatic change on vector-borne diseases can be extremely useful in predicting changes in their epidemiology that might occur as a result of future climatic changes. A good example of the impact of climate on malaria is the influence of the monsoon, in certain parts of India where *Anopheles culicifacies* is the vector. As this species breeds in river beds, the time of onset of the monsoon influences the availability of breeding habitats, the size of vector populations, and disease transmission (World Bank, 1987). In Fig. 5, a range of parameters affecting the epidemiology of vector-borne diseases is presented and some examples of how these might affect specific diseases are given. It should be clear, from these few examples, that climatic change will affect the distribution and prevalence of vector-borne diseases dramatically, and that these changes cannot be ignored.

Non-vector-borne diseases

Non-vector-borne diseases related to water

As is the case for vector-borne diseases, most of the non-vector-borne diseases are concentrated in populations living in tropical and subtropical regions of the world. And, again, water is of paramount importance. While for vector-borne diseases, water plays a role as the habitat of the vector (water-based diseases) (Feacham et al., 1980) or as a necessary factor for its propagation (water-related, vector-borne diseases), it can also act as the habitat and vehicle of the pathogen itself (water-borne diseases), with the infection occurring through direct consumption of the water or through contamination of food. On the other hand, lack of a sufficient quantity of household water invariably leads to poor personal and food hygiene, which is at the root of another group of diseases ("water-washed diseases", i.e., diseases that could have been avoided by better hand-washing and hygienic food preparation). The two latter types of disease are largely conditioned by poverty, and, hence, poor sanitary conditions, with either direct or indirect faeco-oral transmission. Among these diseases, childhood diarrhoea is probably the one taking the heaviest human toll, in terms of years of potential life lost.

Diseases related to water quality (water-borne diseases)

The water-borne diseases include: (i) diarrhoeal diseases caused by a variety of organisms, such as pathogenic *Escherichia coli*, *Vibrio cholerae*, salmonellae, and viruses, (ii) other viral diseases, such as hepatitis A and poliomyelitis, and (iii) two important parasitic diseases: the cosmopolitan giardiasis and the subtropically confined amoebic dysentery. While little can be said about the direct effects of climatic change on these pathogens, it is obvious that whatever the effects might be, they will be largely overshadowed by the indirect effects of migration and resettlement and the lack of access to safe drinking-water (see under migration).

On a more local scale, an increase in rainfall may cause flooding, with contamination of wells, pits, and surface water. This may also occur in regions where, because of increased winter temperatures, it rains instead of snows. Less melting snow will then be available to fill rivers and reservoirs in the spring/summer.

Diseases related to insufficient water availability to households (water-washed diseases)

When households have poor access to water, because of a general shortage, because water points are too far away, or for economic reasons, they are likely to use what water is available for drinking and cooking, rather than for washing.

Many of the above-mentioned water-borne diseases can also be transmitted by contaminated hands, food, and objects. Typical examples are the El Tor variety of cholera, bacillary dysentery (caused by shigellae), and a number of infections by worms, such as *Ascaris*, *Trichuris*, and *Oxyuris*.

As with the water-borne diseases, water-washed diseases are likely to be much more prevalent in conditions of poor sanitation.

Diseases related to the soil

These include a number of infections by helminths, which may, or may not, spend part of their life cycle outside the human body. Nematodes with larval stages in the soil (hookworm, whipworm, *Strongyloides stercoralis*, and others) as well as tapeworm eggs are directly dependent on soil temperature and humidity for their development. Thus, changes in these two parameters may influence the transmission of these worms. Other intestinal helminths, such as *Ascaris* and *Trichuris*, pass the period outside the human host in a relatively heat- and drought-resistant egg stage and, therefore, their prevalence is not likely to be affected by climatic change.

Airborne diseases

While the common cold is a very important source of morbidity during the winter season in temperate regions, most airborne viral diseases transmitted by droplets have a cosmopolitan distribution (Goodlow & Leonard, 1961). Influenza is characterized by pandemic waves that appear to be seasonal rather than temperature dependent. Pneumonia is a major cause of morbidity and mortality in children in developing countries. Climate and seasonality are important determinants in the incidence of these diseases, but the net effects of global climatic changes are difficult to forecast.

Climatic factors appear to be important for epidemics of meningococcal disease in Africa, especially in the semi-arid region south of the Sahara and north of the equator. The change from wet to dry season is associated with an increase in cerebrospinal meningitis cases. The reason for this increase is not known. Drought may well result in an extension of this cerebrospinal meningitis belt, especially towards the equator.

Other communicable diseases

Overcrowding, undernutrition, poor access to health care, disturbed social conditions, and rapid uncontrolled urbanization may be precipitated by climatic changes. Such conditions are likely to increase the occurrence of a variety of other diseases, such as tuberculosis, leprosy, and skin infections, measles and other childhood diseases, infestation by ectoparasites, and possibly bubonic plague.

Human migration

The migration of people as a result of climatic change can be subdivided into three categories:

- temporary migration
- patterned migration
- climate-induced emigration.

Temporary migration following natural disasters

Following natural disasters, such as floods, droughts, hurricanes, and earthquakes, there is often an acute, temporary migration of people seeking shelter and food in areas not affected (Baker et al., 1962). Emergency aid in these cases is directed towards the setting up of camps to provide for the basic needs of these people. Many countries have emergency preparedness plans and, sometimes, extensive experience, but often the health component needs further strengthening. International health organizations have been particularly active in promoting the preparedness of national ministries of health to cope with the effects of natural disasters.

The health implications of natural disasters are well-known, both on-site and off-site, as well as in the emergency camps. Emergency preparedness plans of ministries of health include vaccination of the affected population, vector and pest control, and the provision of food, safe drinking-water, and sanitation.

Should there be an increase in the frequency and/or intensity of such disasters due to climatic change, or should their traditional location (for instance the hurricane belt in the Caribbean) shift to new areas, then the emergency preparedness plans should be adapted accordingly. Ample experience is available from many parts of the world. The increased demands on the resources of governments, the international community, and specialized relief organizations should be recognized and supported.

Patterned migration

Currently, in many countries of the developing world, migration patterns exist that are seasonally determined, often linked to the availability of pastures, in the case of pastoral nomads, or to cropping patterns, in the case of temporary agricultural labourers. Changes in rainfall patterns may affect the seasonality of these migration patterns. Climatic and hydrological changes may result in changed cropping patterns, giving rise to new patterns of migration. It is important to note that this type of migration is mainly unplanned, and that, even in the existing situation, health authorities have great difficulty in preventing migrants from introducing diseases, or forms of diseases, such as drug-resistant malaria, to areas where the diseases were not present before. Alternatively, the migrants themselves may be subject to diseases to which they have not been previously exposed and, therefore, do not have any immunity. The health implications of changed migration patterns, following resource development projects, are well known.

Climate-induced emigration

The massive disruption of ecosystems could lead to the migration of large numbers of people into new zones (environmental refugees). This could create new vector breeding habitats because of inadequate sanitation, and increase the prevalence of vector-borne and other communicable diseases, which would, at best, strain the existing health care system and, at worst, overwhelm it.

One of the most important effects of global warming on human settlements is the expected rise in sea levels. Large parts of low-lying coastal areas around the world, often with large urban centres located in them, may be inundated. The rich fertile river deltas in many developing countries not only contain large urban centres, but are often the most fertile agricultural areas. Salination of these fertile lands, or inundation, will not only reduce agricultural output, but also necessitate the movement of populations to higher areas.

This type of migration is irreversible. Considering the expected rate of the rise in sea level that could take place over the next four to six decades (0.1–0.3 m), enough time should be available for detailed planning. Individual countries and areas must make realistic evaluations of the magnitude of the possible risk and the most appropriate response measures. Countries may choose to spend their resources on building defences against the rising water, rather than on a major resettlement programme. This decision will depend on many factors, including population density, the value of the infrastructure in the threatened area, the cost, and the availability of funds.

There is well-documented experience from virtually all parts of the world on the health effects on resettled and resident populations following the creation of man-made lakes. The incidence of communicable diseases (particularly diarrhoeal diseases, vector-borne diseases, other parasitic diseases, sexually transmitted diseases, etc), mental health problems, and accidents may all be affected, and there may also be substantial changes in nutritional status. The issue should be dealt with on a regional basis (e.g., South and South-East Asia, Africa, China, Europe, and the temporate and tropical zones of the Americas), using major dam resettlement projects as examples. It is less obvious that the movement of people out of areas threatened with inundation may lead to civil strife or even international conflicts, which, in turn, would have repercussions on human health. It should further be stressed that, without exception, all large dam projects have failed to include adequate strengthening of public health services to meet the new demands that were put on them in a changed situation. This inadequacy should not be perpetuated in the planning to combat the health effects of climate-induced emigration.

Chapter 4

Conclusions and recommendations

The potential effects of global warming and ozone depletion are highly complex and will vary widely from one region to another.

The major effects of climatic change on health are caused by:

- heat stress
- air pollution
- alterations in the incidence of communicable diseases
- undernutrition
- inundation.

The health authorities of national governments should undertake a comprehensive evaluation of the possible health implications of such changes, to identify the nature and magnitude of problems in specific areas and the subpopulations that would be susceptible to climatic change. They will need to determine priorities for planning and decision-making.

The health sector must play an active role nationally in formulating and implementing strategies to prevent climatic change and combat its effects. Thus, the health sector should be involved jointly with agricultural, meteorological, environmental, and planning agencies to ensure that health considerations are given adequate weight.

Specific recommendations

National health authorities are urged to install or reinforce surveillance systems for the health problems that are most likely to be influenced by climatic change; this would facilitate:

- the gathering of baseline data for the evaluation of time trends or outbreaks,
- the definition and evaluation of priority fields for action or research,
- the evaluation of actions taken.

Since global warming may lead to a redistribution of vector-borne diseases, national and international efforts are required for their control. In many instances where these diseases are already prevalent, such efforts are inadequate or lacking. The national health authorities should be adequately prepared to handle the control of vector-borne diseases through vector control, the vaccination of individuals at risk, and drug-treatment.

It is important to increase awareness of the potential health effects of changes in the climate. For this purpose, region-specific educational material that addresses particular local health problems should be produced. Such materials should be distributed to professionals (physicians, epidemiologists, architects, etc.), schools, and the general population.

In view of a possible increase in the incidence of malnutrition arising from a disruption in food supplies, the adoption of new crops or new agricultural production techniques should be fostered, particularly for the areas that might be affected.

Although the known, direct health effects of ozone depletion are not considered to be of major importance, studies should be undertaken on the effects of UVR, with particular emphasis on possible injury to terrestrial and aquatic biota and effects on the immune status in man.

It is essential to assess the implications of the substitute technologies for energy production, transportation, and replacement chemicals. Every reasonable effort should be made to avoid the introduction into the environment of even seemingly innocuous chemicals and alternative technologies, before a risk assessment has been made.

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Annex 1

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