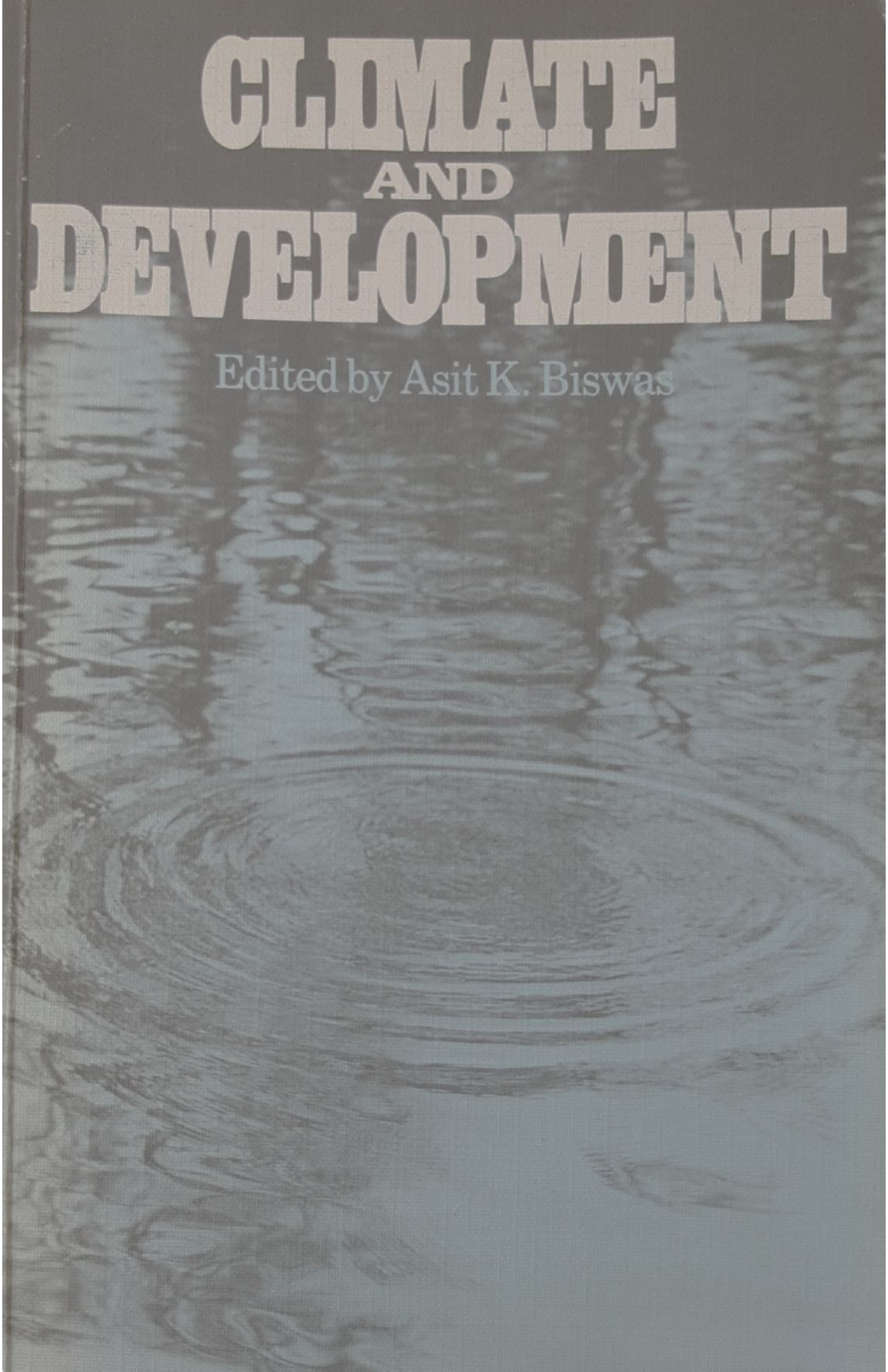
CLIMATE AND DEVELOPMENT

Edited by Asit K. Biswas



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Climate and Development

To F. Kenneth Hare
Humanist, Climatologist and Teacher Extraordinary

Climate and Development

Edited by
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Preface

The interrelatedness of climate and development was clearly illustrated during the early seventies. The aggregation of the climatic events that contributed to the prolonged drought in the Sudano-Sahelian region of Africa, the failure of the Russian grain harvest, the erratic monsoons in the Indian subcontinent, the disappearance of the anchovy fishery off the coast of Peru, and the serious drought conditions in the western part of North America, was a global catastrophe of major magnitude. The gravity of the condition that developed in 1972 can be best illustrated by the fact that the total world output of food declined from the preceding year for the first time in twenty years, due to the adverse weather conditions. The production of cereals — wheat, coarse grains and rice — which form the staple element of diet for most of mankind — declined by 33 million tons instead of an anticipated increase of 25 milion tons. This created a serious world food problem, especially as two of the main food-exporting countries, the United States and Canada, had instituted policies to reduce their large surpluses. Consequently, surplus wheat stock in exporting countries fell from 39 million tons in 1971-72 to 29 million tons in 1972-73, and even further in 1973-74. Rice reserves were virtually exhausted.

Both shortage of cereals and their high world market price created a serious food problem for the developing world. Under such critical conditions, the United Nations General Assembly, in December 1973, decided to convene the World Food Conference at the highest decision-making level. Initially proposed by Henry Kissinger, the then US Secretary of State, the World Food Conference was held in Rome, Italy, in November 1974.

The serious food situation of the early seventies clearly indicated that the opinion expressed by some scientists and decision-makers in the sixties that technological developments have made agricultural production independent of the vagaries of climate was both misplaced and optimistic.

While the interrelatedness of climate and development is self-evident, for various reasons which I have discussed in detail in our earlier book *Food, Climate and Man* (John Wiley & Sons, New York, 1979), development planners on the one hand have seldom considered climate as an explicit factor in the development process and climatologists on the other hand have not generally played an active part in development planning. This situation needs to be rectified as soon as possible in order that the development process can be made sustainable on a long term basis.

For the developing countries of the world, which are located in the tropics and sub-tropics, climate should be considered to be an important resource, which provides certain golden opportunities for development but also simultaneously poses some constraints. Hence, development strategies have to be formulated that specifically attempt to maximize the benefits such opportunities can bring but do not forget the constraints imposed by climate. Technically, such a task is not going to be easy. Furthermore, direct technology transfer from temperate to tropical regions may not be the optimal solution, and in many cases may even be counterproductive.

During the next two decades, the population of tropical countries is expected to increase by 1.5 billion, which will account for approximately 90 per cent of the anticipated global population increase. Provision of basic human needs to these unborn generations, and improvement of the quality of life of the present underprivileged people on this earth, is a critical challenge. If past experience is any indication, it will not be easy.

The task ahead of us is a most challenging and complex one, and it can only be accomplished if we proceed in a scientific and rational way. It is essential that we must draw upon whatever knowledge we have gathered on the tropical areas up to now, and then supplement this information base with as much additional knowledge as is practically possible in order to formulate appropriate strategies for sustainable development.

One luxury we do not have is time. We cannot wait until all the relevant information is available before making development decisions. People are already here on earth, and millions are going to be born before the end of this century, whose needs have to be met from the earth's resources. Herein lies one of the great challenges of the future: how to make the right development decisions despite all the risks and uncertainties involved.

Climate and development are interrelated in many ways, some of which were discussed in our earlier book *Food, Climate and Man*. The main focus of *Climate and Development* is on issues that are of immediate concern to people, especially for those in developing countries of tropics and semi-tropics. While some mention has been made of the climate-development related problems that may arise in the twenty-first century, like carbon dioxide or changes in precipitation and temperature regimes, these have not been discussed in depth. Instead our emphasis has been on the impacts of climate on terrestrial biota, especially agricultural development, on water resources planning and management and human health, and climatic risk assessment through input-output models.

Like *Food, Climate and Man*, the present book owes much to Dr Mostafa Kamal Tolba, Executive Director of the United Nations Environment Programme. Dr Tolba not only encouraged me to undertake the preparation of this book, but also — in spite of his manifold commitments all over the world — generously gave me his time to discuss aspects of the issue, whenever necessary. Without Dr Tolba's encouragement, it would not have been possible to complete this book. For this I am truly grateful.

Asit K. Biswas

March 1984
Oxford, England.

CHAPTER ONE

Climate and Development

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DURING THE LAST three decades, differences between expectations of development patterns and the developments that have taken place are indeed remarkable. As expected, the development patterns of the past three decades have varied not only from region to region, but also within individual countries. They have also varied with time depending on the internal problems and external constraints encountered. There is no reason to doubt that future development trends will be similarly different from what are anticipated due to lack of reliable methodological bases for forecasting as well as unforeseen and unexpected events.

During the past three decades our perception of development has also changed. In an excellent analysis of the changing pattern of perception of development problems, Misra (1981) observed:

> Just thirty years ago, all those who mattered in development — politicians, academics and planners — appeared to know what development meant and how to achieve it. There was a mood of confidence, assurance and urgency. There were instant solutions — decolonization, economic aid, industrialization, etc. There were theories and strategies galore — often contradicting each other, yet accepted ungrudgingly as they were the products of some of the brilliant minds of the time. . . .
>
> Today, thirty years later, the success euphoria of the past has given place to despondency, confusion and stalemate. The developers are still there, and so are the development theorists and planners. But they all concede that development is not as easy as they thought it to be and that there is no panacea for underdevelopment. It is realized that the road to development is tortuous; that development is not economic growth alone, and that many of the issues which were debated in the past, were not the real issues when seen in the light of the problems being faced by the less developed countries today.

Many new nations became independent during the fifties, sixties and seventies, and they made their own plans for future development. Amidst the euphoria of independence, there was hope for the future, and expectations of "good" life for all their citizens. In some cases the dreams have been shattered; many people are now worse off than they were before, and the rosy future they all expected to see in not too distant a timeframe — certainly within their life-time — has retreated even further and further like a mirage. Disillusion and despondency have replaced hope and euphoria. The national expectations of the recent decades had international impact as well. Development goals and targets were agreed to for both the First and the Second Development Decades of the United Nations covering the sixties and seventies. These targets were unfortunately not achieved. Bradford Morse (1980), Administrator of the United Nations Development Programme, reviewing the achievements of the seventies, said:

From one point of view, the 1970s was a decade of disappointments. Adequate gains were not made against poverty and its life-crushing consequences. The global economy fell short of the sustained expansion necessary for moving with much greater speed and effectiveness in the struggle to substantially ease hunger, disease, illiteracy, unemployment and lack of adequate housing. The world became joltingly aware that there were limits to its exploitable resources. Perhaps most frustrating of all was the fact that the industrialised and the developing countries did not achieve greater understanding — much less agreement — about how to deal with these problems effectively and equitably.

Few people will disagree with the above assessment. Similarly, during the Third General Conference of the United Nations Industrial Development Organisation (UNIDO, 1980), held in New Delhi in early 1980, many governments expressed the opinion that the "two United Nations Development Decades had failed in their objectives". The good intentions and objectives of UNIDO's Lima Declaration and Plan of Action of 1975, which stipulated that the developing countries should attain a 25 per cent share of the total world manufacturing output by the year 2000, appears to recede further on the horizon. At the present rate of growth, their share might not exceed 13 per cent by the end of the present century — a figure that is only half the accepted target. The conference stated that during the two decades, "the rich became richer and the poor poorer; more than one-quarter of the world's population was growing steadily poorer." Further, "eight hundred million people, or about 40 per cent of the population of the developing countries continued to live in absolute poverty; roughly a billion people lacked at least one of the basic necessities of food, water, shelter, education or health care."

Agriculture dominates the economies of most developing countries. For low-income economies, nearly 70 per cent of the population are directly dependent on agriculture to earn their livelihood, either as farmers or farm workers. It is not uncommon to find people who have to spend 60 to 75 per cent of their income on food-related purposes. The role of agriculture in overall development of developing countries should not be underestimated. Agricultural products are still the main category of export for most developing countries, and accounted for some 30 per cent of their total export earnings in the late seventies. Experience clearly indicates that those developing countries that embarked on industrialization at the expense of the agricultural sector have not fared well. The latest World Development Report (World Bank, 1982) states categorically that "one point emerges very clearly from the diversity of experience of the developing countries: rapid growth of agriculture and in GDP go together." It has become increasingly evident during the past three decades that sustained development in most developing countries is unlikely to occur without first or simultaneously developing their agricultural potential.

Since agriculture has a major impact in developing countries, at least initially in the development process, and since agricultural production is still closely related to climate, progress in the agricultural sector in the recent past is an important factor to consider for any discussion of the interrelationships between climate and development.

The target for the average annual growth rate for the agricultural sector during the Second Development Decade was established at 4 per cent which, if achieved, would have been comfortably ahead of the rate of population growth. The real average annual growth rate was, however, only 2.8 per cent. It should be noted that this was the average growth rate: it varied remarkably from one country to another. Several countries were significantly worse off. If the developing countries are considered as a whole, certain indicators of agricultural production during the first two Development Decades actually declined. For example, developing countries, in aggregate, were net exporters of grain in the 1950s. At the end of the First Development Decade, the surplus situation had turned into a net deficit. Developing countries as a whole imported 42 million tons of grain in 1970, and this further increased to 80 million tons by 1979. Estimates of total grain import needs by the end of the Third Development Decade in 1990 currently range from 125 to 150 million tons (Biswas and Biswas, 1981).

Similarly, if the index of per capita food production is considered, the situation is not much better for the low income developing countries, defined by the World Bank (1982) as having gross national product (GNP) per capita of US$410 or below in 1980. Of the 33 such countries listed in the World Bank's World Development Report of 1982, the index of per capita food production (1969–71 = 100) declined in 1978–80 for twenty-three countries, remained the same for one, and increased for only nine countries. The index declined to a low of 41 for Kampuchea, 75 for Mozambique and 81 for Togo and increased to a high of 121 for Sri Lanka, 116 for China and 107 for Vietnam. Some of the development indicators of selected countries are shown in Table 1.1.

There is no doubt that the progress during the first two development decades in the agricultural sector has not matched with expectations. Maurice J. Williams, Executive Director of the World Food Council, called it twenty years of neglect when describing the results of the two decades on the agricultural sector in the Third World. According to Williams:

> The disturbing features of the longer term trends relate, in particular, to the inadequate rate of increase in food and agricultural production in the developing countries, the continuing rise in their food imports, the deterioration in their food self-sufficiency, lack of evidence of any reduction in the incidence of hunger and malnutrition, slow progress in the establishment of an effective system of world food security, decline in the share of developing countries in agricultural export earnings and inadequate flow of external assistance. The decade of the eighties is thus starting with a heavy backlog of unresolved food and agricultural problems.

One major problem has been due to the fact that many developing countries did not give the agricultural sector the necessary priority in their national development plans. Fortunately, this viewpoint, which usually fosters heavy industry at the expense of agriculture, appears to be changing. The recommendation of the Group of 77 at the

Table 1.1. Development indicators of selected countries (Source: World Bank, 1982)

Country	Population (10^6) mid-1980	GNP/capita (US$) 1980	Adult literacy (%) 1977	Life expectancy at birth (yrs) 1980	Index of food production/capita 1978-80	Commercial energy consumption (kg coal equivalent) 1979
Argentina	27.7	2,390	93	70	122	1,965
Bangladesh	88.5	130	26	46	94	40
Brazil	118.7	2,050	76	63	117	1,018
China	976.7	—	66	52	92	734
Egypt	39.8	580	44	57	93	539
France	53.5	11,730	99	74	115	4,810
Germany, FR	60.9	13,590	99	73	110	6,264
India	673.2	240	36	52	101	194
Indonesia	146.6	430	62	53	110	225
Japan	116.8	9.890	99	76	93	4.048
Kenya	15.9	420	50	55	86	172
Korea, R.	38.2	1,520	93	65	130	1,473
Mexico	69.8	2,090	81	65	103	1,535
Singapore	2.4	4,430	—	72	147	5,784
USSR	265.5	4,550	100	71	108	5,793
UK	55.9	7,920	99	73	118	5,272
USA	227.7	11,360	99	74	115	11,681

United Nations, which includes all the developing countries, during the finalisation of the strategy for the Third Development Decade, was quite unequivocal. The group called for "a distinct and definite bias in favour of agricultural production," and an average annual growth rate of 4 per cent. They further suggested that food and nutritional planning should form the core of national development policies. This is a positive indication, since the recommendation comes from the group of countries that will be most affected. While this, without any question, is a step in the right direction, it remains to be seen whether such resolutions are rhetorical or will actually be implemented in the countries concerned.

The above discussion, however, should not be taken to imply that developments during the past three decades have been all negative, but rather that expectations were not fulfilled. On the positive side, technological developments and improved management practices increased agricultural output at approximately twice the rate of earlier periods. But rapid population growth, skewed income distribution and changing patterns of growth often tended to exacerbate the overall problem. For example, the world population increased from 2.8 billion in 1955 to 4.4 billion in 1980, a 57 per cent increase in only 25 years. While in South Asia the balance between population growth rates and agricultural growth rates (2.5 per cent and 2.2 per cent respectively) could be maintained during the past two decades, the situation deteriorated significantly in Africa, where agricultural growth rates declined from 2.7 per cent in the sixties to only 1.7 per cent in the seventies. The situation has worsened since the rate of growth of population has accelerated.

The extent and magnitude of unequal income distribution between the masses — both within a country and between countries — is an area of major international concern at present. It is not unusual to find 20 per cent of the people in the highest income bracket of a country account for 50 to 70 per cent of GNP of that country, but the lowest 20 per cent contribute only 5 per cent of GNP. This situation is also generally valid when land ownership is considered. According to FAO statistics, 20 per cent of the richest landowners own 82 per cent of cropland in Venezuela, 56 per cent in Colombia, 53 per cent in Brazil and 50 per cent in India, Pakistan and the Philippines. Since the rich control the political power, not unexpectedly the vested interests would like to maintain the *status quo.*[1] When the two phenomena of increasing population growth and unequal income distribution are considered simultaneously, it means that millions of people have not only sharply reduced food available per capita — compared to earlier periods — but also do not have access to other benefits that could accrue from increasing GNP per capita, that has occurred in the vast majority of developing countries.

Changing patterns of growth is also another concern. According to the World Bank (1982) some 600 million tons of cereals are fed to animals every year at present, enough to feed 2.5 billion people, or more than double the present number in poverty. Furthermore, the efficiency of conversion of cereals to meat is very low: 75 to 90 per cent of calories and 65 to 90 per cent of protein is lost in the process. This, however, does not mean that changing feed grain to food will resolve the world hunger problem.

1. This is exemplified by one of the author's recent experiences when advising an important country to prepare a national agricultural development plan. One of the specific instructions was *not* to consider the problem of land tenure.

Since much of the feed grain used is in developed countries, the production will decline sharply if the market for feedstock is restricted. Until a reliable market for the cereals can be created in developed countries, which means significantly increasing their purchasing powers, the problem is unlikely to be resolved.

CLIMATE AND DEVELOPMENT

It can be legitimately asked why, despite international concern and a multitude of national efforts, agricultural performances in the majority of developing countries have not matched general expectations. This is a difficult and complex question to answer, since many factors are involved and the various issues concerned are mostly interrelated. However, one of the important reasons for such a poor performance in the past has to be the sad neglect of the impacts of climate on the development process itself. As the Nobel-Laureate Gunnar Myrdal (1968), in his monumental work, *Asian Drama* has aptly noted, economic analysis has tended to disregard climate, except occasionally in the location theory, in spite of the fact that "climate exerts everywhere a powerful influence on all forms of life — vegetables, microbial, animal and human — and on inanimate matter as well." It is a sad but true fact that economists, including agricultural and development economists, have consistently ignored climate. Almost all macro- and micro-economic growth models fail to explicitly consider climate as a major parameter. Similarly, climate is seldom discussed in books dealing with regional development theories.

This situation is somewhat surprising, since the impacts of climate on development have been realized for at least 2,400 years, albeit not fully or comprehensively. For example, Hippocrates (460-400? BC), father of medicine, attested:

> I hold that Asia (Minor) differs very widely from Europe in the nature of all its inhabitants and all of its vegetation. For everything in Asia grows to far greater beauty and size; the one region is less wild than the other, the character of the inhabitants is milder and more gentle. The cause of this is the temperate climate, because it lies towards the east midway between the risings of the sun, further away than is Europe from cold.

Very few development specialists in recent years have realized the importance of considering climatic factors in the development of nations. In 1951, Galbraith noted that if "one marks off a belt a couple of thousand miles in width encircling the earth at the equator, one finds within it no developed countries . . . . Everywhere the standard of living is low and the span of human life is short." A decade later, a United Nations (1961) report noted that if "the industrialized countries are marked on a map, they will be seen to be located as a rule in colder climate than the underdeveloped countries. The correlation with climate is as good as most correlations between non-economic factors and economic development." Similarly Myrdal (1968) has urged that every "serious study of the problems of underdevelopment and development in the countries of South Asia should take into account the climate and its impacts on soil, vegetation, animals, humans and physical assets — in short, on living conditions in economic development."

Few other economists have, however, dismissed the role of climate in development. Thus, Lee (1957) stated: "Climate and economic development in the tropics is a convenient bogeyman to be blamed for psychological difficulties whose real origin is much more personal." Similarly, according to Lewis (1955): "Because economic growth is currently most rapid in temperate zones, it is fashionable to assert that economic growth requires a temperate climate, but the association between growth and temperate climate is a very recent phenomenon[2] in human history." Lewis further noted that the "climate hypothesis does not take us very far."

One can, however, ask if development economists have failed miserably to consider climate as an important factor for development planning, why have not the climatologists ensured that such a neglect is not allowed to continue. The answer is fairly simple. Much though the climatologists know about climate, they have not ventured out of their own discipline: they have tended to remain isolated within their own field – a phenomenon that is very common for nearly all professions. Very few climatologists have ventured into such fringe areas as development planning. True, there have been some recent attempts to develop a better fundamental framework of theory in this area (i.e. Kamarck, 1976), but even this has been largely ignored. Accordingly one is indeed hard pressed to name more than a handful of climatologists who are even active in the fringe areas of development. It is a sad but true fact that most internationally acknowledged development planners will find it difficult to name even one climatologist whom they would include within their peer group. Accordingly it is no surprise that an analysis of the proceedings of the World Climate Conference (1979), a "conference of experts on climate and mankind", held under the aegis of the World Meteorological Organization (WMO) of the United Nations, does not contain a single paper that analysed the relations between climate and overall development. It should, however, be noted that in the past often the study of the interrelationships between climate and living organisms was primarily in the domain of physiologists (Tosi, 1975).

DIFFERENT CONDITIONS FOR DEVELOPMENT

While it has been argued earlier that climate has important impacts on development patterns, it should not be construed to mean that the interrelation between them is directly proportional. Nor does it mean that just because economic development has occurred in recent decades in the temperate regions rather than in the tropics and semi-tropics, the regions underdeveloped will continue to remain so in perpetuity. In other words, no sensible person will subscribe to the glib doctrine of pessimistic geographical determinism that was prevalent during the colonial era which explained the poverty of developing countries in terms of their climates. According to this widely

2. In refuting this type of statement, Myrdal (1968) observes that the great civilizations that sprang up in tropical areas in ancient times and that lasted for centuries are different "in fundamental ways from modern ones; also, they often grew up in smaller regions favoured by exceptional conditions; soil erosion and deforestation had not proceeded so far and so on."

believed theory of the time, the economic underdevelopment of the Third World was due to its "unbearable" climate and its impacts on the different components of the biosphere, both living and inert. It indirectly reinforced the concept of the racial inferiority of the colonized people, and according to Myrdal (1968), such a concept of geographical pessimism '"supported the common view, badly needed as a rationalization of Western colonial policy, that little could be done to improve the productivity of the colonies and the life of the colonial people." Reviews of the theories of geographical determinism have been made by Biswas (1979), Kamarck (1976) and Myrdal (1968).

A rigorous analysis of countries in the temperate regions and in the tropics will clearly indicate that the boundary conditions for development for the two regions are not identical: in fact they are very different. Since the boundary conditions, within the context of which economic development takes place, are different in the temperate and tropical regions, it means that the patterns of development experienced in the Western industrialized countries may not be duplicated in the Third World. Myrdal points out that it is "important to take note of the newness of the development problems confronting the countries of South Asia today — and most other underdeveloped countries — because of the tendency to overlook their uniqueness that is inherent in the biases common in research and prevalent also in planning and, generally, in public discussion."

Similar misgivings on differing boundary conditions have been expressed by Streeten (1971): "the deep-seated optimistic bias with which we approach problems of development and the reluctance to admit the vast differences in initial conditions with which today's poor countries are faced compared with the pre-industrial phase of more advanced countries." Similarly, Kamarck (1979) suggested that the proper contrast is not "north-south" but "rich temperate zone-poor tropics".

The different boundary conditions in the tropics and temperate regions are not necessarily reflected by existing widely-accepted development theories or development processes. Boulding (1970) has remarked:

> Development, like economics, has been very largely a temperate zone product. The complexities both of tropical ecology and of tropical societies are beyond easy access for those raised in essentially temperate zone culture. This is not to suggest a naive climatological determinism, but just as tropical biological ecosystems differ very markedly from those in the temperate zone, it would not be unreasonable to suppose that the processes of social evolution would likewise produce marked adaptations to the peculiar rigors and delights of tropical climate and life style.

One can argue that the general failure of development planners and scientists to recognize the importance of climate in the development process may be considered to be another tragic facet that has contributed to numerous instances of failures due to technology transfers between the temperate and tropical regions. Attempts to linearly transfer both development concepts and technologies that originated in the temperate countries to the tropics have often not been successful, and in some instances they have only been partially successful, with highly reduced effectiveness. The agricultural history of the present century is replete with examples in which straightforward transfer of technology from one region to another actually created additional problems. A few select examples are the deep-ploughing of the rice paddies in Java by the Dutch, corresponding operations by the British in Burma, failure of the groundnut scheme in Tanzania, broiler production in Gambia and the folly of cultivating marginal lands which should never have been farmed in many African, Asian and Latin American countries.

Probably the most spectacular failure in agricultural development was the 1947 British plan to develop large-scale groundnut plantations in East Africa, in what was then known as Tanganyika. The area selected covered 3.25 million acres, 70 per cent of which were uninhabited, for what later turned out to be good reasons. All sorts of experts were recruited for the ambitious project, but overall planning left much to be desired. Two of the three areas selected turned out to be unsuitable for cultivation. At Kongwa, the precipitation was too low and the soil was very compact and abrasive. Similarly, at Urambo, much of the land was low-lying and hence subject to waterlogging (Young, 1976). Some of the practices were not environmentally sustainable. For example, bulldozers were extensively used to remove deep tree roots. The soil, as in several other similar cases in the tropics, could not stand up to the machines, and there were severe losses due to wind and rain. Artificial fertilizers were not effective because of lack of water, and germination turned out to be difficult in hard-packed soil. The project was eventually abandoned after six years of desperate efforts and capital investment of some US$100 million. It was a classic example of an attempt to develop a large area without adequate soil and natural resources surveys.

The failures of many agricultural development schemes in the tropics, even though they used well-proven and workable models from temperate regions, should not come as a surprise. Most of the theories in economic development or economic geography are products of the Western world, and their fundamental principles, evolved over the years, are generally based on conditions prevalent in developed countries. Thus, many "classical" theories are being applied in the tropics, even though they are primarily temperate zone products, and thus may be of questionable validity. When these suspect theories are superimposed on a different world, on an alien culture with vastly different socio-economic conditions, religious-cultural practices and institutional infrastructures, the risk of committing a fundamental error is exceedingly high. If, for example, the underutilized labour force, a common condition in Asia, Africa and Latin America, is analysed according to traditional Western concepts of unemployment and under-employment, the resulting figures and conclusions are generally meaningless, or at best, the magnitude of error is so great it would be folly to rely on them to formulate major policy decisions. To quote Myrdal (1968) again:

> The very concepts used in their (theories of classical economics) construction aspire to a universal applicability they do not in fact possess. As long as their use is restricted to our part of the world this pretence of (universal) generality may do little harm. But when theories and concepts designed to fit the special conditions of the Western world — and thus containing the implicit assumptions about social reality by which this fitting was accomplished — are used in the study of underdeveloped countries in South Asia, when they do *not* fit, the consequences are serious.

Since development theories from the Western industrialized countries generally do not fit the tropics, why are not appropriate theories being formulated by scientists from the developing countries themselves? Herein lies one of the great dilemmas of the modern times. At present most of the elite in the developing world tend to be trained in the West, and in general, Western thinking is considered to be more "progressive", "advanced" or "scientific". Because of such training and social attitudes, these intellectuals usually produce dissertations replete with the traditional theories of classical Western economics. Many are familiar with the latest abstract growth models originating from Harvard or Oxford, but very few question the validity of their use within the context of differing socio-economic and institutional conditions in their own countries. This means the underlying biases go undetected and are perpetuated, when at the very least they should be identified and questioned, and better still corrected. In addition, such uncritical acceptance of the bias in Western concepts and theories on the part of academia is not confined to any specific country or to a regional grouping of countries: it seems to permeate through all countries having similar economic systems. Fortunately, it appears that this situation is beginning to change: increasingly a few are questioning their validity and usefulness.

Climate has impacts on many different aspects of development. Only some of the important aspects will be discussed herein.

TROPICAL CLIMATES: THE DIFFERENCE

During the happier days of the sixties, many people claimed that technological developments had freed modern agriculture from the vagaries of climate. To some extent, such overconfidence can be accounted for by the generally benign nature of the climate in the sixties. It became clear during the early seventies that climate still was a major factor for overall agricultural production, and that earlier technological overconfidence was highly misplaced.

Since both the climatic and environmental conditions between the tropics and temperate regions are different, the agricultural practices of the industrialized countries cannot be directly duplicated in developing countries. The difference in boundary conditions on factors that affect land, which makes direct technology transfer process hazardous, is worth analysing.

The two most important climatological factors that affect agricultural production are rainfall and temperature. The nature and distribution of rainfall, both within a year and from year to year, tend to be different in the tropics when compared to temperate locations. Table 1.2 shows the average monthly rainfall in millimetres at London, Sokoto on the southern border of the Sahel, and at Lagos, Nigeria, representing typically equatorial rainfall (Ormerod, 1978). The yearly average rainfall for London and Sokoto do not differ appreciably: 568 mm and 668 mm respectively. However, when distribution of rainfall throughout the year is concerned, the two cases are very dissimilar. The rainfall pattern of London, which has a temperate climate, can be characterized by a low but reasonably uniform monthly rate over the entire year. It varies from a maximum of 61 mm in October to a minimum of 35 mm in April. Similarly rainfall retained in the soil is reasonably uniform. The situation is very different for Sokoto, where the rainfall is intense during July to September, but virtually non-existent between October to April. The rainfall varies from a maximum of 239 mm in August to zero between November to March. Furthermore, Sokoto has a significantly lower rainfall retention rate in the soil when compared to London. Thus, even though the total average annual rainfall in Sokoto is actually 15 per cent higher than in London, its distribution throughout the year is very

Table 1.2. Average monthly rainfall in millimetres. Bracketed figures are for rainfall retained in soil (Source: Ormerod, 1978)

Month	London	Sokoto	Lagos
January	41 (245)	0 (25)	26 (100)
February	37 (276)	0 (16)	46 (73)
March	41 (290)	0 (9)	100 (60)
April	35 (281)	10 (5)	148 (60)
May	41 (253)	48 (3)	269 (182)
June	48 (213)	86 (2)	457 (300)
July	56 (175)	147 (2)	273 (300)
August	58 (152)	239 (104)	64 (250)
September	42 (138)	145 (107)	138 (266)
October	61 (156)	13 (67)	205 (300)
November	54 (187)	0 (42)	68 (230)
December	54 (226)	0 (31)	26 (150)
Total	568	668	1,820

uneven, making Sokoto very arid. The annual rainfall in Lagos is very high, 1,820 mm, but this occurs during two parts of the year, long rains between March to July and short rains during September and October. The rainfall is very low between November to February and again in August. The maximum rainfall is in the month of June, 457 mm, which represents nearly 80 per cent of the annual average rainfall of London, and the minimum is 26 mm for the months of December and January. The monthly distribution of rainfall retained in the soil varies from a minimum of 60 mm to a maximum of 300 mm — a factor of 5. For London, the identical ratio is only 2:1.

Another feature worth noting from Table 1.2 is the relatively poor moisture retention capacity in the two tropical stations, which is likely to be primarily due to the difference in organic content of the soil. Generally, organic content of soil comprises several compounds of the humic and fulvic acid types, which are formed by microorganisms in the breaking down of cellulose (Schnitzer, 1976). While there is no fundamental difference between tropical and temperate soils in terms of the characteristics of these compounds, remarkable differences often exist in terms of their overall content (Schnitzer, 1977). These compounds are important for soil because of their ability to retain water and mineral salt and resistance to leaching. Ormerod (1978) points out that "high temperatures, long periods of drought, intense ultraviolet radiation and particularly high kinetic energy rainfall, which destroys the granular structure of the soil, decrease the activity of soil microorganisms so that there is little possibility in open land for the stable organic content of the soil to build up; indeed there is a tendency for it to be destroyed." This, however, does not mean that high organic content cannot be built up in tropical soils under certain specific conditions, a point which will be discussed later.

The variation in rainfall in tropical climates often tends to be greater than in temperate regions. For example, in Pakistan, total annual rainfall in any given year can be expected to exceed or fall short of the mean annual rainfall by an average of 30 per cent or more (Stamp, 1966). This type of erratic rainfall is problematical from an agricultural viewpoint, since the rainfall could be either too much or too little, thus requiring extensive and expensive water control systems for irrigation,[3] drainage and flood control.

In the monsoon countries, the timing of the onset of the monsoon is vitally important. Many a famine in the Indian sub-continent is directly due to the fact that the monsoon rains did not start at the right time. Equally important is the continuation of the rain once it has started. There have been several years when the onset of the monsoon rains were at the appropriate time but failed soon thereafter causing agricultural havoc. For the areas of Asia cultivating wet rice with rainfed farming, both the onset and continuation of the monsoons are vitally important factors. The importance of wet rice can be realised by the fact that it currently supports the highest density of people in the humid tropics, especially in Asia.

Rainfall has a direct impact on soil erosion all over the world, but the potential ability of the tropical rainstorms in causing soil erosion is far higher than in the temperate regions. This could be attributed to the high kinetic energy of the tropical rainstorms when compared to the gentler kinetic energy of rainfall in temperate regions. Kinetic energy of rainfall depends on the size of drops, intensity and wind velocity. While long-term detailed data on tropical rainfall are not available, it appears that median drop size of well above 3 mm are not uncommon. Drop sizes as high as 4.9 mm have been observed. From these data, a preliminary observation could be that the drop-size distributions of rainstorms is much higher in the tropics than in temperate regions.

Kinetic energy of rainfall is an important consideration since kinetic energy and the impact of raindrops initiates loosening and detachment of soil particles, the first essential step for soil erosion. Once soil is loosened, the particles are washed away, thus contributing to serious soil erosion problems.

So far as intensity of rainfall is concerned, it appears that its erosive power significantly increases at about 35 mm h^{-1}, which can be considered to be a threshold for erosion. Since more rainstorms in the tropics equal or exceed the level of this erosive threshold, the erosive potential is higher in the tropics when compared to the temperate parts (Hudson, 1971).

Another climatic aspect further contributes to soil erosion. The rainfall and temperature distribution patterns in tropical climates, especially in those areas having pronounced dry and wet seasons, the soil erosion problem is accentuated. During the long dry season, there is some loss of topsoil due to wind erosion. However, far more damage is done during the onset of the rainy season. The vegetative cover, at the end of the dry season, is already reduced and often at an absolute minimum. Thus when a heavy thunder shower occurs, the water does not infiltrate into the soil as it might in light steady rain, and year after year soil erosion takes place due to surface runoff. Tempany and Grist (1958) have suggested that if the heavy rains double the water flow, "scouring capacity is increased four times, carrying capacity thirty-two times and the size of particles carried sixty-four times." Fisher (1961) estimates that these processes have contributed to the erosion of nearly 150 million acres in India alone. Even considering the fact that soil is

3. It is interesting to note that even though much food is produced in the United Kingdom there is very little irrigation.

formed more quickly in the tropical region than in temperate climates — Veleger, according to Fisher (1961) estimates it to be ten times faster in the tropics — the soil formation is much too slow to replace the loss.

The above discussion does not mean to imply that tropical soils cannot be protected from severe erosion. By appropriate land use patterns and management techniques, it should be possible to reduce and control the erosion problem significantly. The overriding fact, however, remains; we still do not know enough about tropical soil taxonomy. Furthermore, since most of the research on soil taxonomy has occurred in the West — where tropical or sub-tropical regions generally do not exist — climatic information on many tropical soils remain unknown (Vehara 1981). Under these circumstances technology transfer is not an easy process.

Tropical forests and woodlands provide an interesting case. They are stable because over long periods of evolution, spanning the geological time scale, they have developed resilience which allows them to withstand climatic and other natural environmental hazards. However, faced with modern development and technology, the ecosystems may prove to be quite vulnerable. The ecology of tropical forests has to be much better understood before any long-term sustainable development plans can be made with any degree of confidence.

Tropical vegetations often give a deceptive impression of soil fertility. Major tropical forests often grow on nutrient-poor soils, especially in terms of phosphorus and potassium. During their evolutionary process, they have become adapted to such poor soil conditions by developing complex nutrient-conserving mechanisms, so that the loss of nutrients through drainage is compensated for by nutrients from rain and dust of the atmosphere and weathering of minerals in the soil. Furthermore, since the major part of the nutrients is usually held in biomass rather than the soil, the resulting loss through drainage water is minimal. If we consider the build-up of organic contents in the soils of such specialised ecosystems, it provides an excellent illustration of how nature maximises the advantages of tropical areas. Incidence of high temperatures, humidity and rainfall, total absence of frost and varied species diversity, contribute to a higher number of life-cycles and higher production of biomass than possible in temperate regions. As long as the systems remain closed, the nutrient cycle continues undisturbed. When the cycle is broken by the destruction of the rain forest due to farming, logging or overgrazing, the organic content of the soil is destroyed. The loss of nutrients under such conditions is extremely high. Accordingly, if the forest sites in the humid tropics are to be converted into agricultural areas, inputs of fertilizers often become necessary, since they are rapidly leached away by rain, and thus are somewhat transitory in their effects (Richards, 1977). This creates two problems: agriculture under such conditions is often uneconomic, and leached fertilizers could contribute to adverse environmental effects. Richards (1977) states that "in some areas climax forests exist under conditions of nutrient deficiency so extreme that they cannot be replaced by any form of permanent agriculture, e.g., the 'campinas' and 'pseudo-caatingas' on podzolic sands in the Rio Negro region of Amazonia and the 'kerangas' (heath) forests of Borneo."

There are other problems with tropical soil as well. Preparation of the land for planting is generally carried out prior to the onset of the rains. This means that this arduous task has to be carried out very often in what turns out to be the hottest and driest season of the year by labour-intensive means with people who are mostly undernourished. In contrast, in temperate climates, precipitation exceeds evaporation during winter months, and consequently it is comparatively easier to work with the moist soil in the spring.

BIOLOGICAL DIVERSITY

Another important area where climatic factors have a significant bearing on the development process is biological diversity. Ecosystems are formed by the interaction between abiotic and biotic environments. Climate influences both biotic and abiotic environments. Since ecosystems are fundamental building blocks for development, climate has a major bearing on the development process.

There are two principal methods for quantified classification of ecosystems at the climatic level (Tosi, 1980) — coincidentally both of which were initially postulated during the same year, 1948 — by Holdridge (1948, 1967) and Thornthwaite (1948). Of the two methods, Holdridge's World Life Zone System is more ecologically oriented, since it provides a good framework for classification of various terrestrial ecosystems on a quantifiable basis. This multifactorial classification scheme provides a predictive relationship between climatic parameters and the principal features of associated vegetation. Climatic factors considered for this classification system are long-term average annual temperature, precipitation and humidity. Each life zone defines a distinctive set of possible ecosystems, known as *associations*, that are unique to the given climate. In other words, a specific *association* will not occur in more than one life zone.

Globally, approximately 125 different bioclimates can be observed under the life zone system, although the classification system does not prescribe an absolute upper limit for such numbers since some may fall outside the climatic limits on which the system is based. A significantly higher number of more common life zones can be observed in the tropics and sub-tropics where frosts do not occur. Thus, nearly 38 life zones can be observed in the tropics, and another 30 in the subtropics. In other words life zones in the tropics and subtropics account for approximately 60 per cent of the world total. In contrast, warm temperate regions contain 23 life zones and cool temperate regions another 16. Only 9 life zones can be observed in the boreal region. In spite of this difference in diversity of life zones between the tropical and temperate regions, virtually all the industrialised countries and high-yielding, agriculturally successful cases appear to be concentrated within these two temperate, mid-latitude regions (Tosi, 1975).

The diversity is even more remarkable if specific countries are considered. An extraordinary number of life zones can be noted in a country like Peru, 71 in two regions. In part this notable diversity is due to the differing landforms, orographic and climatological conditions that exist due to the Andean mountain range (Tosi, 1980). Two small countries — Costa Rica and Panama — have 12 life zones each, a clear indication of pronounced diversity of bioclimates within a limited area. In comparison, the situation in temperate climates is very different. The Netherlands has only one life zone, and the vast geographical area of the United States, east of the 102° meridian has only 10.

As to be expected under this situation, the biological diversity of the tropics is significantly greater than in the temperate regions. In spite of this difference, the unfortunate point is that the existing state of knowledge of species in the tropical regions is highly limited. During the past three centuries, attempts have been made to classify and catalogue organisms. Currently, approximately 1.5 million varieties have been named, out of which only about one-third is from the tropics (NRC, 1982). It was noted during the 1975 Congress of the International Botanical Congress in Leningrad that while the tropics hold 70 to 90 per cent of all plant species, nearly 90 per cent of botanical taxonomic work is done on the plants of the temperate region.

A recent report by the United States National Research Council (1982) estimates that the number of species of organisms in the tropics is approximately twice the number found in temperate climates. This estimate is based on an analysis of species of birds, mammals and butterflies, which are relatively well-documented. For these groups, nearly twice as many species can be observed in the tropics as compared to temperate regions. The same NRC report provides a very rough estimate of the total number of species of plants, animals and organisms in the tropics as approximately 3 million and 1.5 million for temperate regions. This means only about 17 to 18 per cent of tropical organisms have received any scientific attention thus far.

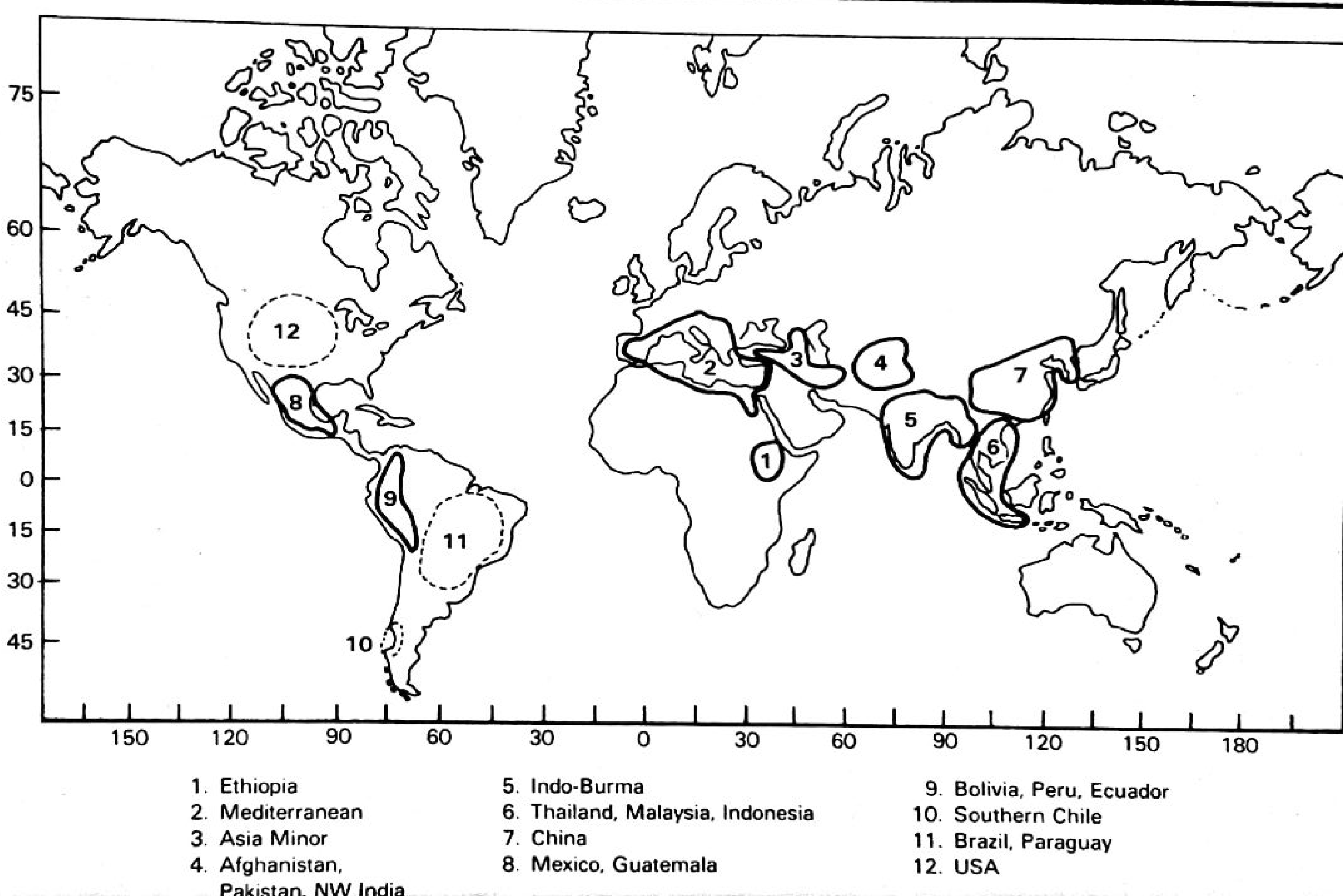
The lack of scientific knowledge of tropical species is further highlighted in another report of the United States National Research Council (1980). It points out that information on even economically important tropical species, e.g. freshwater fishes or higher plants, is still very limited. For example, if Latin America is considered, it contains about 80,000 land plant species, which is approximately 33 per cent of all the different varieties in the world. Nearly one in eight of these plants has not yet been classified since they are still not known to scientists. If freshwater fishes in South America are considered, nearly 40 per cent of an estimated 80,000 species have yet to be discovered (Böhlke *et al.*, 1978).

The situation, as to be expected, is significantly worse for lesser known organisms. Thus, fewer than 15,000 of several hundred thousand nematodes to be found globally have been catalogued (NRC, 1982). This does not mean that they are not economically important, since many are parasites of economically useful plants and animals. Similarly, if fungi are considered, currently it is "virtually impossible to prepare regional catalogues for any area, because there are none in the tropics for which the fungi are relatively well known" (NRC, 1982). This is despite the fact that fungi currently cause tens of billion dollars of damage every year (Day, 1977).

Biological diversity is an important factor for development. Without information and knowledge of different alternatives available, it is not possible to develop sustainable, productive systems in the tropical climates that are appropriate to specific regions and conditions. This is important, especially when it is considered that the number of species on which detailed information is available is strictly limited. It is because only some 5,000 plant species have been used historically for food and fibre, out of which only about 150 are used extensively. The situation is even more skewed if human energy requirements are considered, where only 3 species — wheat, rice and maize — provide more than 50 per cent of the energy as shown in Figure 1.1.

Even though few species of plants are used at present extensively throughout the world for food, it should not be assumed that they always existed in various places all over the world. In fact, the situation is generally the reverse. The species either originated or evolved rapidly in a limited area. The eminent Russian plant breeder and

Figure 1.1. Centres of origin and variability of cultivated plants (after Vavilov, 1935).

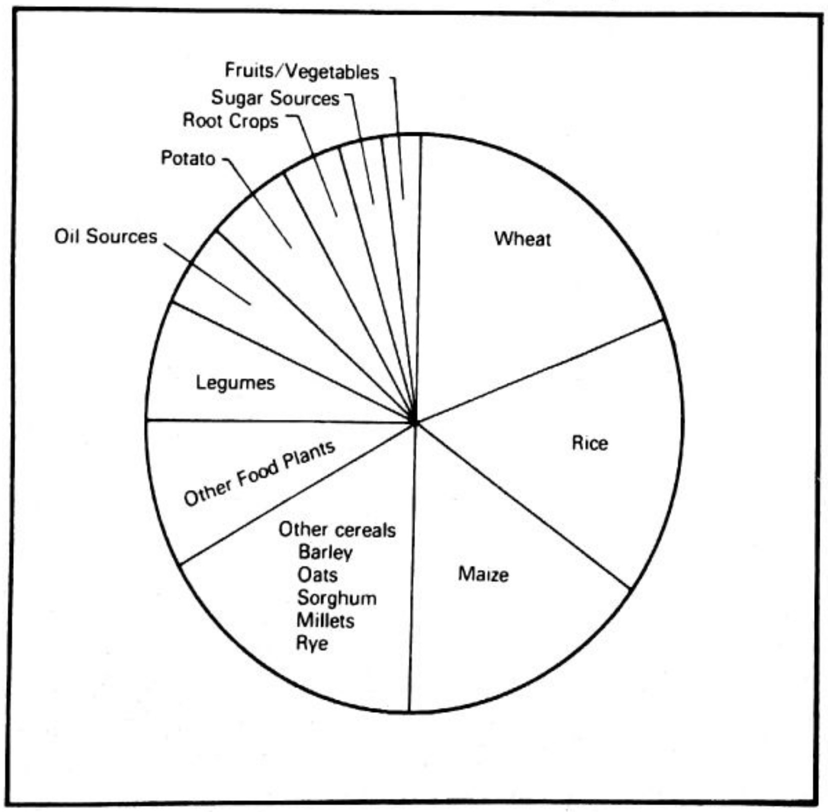


geneticist, N.I. Vavilov, analysed the areas where such development took place, and then identified 12 areas — 9 major and 3 minor — which provided much of the genetic diversity of the presently cultivated plants. These 12 centres of origin — known as Vavilov Centres — are predominantly from the tropical regions as shown in Figure 1.2.

With increasing demand for food production, the global system is becoming increasingly homogenised. The reason is relatively simple. Comparatively few species that are being used as food crops have received universal acceptance because of their taste and nutritious value, as well as being relatively easy to grow under different conditions, and readily amenable to storage, transportation and marketing.

The worldwide success of these few crops, however, could pose a serious problem for mankind in the future. The uniformity of modern agriculture means that large areas had to be cleared or are being cleared for monoculture under controlled conditions. During this clearance process, natural vegetation that existed earlier had to be destroyed. This naturally reduces the biological diversity of the area, since few species of crops are displacing the numerous varieties that existed before. Thus, crop germplasms disappear during this development process. This is especially important for the Vavilov centres of the tropics, where biological diversity is high. Accordingly, unless crop germplasms are carefully preserved, there is a real danger that these may be permanently lost to mankind. Furthermore, since our knowledge of plant species of

Figure 1.2. Human calorie sources from plants



the tropics is somewhat limited, it could mean potentially useful varieties may not even be discovered. This could become a serious long-term problem.

The usefulness of biological diversity for economic development should not be underestimated. During the past few decades much progress has been made in genetic research which has contributed to the raising of the yields of major plants and animals. Because of increased yields, the general pattern of agricultural development has tended to concentrate increasingly on a few high-yielding and low-cost crops, that are resistant to certain pests and diseases. A direct consequence of this development has been greater and greater dependence on a few select varieties of crops. Thus, more than half of the Canadian prairies cultivate only a single variety of wheat — Neepawa — and only four varieties of wheat account for 75 per cent of wheat produced in that region. The situation is not much different in the United States, where 72 per cent of potato production is due to only four varieties and only two varieties account for the pea production (OECD, 1982).

A major problem that often arises from a high degree of genetic uniformity is the difficulty of controlling pest outbreaks on a massive scale in areas where monoculture is both intensive and extensive. Good crop yields for several years often tend to lull farmers into a false sense of security, and when major pest and disease outbreaks occur, the consequences could be catastrophic. Several such historical precedents exist at present.

Probably the most well-known example of such a failure is the disastrous potato crop failure in Ireland and Europe in the 1840s due to blights. Some 2 million people died due to starvation, and another 2 million emigrated (Carefoot and Sprott, 1967). Between 1870 and 1890 rust virtually destroyed the coffee production of Sri Lanka, which was then the world's largest coffee-growing nation (CEQ, 1980). The infamous Bengal famine of 1942 was precipitated by the failure of paddy production due to a fungus, which ultimately resulted in the death of thousands of people. Chestnut blight has virtually decimated American edible chestnut trees. Periodically pest outbreaks have severely reduced corn, oat and wheat production in the United States. Furthermore, severe pest outbreaks and the subsequent difficulties in controlling them can radically alter locations of monocultural plantations. Typical examples are translocation of banana plantations from the Caribbean to the Pacific side of Central America due to heavy losses from Panama wilt *(Fusarim oxysporum)*, and shifting of rubber plantations from Brazil to Asia due to massive incidence of South American leaf blight (*Microcyclus ulei*) (NRC, 1982).

As a general rule, the number of species of pests in tropical monocultural plantations increases with time. Thus, the longer a crop is grown in a specific site, the higher would be the varieties of pest (Strong, 1974). It has been suggested that a new variety of wheat can probably be cultivated for about 10 years, before its resistance is broken down by constantly evolving persistent attacks by pests and pathogens (CIMMYT, 1974).

There are some exceptions. For example, some species such as teak in India and Indonesia and *Eucalyptus* in Brazil have not had serious pest outbreaks for decades. However, the reason or reasons as to why certain species do not have serious pest problems for a prolonged period is still not known (NRC, 1982).

This general state of affairs means that farmers have to be flexible with monocultural plantations. When a particular variety of crop suffers extensively from pest outbreaks, it becomes vulnerable and may no longer be economic to grow. Better management practices can control losses on a short-term basis, but they are not long-term solutions.

Use of chemical insecticides can help initially, but climatic conditions are favourable for pest growth in the tropics. This means pests can go through many generations within a short period of time, and during this process can become immune to the pesticide being used through evolutionary adaptation. Thus, in Egypt, chemical pesticides being used for cotton pests have to be changed frequently.

Substitution of a vulnerable variety of crops with a more desirable variety is one solution, but it is not an easy process in most cases in developing countries of the tropics, where continual pest monitoring and adoption of optimal pest control practices may not be possible. In addition, lack of suitable infrastructure to give appropriate advice, especially in rural areas, and limited availability investment capital, credit and necessary agricultural inputs, severely restrict the options available.

The problem can be more serious in developing countries of tropical climates than industrialised countries of temperate zones. As mentioned earlier, biological diversity of tropical climates is much higher than in temperate climates. This holds true for plant pests and pathogens. Accordingly, crops in tropical and subtropical climates face far more varieties of pest problems than their temperate counterparts. This is clearly shown in Table 1.3 where the number of diseases reported for different crops are shown for tropical and temperate regions (Swaminathan, 1979).

In addition to a higher diversity of pests in the tropics, the climatic conditions in the tropics — temperature, precipitation, soil moisture, and sunlight — are more favourable to pests than in temperate regions. The absence of frost in the tropics means that insects, pests and parasites live and proliferate without any interruption throughout the entire year. In contrast, in temperate climates, frost and snow act as the great executioner of nature in eradicating pests.

There is an urgent necessity to develop reliable pest forecasting methods which need to be integrated with climatological factors. Such integration is likely to pay rich dividends, especially in tropical areas. Already some benefits are being obtained from the limited information available. For example, healthy seed potatoes are now being grown in Northern India, because it was found that aphids, which are vectors of several virus diseases, are absent during certain months of the year (Swaminathan, 1979).

In future, agriculture will have to depend on continued input of genetic diversity, and accordingly maintenance of biological diversity is essential. Such genetic developments have already made significant contributions to pest control and

Table 1.3. Comparison of crop diseases in tropical and temperate climates (Swaminathan, 1979)

	Number of diseases reported	
Crop type	Tropics	Temperate zone
Rice	500-600	54
Corn	125	85
Citrus	248	50
Tomato	278	32
Beans	250-280	52

management. Thus, recent improvement in resistance of peanuts to leafspot has been made possible from the wild varieties *(Arachis monticola, A. batizocoi* and *A. vilosa)* of the tropical forest of Amazonia. The annual value of this development has been estimated at US$500 million (NRC, 1982).

Maintenance of biological diversity is not only essential for pest control but for other areas as well. A prime beneficiary is the pharmaceutical industry. It has been variously estimated that 25 per cent (NRC, 1978) to more than 40 per cent (OECD, 1982) of the prescriptions written every year in the United States contain drugs derived from organisms. According to OECD (1982), 25 per cent come from higher plants, 13 per cent from microbes and 3 per cent from animals. The commercial value of these preparations has been estimated from US$3 billion (Farnsworth and Morris, 1976) to over US$10 billion (OECD, 1982). Whatever may be the true value of these prescriptions, it is obvious that it is substantial. On a global basis, the figures are likely to be higher by several magnitudes. Currently, it is estimated that some 3,000 plant species possess anti-cancer properties, 70 per cent of which grow in humid tropical forests (Wilkes, 1981, as quoted by NRC, 1982).

In animal genetic resources the problem is not any less serious when compared to plant genetic resources. Like their plant counterparts, very little is known about genetic resources of domesticated tropical animal varieties such as goats, camels, water buffaloes, llamas or alpacas (FAO, 1978). Information on native cattle, poultry and pigs is also limited, and many of the indigenous breeds are threatened with extinction. The situation is also serious in many temperate regions. For example, 115 of the 145 of the cattle strains that are indigenous to Europe and the Mediterranean region are threatened with extinction.

Increasing population pressure is threatening the biological diversity of the tropics. Deforestation is a major contributory problem. At least 50 per cent of deforestation in the humid tropics can be accounted for by shifting cultivation, which currently provides marginal subsistence for some 200 million people (NRC, 1982). This practice is contributing ultimately to endangering and disappearance of many plant and animal species about which we know very little, but which could be potentially beneficial in the future. Unless germplasms are carefully preserved, it could mean substantial losses in the future.

TROPICS AND DEVELOPMENT

In the preceding discussion, an attempt has been made to show that climate is an important factor that has a direct bearing on both the biotic and abiotic community. Since economic development is clearly dependent on the available biotic and abiotic resources, climate is clearly a factor that has to be considered explicitly in any economic development theory of the tropics and the subtropics: otherwise the theory is unlikely to be viable on a long-term basis. Furthermore, the physical, social, economic and cultural conditions and institutional infrastructures are often very different in the tropics, when compared to their counterparts in temperate climates.

Table 1.4. Difference between temperature and tropical agriculture (NRC, 1982)

Conditions and practices	Temperate zone agriculture	Humid tropical agriculture
Controlling factors	Mostly physical	Mostly biological
Growing season	3 to 8 months	12 months
Dieback, frost, aridity	Common	None
Deforestation (land clearing)	Customary	Partial
Bare soil present	Common	Ideally none
Changes in water relationships	Common	Common
Nutrient cycle	Open	Partly open
Annuals and perennials	Quick annuals (3 months)	Perennials and annuals (more than 5 months)
Dominant crops	Seed	Vegetative, root, and seed
Year-to-year fluctuation in production	Wide variance	Little variance
Labour factor in productivity	Machine-intensive	Hand-labour-intensive
Planting density	High	Low
Field structure	Monoculture	Polyculture
Diversity of genotypes	Low	High
Competitors	Few	Many
Storage of products	Long-term	Short-term (fungi and pests abundant)
Individual biomass	Low	High
Food chains	Short	Long, complex
Cropping pattern	No stratification of fields	Multicropping

Thus, a development plan or process that has proved to be a success in a temperate zone may not necessarily be successful in tropical climates. For an important human activity such as agriculture, there are some fundamental differences in conditions between temperate and tropical zones as shown in Table 1.4 (NRC, 1982).

It is interesting to note how scientific opinion on the potential of tropical agriculture has changed during the past century. Discussing the agricultural developments of the late nineteenth and early twentieth centuries, Tempany and Grist (1958) have noted: "Many mistakes have been made because European planters and administrators were unaware that, under tropical conditions, factors require to be taken into account which are operative only to a minor degree in temperature countries, often coupled with an erroneous belief that tropical soils are well-nigh of inexhaustible fertility." By the second and third decade of the twentieth century, it was being gradually recognized that luxuriant tropical vegetation did not necessarily represent abundant fertility.

The optimism of the earlier decades was somehow replaced by the pessimism of many people during the sixties and seventies. The failure of many development plans convinced some people that agricultural development in the tropics would have to be limited.

This overtly pessimistic view is as inappropriate as the earlier highly optimistic expectations. It is being argued here that failures of many of the past policies and plans are to be expected because some of the fundamental assumptions on which they were based were incorrect. A reorientation of attitudes to and perceptions of development in the tropics is necessary.

Over the last two to three decades, many myths have grown about the tropics, the majority of which are pessimistic. It is often now believed that tropical soils are very low in fertility, climatic conditions are extreme, plant and animal pest problems are insurmountable, human health problems are serious, etc. While there is an element of truth to many of these issues, which presumably is the reason why these myths grew, it is neither possible nor scientific to make such generalized statements for a vast area containing very different physical, social and economic conditions.

One is tempted to consider what might have been the general feeling, if the situation was the reverse of what exists at present. Let us assume that it was the tropical countries that were developed rather than the temperate zone countries and that most of the research of the past two centuries was carried out on tropical conditions. Under this situation, the future prospect of the "under-developed" temperate regions, on which limited information was available, may not have appeared to be bright. One can easily think of the problems of the temperate zone that might have appeared to people to be almost insurmountable:

— the growing season is short for agricultural development — only between three and a half to six months. Cropping intensity cannot approach tropical conditions, and hence one crop a year has to last a family the entire year.
— Biological diversity is low. Many crops will be difficult to grow economically.
— Long winter months with heavy snowfall means high energy costs for human survival. Clothing costs will be far higher than tropical climates.
— Transportation will be difficult in winter. Navigation will be impossible because many rivers are frozen in winter.
— Domestic animals have to be protected carefully during the long winter months.
— Diseases of temperate climate, some known and others unknown, would create havoc with a large population.

If the table was thus reversed, one may very well have been pessimistic on the future prospects of the development of temperate regions. These would, however, have been false concerns, stemming directly from the lack of knowledge as to how to develop the region appropriately. We currently face the same problem with the tropical countries. As discussed earlier, our knowledge of tropical conditions is limited. We still do not know enough about tropical plants, many of which can be successfully exploited as sources of food, fibre, forage and fuel. We need more information on tropical soil, and ways by which sustainable agricultural yields can be obtained. Ways and means of carrying out scientific research have improved tremendously during the past two to three decades, and thus it should not take us another two centuries to ascertain sustainable development processes for the tropics.

The crucial problem is time. Current estimates indicate that the population of the tropical countries may increase by another 1.5 billion during the next two decades. Provision of adequate basic needs to this increasing population is not going to be an easy task. The most fundamental problem facing the planners and decision-makers is how to devise and implement appropriate development strategies for the tropical countries which will satisfy short-term requirements of immediate economic development but will have no long-term adverse irreversible consequences. When it is further considered that the right policies have to be devised in spite of inadequate scientific knowledge, the problem is going to be a most difficult one to resolve. Given the political will in both temperate and tropical countries, the problem can be solved. If not, the future will be bleak indeed.

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CHAPTER TWO

Climate and Health

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THE NOTION THAT climate is related to health dates back to antiquity. In the famous health compendium of Hippocrates (400 to 370 BC approximately), the Aphorisms, in Section III not less than 23 of the short categorical statements refer to the effects of seasons and weather on health. Thus we read in Aphorism 15 of Section III: "of the constitutions of the year, the dry, upon the whole are more healthy than the rainy and attended with less mortality."

Climate and weather continue to play a conspicuous role in human health. They govern our comfort, they may promote disease or affect disease vectors, but they can also support healing and favour recreation. Thus there are wide geographical differences in the bioclimate affecting humans. The physiological and pathological reactions to the atmospheric environment have been in part brought about by the spreading of humans all over the globe. This has brought many into regions where they are subjected to rigours for which nature has not endowed them. Only potent engineering methods, including housing, clothing, heating, and cooling permit survival and capacity to work efficiently in many areas.

The climate, which is nothing but the composite of many individual weather situations over a longer interval of time, in most localities exhibits a notable annual course. There are cold and warm, wet and dry, windy and calm seasons. These rhythms have profound biotropic influence and often steer the course of human well-being and of illness.

Weather elements can act singly or in concert to bring about effects in our bodies. There is a long list of components which may induce reactions. This includes atmospheric composition and suspensions; solar, sky and earth radiation; air temperature; atmospheric water vapour content (humidity); wind speed; and — generally indirectly — precipitation and electrical phenomena.

Also, we cannot overlook the direct hazards of atmospheric events. Violent storms cause many casualties and deaths each year. In the United States alone, in spite of a good warning system, annual tornado deaths average over 100 and a set of such storms on April 3 and 4, 1974 caused 315 deaths and over 6,000 injuries. Lightning in the US kills, on an average, 200 persons annually and injures about 500. Sudden floods are also major killers and storm surges along coast lines where hurricanes and typhoons occur have caused mass casualties. Thus, a tropical cyclone in November 1970 in the Bay of Bengal swept over 20,000 people in Bangladesh to a watery grave, and a West Indian hurricane on September 21, 1974 killed 8,000 in Honduras.

The focus of our discussion here will, however, be on the more subtle effects of the ever-changing atmosphere on individuals and populations.

EFFECT OF SINGLE FACTORS

Some of the atmospheric elements will provoke single effects in humans. These are principally the partial pressure of oxygen and the radiation field surrounding man.

Oxygen (O_2)

Molecular oxygen (O_2) is a normal constituent of the atmosphere. At sea level it is about 21 per cent by volume of the surrounding air. With nitrogen (N_2, about 78 per cent) it constitutes 99 per cent of air. The outstanding one per cent is a mixture of minor constituent gases of which only one, radon (Rn) has biological importance, because it is a natural radioactive element emanating from the soil. Invisible water vapour is also an ubiquitous admixture to the air. We will encounter its influence later. Oxygen, the essential element in respiration, is an absolute necessity for humans and animals. It is used for oxidation in the metabolic process, which furnishes the energies used for survival. The need for oxygen increases with higher levels of metabolism, which in turn is geared to the degree of activity.

Table 2.1 shows the decrease of the partial pressure of oxygen with elevation for the lowest levels in the atmosphere where appreciable populations live. Mountain climbers in the high Andes or Himalayas will encounter even lower values.

The table also indicates the approximate saturation of the oxygen-carrying constituent of blood, the haemoglobin (Hb). For the person adapted to sea level pressure a rapid change to higher levels will lead to hypoxia with accompanying symptoms of distress, including rapid breathing, giddiness and tachycardia. This may eventually lead to complete collapse. Airplanes flying above the 2 kilometre level therefore require pressurisation.

In the lowest few kilometres healthy persons can gradually acclimatise to lower oxygen pressure. Full acclimatisation may take several months. During that time lung

Table 2.1. Partial pressure of oxygen as function of elevation

Elevation m	0	1,000	2,000	3,000	4,000
p_{O_2} millibar (Hectopascals)	204	188	167	139	123
Saturation of haemoglobin	100	97	94	90	80

capacity increases due to an increased number of alveoli and the number of oxygen-carrying red blood corpuscles (erythrocites) multiplies. Discomfort will also occur in persons adapted to life in higher elevations by a rapid move to sea level. Again several months of acclimatisation are needed to restore physiological equilibrium.

Radiative factors — Ultraviolet

Humans are immersed in radiant energy from space and the environment. They also exchange radiative energy with that environment. The electromagnetic spectrum of radiation extends over 24 orders of magnitude in the frequency domain. Many portions have biological effects. Among these are x-rays (10^{16} to 10^{20} Hz); γ-rays (10^{20} to 10^{22} Hz); cosmic rays (10^{22} to 10^{24} Hz); radar waves (10^{8} to 10^{10} Hz); microwaves (10^{10} to 10^{12} Hz). But most important in a climatic sense is solar radiation, which ranges from 10^{12} to 10^{16} Hertz.

In bioclimatic practice the subdivisions are usually expressed in wavelength rather than frequencies. Three spectral regions are distinguished: The visible (400 to 800 nm), the ultraviolet (100 to 400 nm) and the infrared (800 nm to 1 μm). The radiative flux from the sun in travelling through the atmosphere is considerably modified by absorption and scattering. The shortest wavelengths of ultraviolet radiation, which constitutes about 7 per cent of the solar radiation arriving at the earth, are most weakened. Their nemesis is the ozone layer (O_3) which has its maximum in the stratosphere at about 25 kilometres. This layer, formed by photochemical reactions, is of greatest biological importance. It will not permit any appreciable amounts of the short-wave ultraviolet (UV-C), <280 nm, to penetrate to the surface.

The medium-wave ultraviolet (UV-B), 280 to 315 nm, and the long-wave ultraviolet, (UV-A), 315 to 400 nm are weakened also in the atmosphere but will reach the surface both as direct and as scattered flux. Their intensity depends greatly on suspended atmospheric particles. This intensity is largely dependent on solar elevation above the horizon. Thus midday and, in higher latitudes, summer, are the times when ultraviolet radiation reaches its peak.

Ultraviolet solar radiation has a number of biological effects. The shorter wavelengths (UV-C, UV-B) will activate ergosterol to produce vitamin D in the skin and thus will be beneficial by preventing rickets and spasmophilia. These rays are also germicidal. On the other hand lengthy exposure will cause sunburn (erythema). This is not only painful but can lead eventually to skin cancer. The risk of skin cancer, mostly basal cell or squamous carcinoma, is greater in certain ethnic groups than others. It is quite hazardous for Caucasians of Celtic extraction. In contrast, highly pigmented ethnic groups will not suffer from ultraviolet-induced skin cancer (Belisario, 1959). Studies in Hawaii with a multi-racial population have shown that skin cancer rates in Caucasians are 138 per 100,000 population and only 1.6 per 100,000 in native Hawaiians, with a 3.1 rate per 100,000 for all non-Caucasians (Quisenberry, 1962). It must be noted also that there are other causes of skin cancer than ultraviolet radiation. Early detected basal cell or squamous skin carcincoma is readily cured. This is not the case for malignant melanoma. There is a strong suggestion that this form of cancer can also be activated by ultraviolet radiation. Figure 2.1 shows US cases of melanoma as

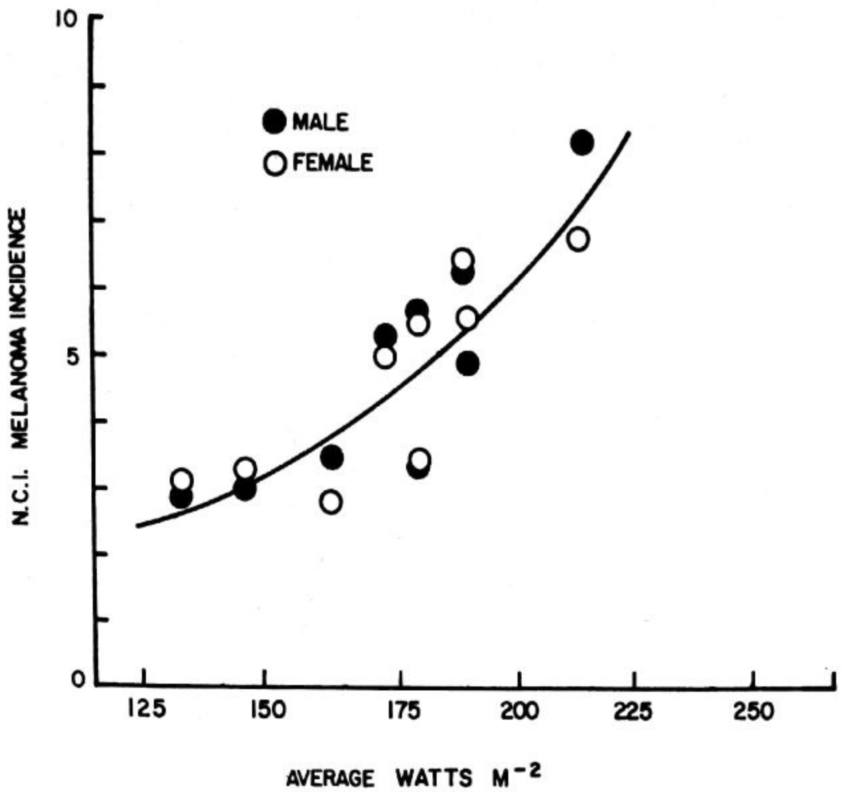


Figure 2.1. Incidence of malignant melanoma in the US as related to total incident solar (global) radiation (NCI = National Cancer Institute)

related to total average daily solar radiation. There is strong correlation between the ultraviolet portion of the radiative flux and the total. The rise of melanoma cases with the incident radiation is certainly indicative of a relation.

The etiology of skin cancer development is assumed to occur via the destruction of DNA. It is still controversial whether there is natural repair of the damage for small doses. The first sign is usually keratoses or thickening of the skin. And it is quite clear from the skin cancer incidence that there is likely to be cumulative effects of ultraviolet exposure. The age-related statistics show that in the United States there are about 2 cases per 100,000 people in the 20-year age group, 20 cases per 100,000 in 50-year olds, and about 200 per 100,000 for 70-year old persons. The fact that neck and facial features are the most common locations of skin cancer indicates solar influence. Persons in outdoor occupations are also most affected (Haenszel, 1962; Segi, 1962).

Ultraviolet A also has biological effects. It activates melanin in the skin and thus causes tanning. Persons who get sunburn and have difficulty developing a tan are most at risk of skin cancer. In this context it has been suggested that human skin pigmentation was genetically developed as protection against ultraviolet radiation and was lost by ethnic groups living in predominantly cloudy regions (Loomis, 1967).

Possible anthropogenic effects on the ozone layer have been widely cited as threatening increases in the skin cancer rates in the future (National Academy of

Sciences, 1979). Although the formidable array of stratospheric chemistry is not yet completely understood, man-made chlorine compounds, such as chlorofluoromethanes have been cited as agents causing ozone reduction. For every one per cent decrease in ozone a two per cent increase in skin cancer incidence has been projected (National Academy of Sciences, 1975; Ambach, 1978).

The ultraviolet radiation intensity, as do all solar radiation fluxes, depends on solar elevation above the horizon. Thus the greatest dosages are received close to solar noon. In higher latitudes the summer values are considerably higher than those in winter. Atmospheric turbidity plays an important role. In urban areas with high values of air pollution by particulates the solar ultraviolet is notably weakened. Another factor is cloud cover and type, and finally sea-level elevation. Table 2.2 shows the average weakening of solar ultraviolet radiation in cloudless sky depending on solar elevation. The rapid drop-off is notable. The values of the daily totals between summer and winter in middle latitudes on clear days show an order of magnitude difference.

There is also a substantial increase in solar ultraviolet with altitude. Measurements resulted in the relative values shown in Table 2.3 (Robinson, 1966).

Total radiation on a horizontal surface increases in the lower atmospheric layers by 10 to 12 per cent for each 1,000 metres altitude difference, but the total ultraviolet (all bands) increases by about 15 per cent per 1,000 metres. Actually the ultraviolet load can be notably increased by various reflective surfaces. Among them are bright cumulus clouds in the sky quadrant away from the sun. Also, highly reflective surfaces will increase the exposure, such as a fresh snowfall which may reflect 80 per cent of the incoming short-wave solar radiation or a white sand, which may reflect 30 per cent. This extra radiation explains why skiers in the high mountains even in winter and sun bathers on sunny beaches get rapidly tanned or acquire sunburns.

Radiative factors — visible and infrared

Most of the radiative exposure of humans is to visible and infrared portions of the spectrum. The visible, aside from energy exchange, affects the eye sight. This part of

Table 2.2. Relative intensities of solar ultraviolet (in per cent) in dependence of solar elevation

Solar elevation, degrees	90	70	50	40	30	20	10
Increase in optical air mass %	0	6	30	55	100	190	460
Decrease in ultraviolet %	100	86	57	41	23	11	4

Table 2.3. Ultraviolet-B radiation as function of altitude, in per cent of low-level value (after Robinson, 1966)

Altitude m	200	500	1,000	1,500	2,000	2,500	3,000	3,500
Summer	100	125	145	170	182	190	195	200
Winter	100	150	220	280	330	390	440	480

the spectrum is highly dependent on cloudiness. On overcast days at sea level in summer only one-quarter of the illumination may reach us compared to clear days. In winter, depending on latitude, the ratio may be even more unfavourable. In individual hours with thick cloud cover, there is even in midday, less than 3 per cent of the illumination than on a day with sunlight and bright cumulus clouds in the sky. In winter thick cloud cover will generally require artificial light for adequate illumination. Light has effects on the vegetative nervous system and in humans as in animals can stimulate certain hormonal secretions. Changes in illumination can also provoke psychological reactions. Lack of light can be the cause of depressions.

Specific effects of bright light and dazzling have been found in many (but not all) persons suffering from migraine. Such conditions can be often encountered in the presence of snow cover. In sensitive persons, by as yet unknown phototropic chemical reactions, vasoconstriction, leading to these headaches, are provoked. Avoidance of intense illumination and wearing of dark glasses often help (Tromp and Faust, 1977).

Infrared radiation has no known damaging effects but may occasionally provoke what has been described as heat erythema. This is better labelled as hyperemia by dilation of peripheral blood vessels which greatly increases the blood flow to the skin.

The main effect of the combined solar radiation fluxes is their influence on the human energy balance. They are an essential part of the complex system of metabolic heat loss from the body to the environment and the heat gain from the environment. These must remain in equilibrium for survival. The radiative interplay is quite complex and comprises a number of fluxes. The radiative income is composed of direct radiation from the sun, solar radiation scattered by molecules and particulates (sky radiation), radiation reflected from clouds, solar radiation reflected from the ground (as for example, by sand and snow), long-wave radiation from the ground and from radiating gases in the atmosphere, such as water vapour and carbon dioxide. In addition there is long-wave radiation from objects, such as walls or trees. The human body also loses energy by such infrared radiation to the sky, the ground, and surrounding objects. Figure 2.2 shows these various fluxes. Mathematically the net energy gain or loss by radiation can be expressed as follows:

$$(1) \qquad \pm Q_N = Q_s + Q_{sc} + Q_{rc} + Q_{LG} + Q_{LA} + Q_{LO} - Q_{rB} - Q_B$$

where Q_N = net energy gain or loss
Q_s = total energy in direct beam of the sun
Q_{sc} = short-wave energy scattered by sky and particles
Q_{rc} = short-wave energy reflected from clouds
Q_{rg} = short-wave energy reflected from the ground
Q_{LG} = long-wave energy emitted by the ground
Q_{LA} = long-wave energy back-radiated by the atmosphere
Q_{LO} = long-wave energy emitted by objects in the environment
Q_{rB} = reflected short-wave energy from body (or clothing)
Q_B = long-wave energy emitted by the body (or clothing)

The reflected energies are determined by the albedo (fraction of the incident radiation reflected from a surface) of the various surfaces. The long-wave radiation emitted by various surfaces, including the body is determined by their emissivity *e* and

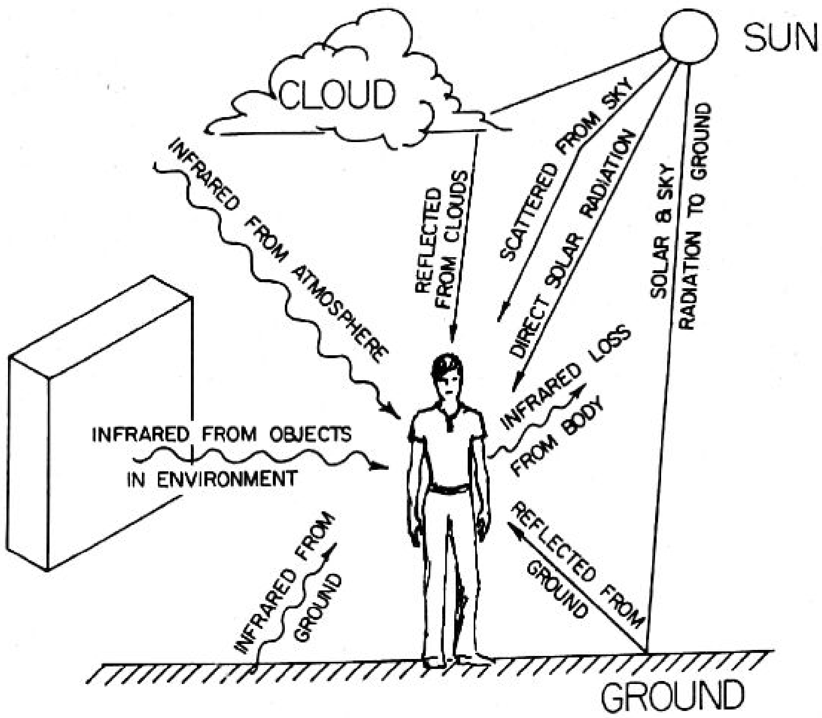


Figure 2.2. Radiative fluxes producing the radiative energy exchange between body and environment

by their absolute temperature T (in °K):

$$(2) \qquad Q_L = e\sigma T^4$$

where σ is the Stefan-Boltzmann constant 5.67×10^{-8} mW cm^{-2}K^4.

The albedo of human skin is only about 1 to 2 per cent in the ultraviolet and averages around 5 per cent of the incoming radiation in the infrared. In the visible there is a wide range depending on the individual wavelengths and skin pigmentation. In first approximation, light skin will reflect about 30 to 40 per cent and pigmented skin 15 to 20 per cent of the visible radiation. The energy loss of bare human skin to a clear sky, at two skin temperatures, for various air temperatures and a relative humidity of 50 per cent is shown in Table 2.4 (Buettner, 1938).

The radiative heat loss at low temperatures is very severe. One can estimate that an adult person with 1.6 m^2 body surface will lose 16 kw h per day. The daily metabolism will produce 4 kw h so that a deficit of 12 kw h has to be covered by radiative heat from the environment. Should the temperature of the radiating surface of a human at any time drop more than 7°C below that of the environment, the radiative loss will exceed

Table 2.4. Heat loss of skin against sky at various air temperatures

Air temperature °C		−10	0	10	20	30	
Skin temperature	20°C (293°K):	230	197	153	96	49	W m^{-2}
	30°C (303°K):	292	254	207	151	103	W m^{-2}

the metabolically produced heat and endanger the person. This can be the case at night under a clear sky, especially in deserts where the atmospheric counter radiation is very low due to the very low water vapour content of the air. Indoors the radiation from floors, ceiling, and walls with suitable heating devices will make up the deficit. Special clothing reflecting some body radiation back is helpful. The albedo of clothing which can reduce heatload on days with intense direct solar radiation has been determined at 60 per cent for white silk and 45 per cent for light flannel. On the other hand nylon has only 10 per cent albedo and dark wool even less than that. Other properties of clothing will be discussed later.

The distribution of solar radiation over the globe is quite complex although latitude plays a major role. It governs in particular the seasonal variation. The polar regions remain, of course, dark during their respective winter months and have a relatively high radiation income in summer. The high latitudes, just below the Arctic circle also have low amounts of radiation in winter. In the southern hemisphere there is also no land and no settlements in those latitudes but in the northern hemisphere vast land areas with considerable population exist there. The meteorological conditions, especially in northern and northwestern Europe, also cause much cloudiness so that the cold season is distinctly gloomy. This has been invoked by some psychologists as a contributing factor to alcoholism and high suicide frequency in some countries in that area. In low latitudes the season variation is not great but there are considerable differences between the low-latitude deserts and rainforests. These deserts have the highest direct radiative energy income but their high albedo reflects much back to space. The combination of these two short-wave fluxes place considerable burdens on humans in daytime. A general conception of the important direct solar and sky flux as it is received on a horizontal surface can be gained from Figure 2.3. An attempt to evaluate the various fluxes as they affect man, by latitude and elevation has been made by Terjung and Louie (1971) to whose formulations and extensive tables we refer the reader.

COMPLEX FACTORS AFFECTING THE THERMAL BALANCE

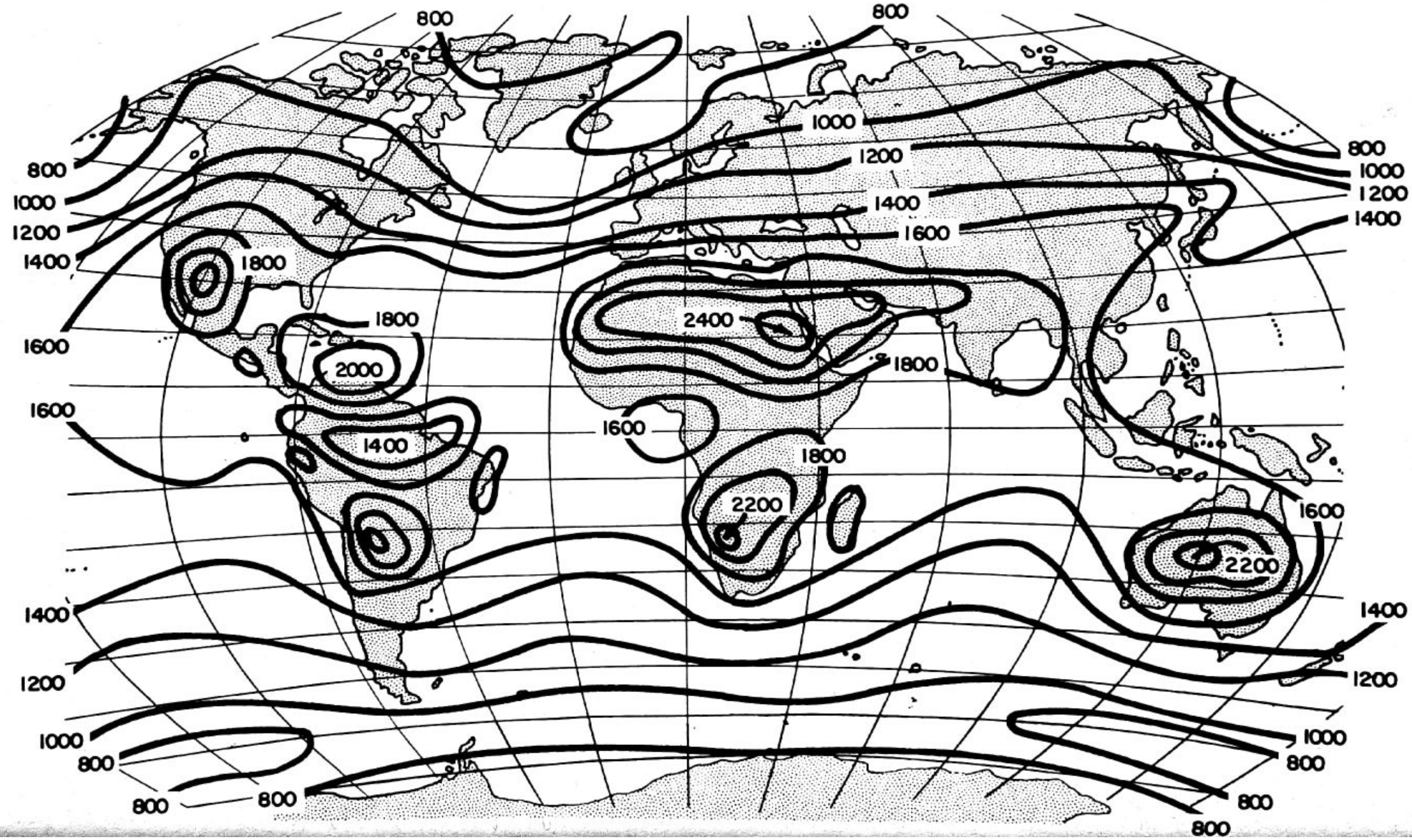
Metabolic equilibrium

Radiation fluxes, albeit very important, are not alone in affecting the thermal balance of humans. Air temperature, air humidity and air motion usually in combination play a major role. For homeotherm living beings, which includes *Homo sapiens,* maintenance of thermal equilibrium is absolutely essential for survival. We can express this formally:

$$M \pm Q_N \pm C - LE = 0 \qquad (3)$$

where M = heat generated by metabolism
Q_N = net radiation
C = heat gained or lost by convection
LE = heat lost by evaporation

Figure 2.3. Average annual radiation flux from sun and sky to a horizontal surface over the globe in KWh m-²yr-¹



The quantity M is governed by a person's level of activity. The physiologists have conventionally given this in metabolic units or METs. One MET is defined as body heat production of 50 kilogram calories per square metre of body surface (581.5 W h m^{-2}).[1] One MET represents the metabolism of an non-sleeping person at rest. This is the so-called basal metabolic rate. The relative values of this unit are shown in Table 2.5 for various levels of activities.

The convective factor involved in the thermal equilibrium condition is itself composed of the temperature difference between body (or body surface), the surrounding air and the ambient wind speed. The evaporative factor also has two components: heat lost from evaporation of perspiration from the skin and heat lost by expiration of warm saturated air from the lungs. In the symbol of formula (3) L is the latent heat of vaporisation from water to vapour and E the amount of water evaporated. At 35°C the value of this quantity is about 6.7 kw h $m^{-2}g^{-1}$. The heat loss by respiration is mostly from evaporation but a small amount of heat is lost by warming the cool inhaled air. Table 2.6 shows the usual partitioning of heat loss.

Table 2.5. Metabolic rates in humans during various activities

Activity	Number of MET units
Sleeping	0.8
Resting awake	1.0
Standing	1.5
Light office work, driving	1.6
Standing, light work	2.0
Moderate work; walking on level ground 4 km hr^{-1}	3.0
Moderately hard work; walking 5.5 km hr^{-1}	4.0
Sustained hard work; walking 5.5 km hr^{-1} with 20 kg pack	6.0
Very heavy activity; mountain climbing; athletic competition	10.0

Table 2.6. Shares of various heat loss mechanisms of humans

Process	Average per cent loss
Radiation	60 to 70
Evaporation	20 to 25
Convection	8 to 12
Conduction (to ground, or support)	2 to 4

1. Body surface is a function of height (l in cm) and weight (p in g). It can be calculated in m^2 from the empirical formula: $A = 71.84\ l^{0.725}\ p^{0.425}$.

Survival is predicated on maintaining a nearly constant core temperature of 37°C. Peripheral and skin temperatures of 33°C provide a gradient which will permit a heat flux to the environment to rid the body of metabolic heat. The maximum tolerable variation of core temperature is about ± 4°C. At 32°C consciousness is lost by hypothermia and at 41°C hyperpyrexia will cause collapse of the circulatory system. Death will occur for core temperatures below 28°C and above 43°C. Air temperatures beyond these limits are quite common on earth, far more at the lower end than at the higher. There is some physiological adaptability but the values of human homeothermal conditions in relation to the environmental thermal factors clearly demonstrate that humans in their natural state must have developed in tropical regions. It also follows that survival in cold regions depends on clothing, housing, and artificial heat production. It is clearly evident that modern humans have literally engineered their independence from climate. The limits to this will be separately discussed for cold and hot climates.

Humans in cold surroundings

Shelter and clothing are the first line of defence against cold. But humans are not entirely dependent on these artificial means. Short exposures to mild cold can be compensated for by physiological reactions. One of these is vasoconstriction in the extremities. This will reduce the skin temperature and hence lower the radiative heat loss. This has the concomitant result of numbing finger and toes, and in the case of fingers, will notably decrease dexterity. For example, exposing healthy young men without clothing in Norwegian laboratory tests by lowering a tolerable 28°C environmental temperature to 25°C, caused toe temperatures to drop by about 3°C and average skin temperatures to fall by about 1°C (Andersen *et al.*, 1965). A second defence mechanism is a stepped up metabolism which in many cases manifests itself as shivering, an involuntary muscular activity. In the Norwegian experiments a 15 per cent increase in resting metabolism was observed.

It may be noted here that voluntary food intake is considerably higher in cold regions than in warm regions. Available information indicates a linear increase with environmental temperature decrease. Within the limits of 10°C to −15°C sustained average environmental temperature the change in voluntary caloric intake for young men in fairly strenuous work is

$$(4) \qquad VMI = 35\Delta T + 3600$$

where VMI = voluntary metabolic intake in calories
ΔT = temperature difference below 10°C, in°C.

Natives of cold climates and acclimatised persons usually adjust their diet to include high-calorie foods, particularly fats. It has been shown for Eskimos in Alaska that their metabolism is about 30 to 40 per cent greater than that of unadapted persons. Their peripheral blood flow is also markedly better than that of unacclimatised individuals. It might be noted that blood flow to the fingers can be increased by biofeedback exercises. yet experience has shown that environmental cold is a severe handicap for human efficiency. This has been shown principally for the use of tools

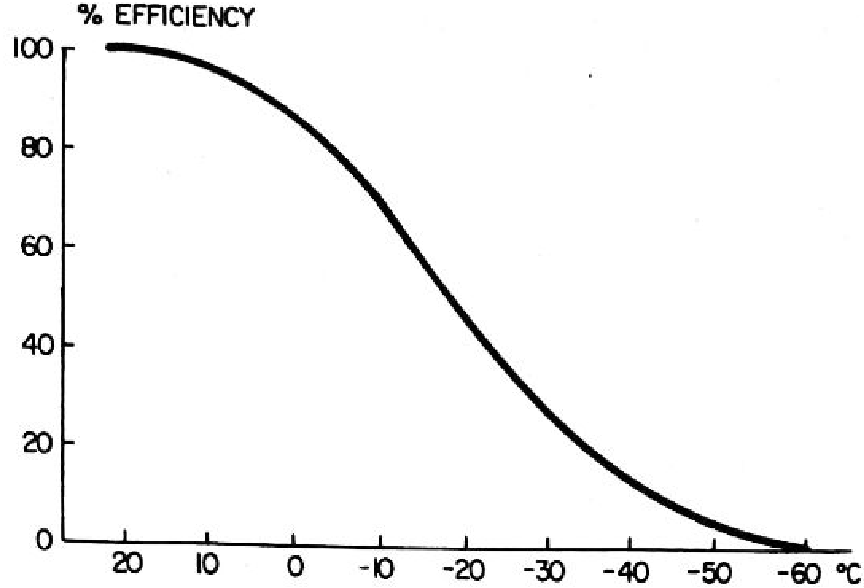


Figure 2.4. Dexterity efficiency as function of environmental temperature

outdoors. Figure 2.4 shows this for temperatures between 18°C, where dexterity is 100 per cent, and -60°C where it is 0 per cent and where all effort is essentially devoted to survival.

Actually temperature alone is an inadequate measure of environmental cold. It is rather a combination of temperature and wind speed which governs the thermal sensation outdoors in cold climates. This combination has been termed wind chill. The wind's role is the increase in convective heat loss it produces. A wind chill index was first developed during Antarctic expeditions. It was based on the amount of time it took, under given environmental conditions, to freeze a particular quantity of water. Translated into calories Siple and Passel developed an empirical model of atmospheric cooling power of the following form.

$$(5) \qquad C = (10\sqrt{u} + 10.45 - u)(33 - T_a)$$

where C = cooling power in kcal m^{-2} h^{-1}
u = wind speed, m sec^{-1}
T_a = air temperature, °C.

Cooling values obtained from this formula are represented by a series of lines for different combinations of wind speed and air temperature in Figure 2.5.[2]

For lay persons the wind chill index is not a readily understood concept. It has therefore also been converted into a wind chill equivalent temperature, also called chill factor. These equivalent temperatures are shown (both in English and Metric units) in Table 2.9. These temperatures depict the equivalent sensation felt for a calm air at that temperature compared with the prevalent temperature and wind. In full sunshine these

2. Note that the conversion factor for kcal to watt hours is 1.163, for use in the SI.

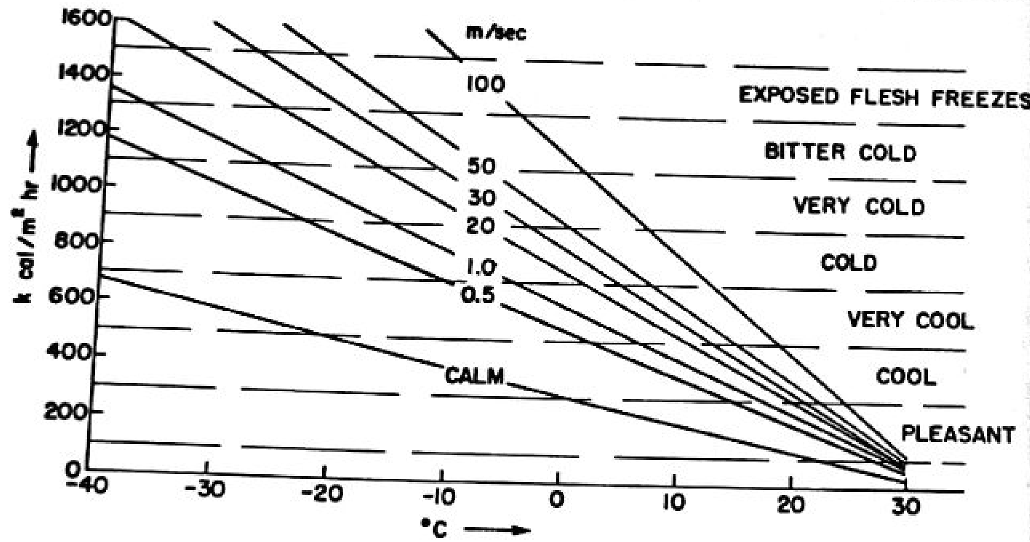


Figure 2.5. Heat loss by various combinations of temperature and wind speeds (wind chill)

wind chill equivalent temperatures are modified by the radiation received. Steadman (1971) estimated that the increase is about 14° in calm air and about 7° in strong wind. It might also be noted here that for a person walking at a 5 km h^{-1} pace in a cold environment, the wind chill is calculated for the ambient temperature and a wind speed of 1.4 m sec^{-1}.

Gregorczuk (1971) has calculated average wind chill values for the globe. The distribution of these values is shown for January and July in Figures 2.6 and 2.7. In the respective winter hemisphere the values range from > 1400 kcal m^{-2} h^{-1} (freezing of exposed human flesh) in polar regions to < 200 kcal m^{-2} hr^{-1} (pleasantly warm). In the summer hemisphere the ranges are in the north <50 >800 kcal m^{-2} h^{-1}, in the south < 100 to > 1200 kcal m^{-2} h^{-1}. These values only give a very crude first indication of the geographical distribution of bioclimate and it must be remembered that there are large standard deviations attached to these values.[3] From work by Flach and Morikofer (1962-67) one can gather that for mean winter-month values in the Arctic the standard deviation is about 150 kcal m^{-2} h^{-1} and in the Mid Atlantic States of the US about 100 kcal m^{-2} h^{-1}. The average diurnal variation is also fairly large. It is shown for three locations in Figure 2.8. That figure also shows another frequently used sensation scale, the cooling power which can be measured by various devices such as a katathermometer or a frigorimeter. These measurements can be approximated by the following formula

$$CP - (0.23+0.47\,u^{0.52})(36.5-T_A)[\text{mcal cm}^{-2}\text{ sec}^{-1}] \qquad (6)$$

where u = wind speed in m sec^{-1}

T_A = air temperature, °C.

3. More detailed charts are available for several countries: US (Bristow, 1955; Terjung, 1966); Poland (Gregorczuk, 1971); UK and Ireland (Mumford, 1979).

Figure 2.6. Isolines of average wind chill (kcal m^{-2} hr^{-1}) over the globe in January (after Gregorczuk, 1971)

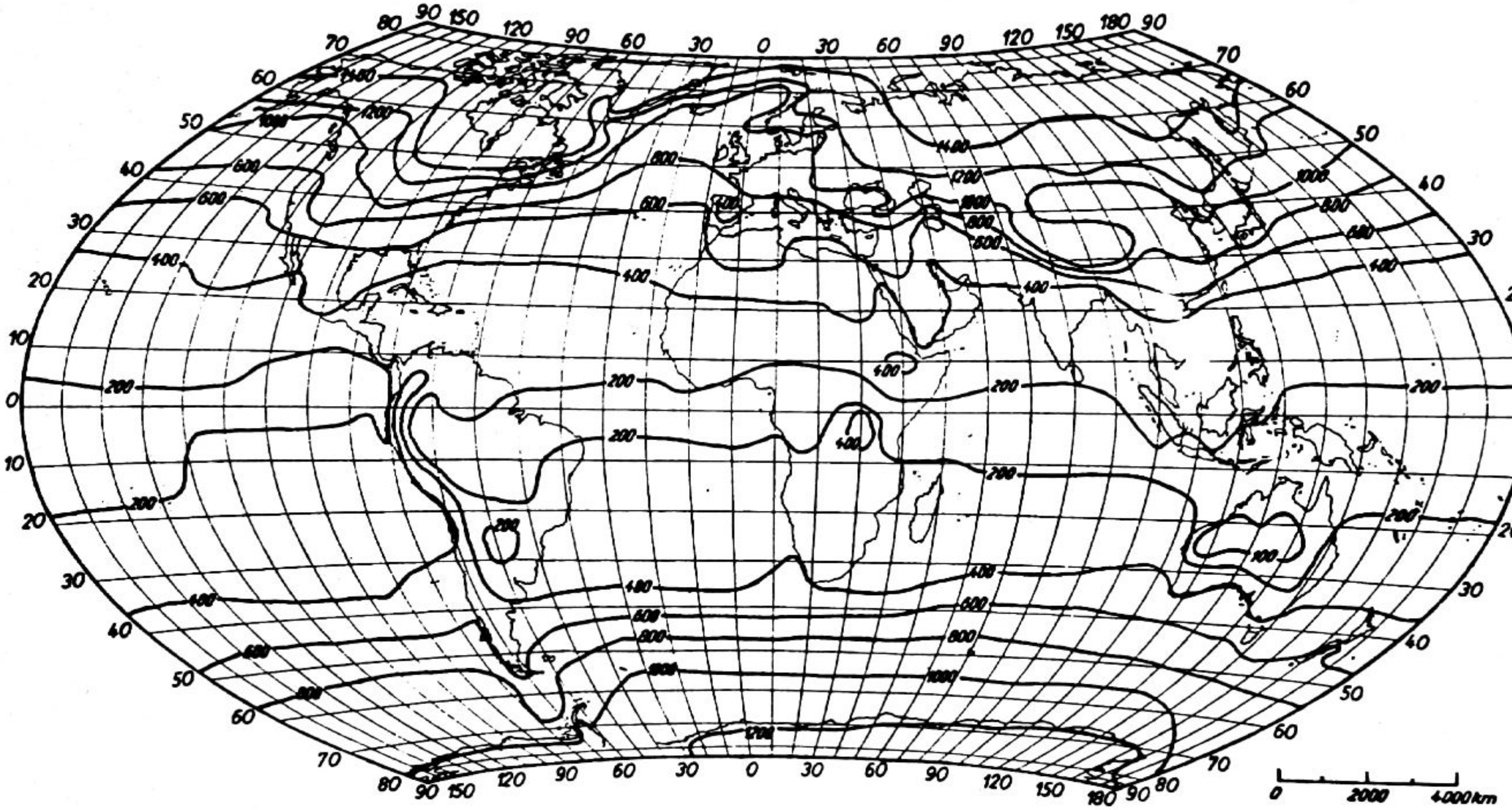
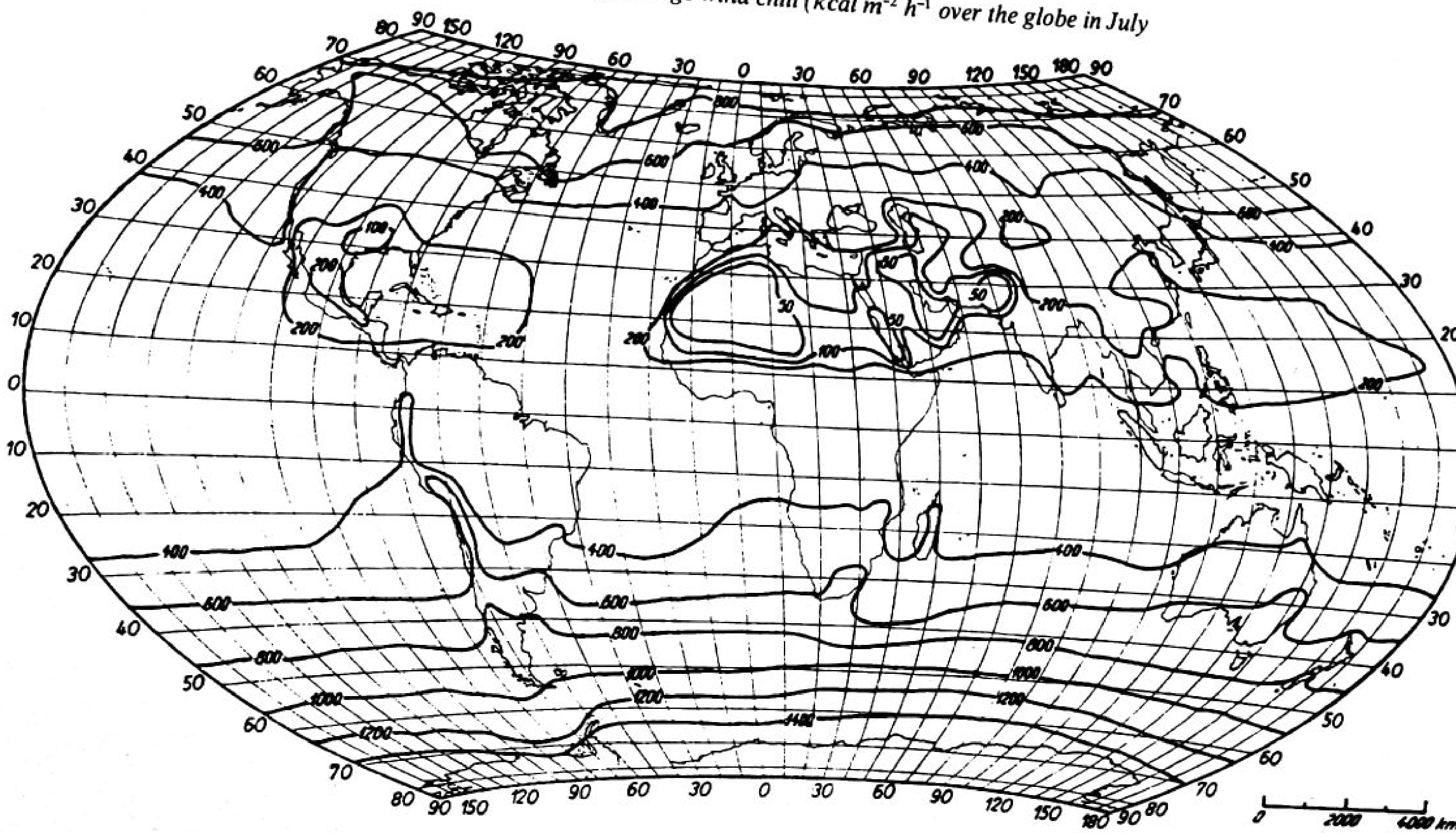


Figure 2.7. Isolines of average wind chill (kcal m^{-2} h^{-1} over the globe in July



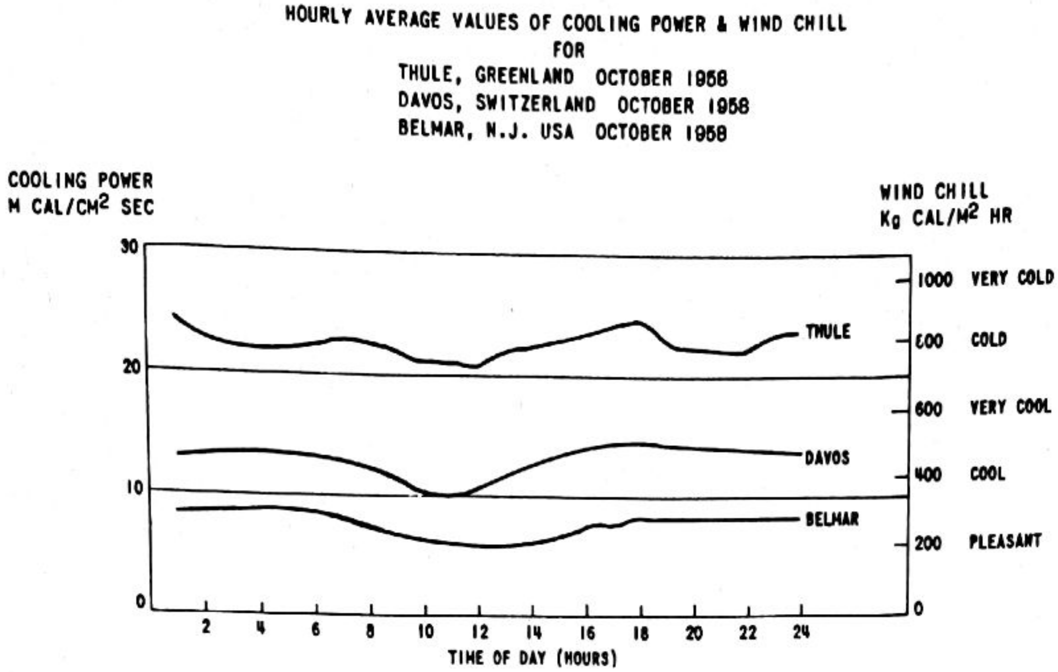


Figure 2.8. Diurnal variation of wind chill and cooling power in three different environments (from work by Flach and Mörikofer, 1962-67)

The first term represents the wind influence, which in this and similar representations shows that the square root of the wind speed governs the effect. The second term represents the difference between body and air temperature.

The wind chill equivalent temperature, which is broadcast in winter by many radio and television stations, is a valuable aid for persons exposed to a cold outdoor environment to choose appropriate clothing. This can prevent frostbite, disease or even death (Falconer, 1968). Much effort has been spent to design adequate protective clothing for a variety of climatic conditions. Space permits only a very short discussion here. For elaborate details the reader is referred to books by Fanger (1970) and Hollies and Goldman (1977).

The principal objective of clothing is insulation against the effects of atmospheric conditions on the human heat balance. It is essentially an artificial device to maintain homeostasis. Clearly the main problem is to guard against excessive heat loss. This is achieved by fabrics which incorporate air and keep stagnant air layers near the body. Air is an excellent insulator. The resistance to heat transfer is given by a dimensionless unit reflecting the insulation of clothing:

$$(7) \qquad I_{cl} = \frac{T_s - T_a}{Q_h} - \frac{I_h(Q_h - Q_e)}{Q_h}$$

where I_{cl} = insulation of clothing
T_s = skin temperature (in equilibrium assumed to be 33°C)
T_a = air temperature, °C

I_b = resistance to heat transfer of boundary layer of air at surface of clothing. ($I_{cl}+I_b$ give resistance to both radiative and convective heat transfer)

Q_b = heat flux from body (generally set at constant value of 75 per cent of metabolic rate)

Q_e = radiative heat flux from environment (outdoors principally the direct solar and sky radiation)

For practical purposes a unit has been introduced which represents the amount of insulation which will permit the flux of 1 kcal m^{-2} h^{-1} through a garment with a temperature difference of 0.18°C between the inner and outer surface of the fabric. This unit has been dubbed *clo*. It is the amount of insulation needed by a person sitting quietly in a room at 21°C with an air flow of $u < 5$ cm sec^{-1}. By these definitions

$I_{cl}=\frac{R_{cl}}{0.18}$ Clo. The value of the quantity of the boundary layer of air insulation is generally set at

$$(8) \qquad I_b = \frac{1}{0.62+0.19u^{0.5}} \text{ clo}$$

where w = is air motion in m sec^{-1}.

Another unit has also been used occasionally. It is called a tog, which is about 0.645 clo.

Substituting the value of I_{cl} in formula (7) a combined approximation results (de Freitas, 1979):

$$(9) \qquad I_{cl} = \frac{33-T_a}{0.155Q_b} - \frac{Q_b+Q_e}{(0.62+0.19u^{0.5})Q_b}$$

Air temperature and wind speed are readily obtained and the metabolic heat flux can be quite well estimated from a person's activity level. The only element which is more difficult to enter is the environmental heat flux. Usually only the sun and sky radiation on a horizontal surface is available from meteorological observations. That leaves the value of the reflected and infrared radiations usually open. In particular, there is generally very little information on the nocturnal atmospheric counter-radiation. Hence calculations of the clothing required according to formula (9), are difficult but a good guess can be made. The proper choice can be made by knowledge of the insulating values of various fabrics. From a number of sources and many chamber experiments the information presented in Table 2.7 has been gathered.

If this table looks biased towards male attire, it must be noted that the tests leading to this clothing classification were mostly made on military uniforms. For very cold weather designs of outer-wear jackets of quilted, fibre-filled material have become in recent years popular with both sexes and the last two categories of the table are not much different for male or female. Specially designed thermal underwear is readily available for cold regions. Military tests have also shown which environmental temperatures are considered comfortable with clothing of 1 clo at various metabolic rates, as shown in Table 2.8.

Table 2.7. Insulation value of various garments

Type of clothing	clo value
Tropical: open-neck shirt, shorts, sandals	0.1
Light summer wear: open-neck shirt, slacks, ankle socks, shoes	0.3-0.4
Comfortable weather wear: business suit, short cotton underwear, socks, shoes	1
Cool weather wear: business suit, light underwear, socks, shoes, light overcoat	1.5
Cold weather wear: business suit, underwear, heavy socks, shoes, hat, overcoat	1.8-2.5
Very cold weather wear: as for cold weather plus gloves and heavy overcoat, hat	2.6-3.5
Polar region wear: woollen underwear, coveralls, parka with hood, mittens, fur-lined boots	3.6-4.7

Table 2.8. Relation of metabolic rate to environmental temperature with clothing insulation of 1 clo

Activity	Metabolic rate (MET)	Air temperature °C
Sedentary desk job	1	21
Marching with pack	3	4
Running with pack and rifle	6	−20

Hot climate problems

The challenges of cold climates can be readily overcome by proper clothing, heating of dwellings, and adequate diet; the problems of hot seasons and climates are more difficult to overcome. Even though humans are a product of the tropics, there are often forbidding atmospheric conditions which they cannot cope with physiologically. The artificial defences against heat outdoors are far fewer than those against cold. There is nothing to shield us from high temperatures, or what is worse, a combination of high temperature and humidity. There is some protection against intense short-wave solar and sky radiation by reflecting clothing or by shade-producing parasols. Indoors, of course, one can use air conditioning, which can both lower the temperature and the humidity. Artificial ventilation will also help. However, the energy costs of air conditioning are high.

The physiological defences against heat and humidity have been well explored and a large literature exists (Ladell, 1957; Sulman, 1976). Again the body will try to maintain its core temperature. An internal temperature rise will trigger the heat-regulatory function of the hypothalamus gland. At first this will lead to vasodilation in the extremities, especially hands and feet. The amount of blood flowing through the

Table 2.9. Wind-chill equivalent temperature

Wind velocity (mph)	(m sec⁻¹)	Dry-bulb ambient temperature (°F and °C) 50 (10.0)	41 (5.0)	32 (0.0)	23 (-5.0)	14 (-10.0)	5 (-15.0)	-4 (-20.0)	-13 (-25.0)	-22 (-30.0)	-31 (-35.0)	-40 (-40.0)	-49 (-45.0)	-58 (-50.0)
		Equivalent temperature (°F and °C) (equivalent in cooling power on exposed flesh under calm conditions)												
Calm	Calm	50 (10.0)	41 (5.0)	32 (0.0)	23 (-5.0)	14 (-10.0)	5 (-15.0)	-4 (-20.0)	-13 (-25.0)	-22 (-30.0)	-31 (-35.0)	-40 (-40.0)	-49 (-45.0)	-58 (-50.0)
5	2.2	48 (8.9)	38 (3.3)	27 (-1.7)	20 (-6.7)	10 (-12.2)	1 (-17.2)	-9 -22.8)	-18 (-27.8)	-28 (-33.3)	-37 (-38.3)	-47 (-43.9)	-56 (-48.9)	-65 (-53.9)
10	4.5	40 (4.4)	29 (-1.7)	18 (-7.8)	7 (-13.9)	-4 (-15.6)	-15 (-26.1)	-26 (-32.2)	-37 (-38.3)	-48 (-44.4)	-59 (-50.6)	-70 (-56.7)	-81 (-62.8)	-92 (-68.9)
15	6.7	36 (2.2)	24 (-4.4)	13 (-10.6)	-1 (-18.3)	-13 (-25.0)	-25 (-31.7)	-37 (-38.3)	-49 (-45.0)	-61 (-51.7)	-73 (-58.3)	-85 (-65.0)	-97 (-71.7)	-109 (-78.3)
20	8.9	32 (-0.0)	20 (-6.7)	7 (-13.9)	-6 (-12.1)	-19 (-28.3)	-32 (-35.6)	-44 (-42.2)	-57 (-49.4)	-70 (-56.7)	-83 (-63.9)	-96 (-71.1)	-109 (-78.3)	-121 (-85.0)
25	11.2	30 (-1.1)	17 (-8.4)	3 (-16.1)	-10 -23.3)	-24 (-31.1)	-37 (-38.3)	-50 (-45.6)	-64 (-53.3)	-77 (-60.6)	-90 (-67.8)	-104 (-75.5)	-117 (-82.8)	-130 (-90.0)
30	13.4	28 (-2.2)	14 (-10.0)	1 (-17.2)	-13 (-25.0)	-27 (-32.8)	-41 (-40.6)	-54 (-47.8)	-68 (-55.6)	-82 (-63.3)	-97 (-71.7)	-109 (-78.3)	-123 (-86.1)	-137 (-93.9)
35	15.6	27 (-2.8)	13 (-10.6)	-1 (-18.3)	-15 (-26.1)	-29 (-33.9)	-43 (-41.7)	-57 (-49.4)	-71 (-57.2)	-85 (-65.0)	-100 (-73.3)	-113 (-80.6)	-127 (-88.3)	-142 (-96.6)
40	17.9	26 (-3.3)	12 (-11.1)	-3 (-19.4)	-17 (-27.2)	-31 (-35.0)	-45 (-42.8)	-59 (-50.6)	-74 (-58.9)	-87 (-66.1)	-102 (-74.4)	-116 (-82.2)	-131 (-90.6)	-145 (-98.3)
45	20.1	25 (-3.9)	11 (-11.7)	-3 (-19.4)	-18 (-27.8)	-32 (-35.6)	-46 (-43.3)	-61 (-51.7)	-75 (-59.4)	-89 (-67.2)	-104 (-75.5)	-118 (-83.3)	-133 (-91.7)	-147 (-99.4)
50	22.4	25 (-3.9)	10 (-12.2)	-4 (-20.0)	-18 (-27.8)	-33 (-36.1)	-47 (-43.9)	-62 (-52.2)	-76 (-60.0)	-91 (-68.3)	-105 (-76.1)	-120 (-84.4)	-134 (-92.2)	-148 (-100.0)
		Little danger				Increasing danger			Great danger					
		Danger from freezing of exposed flesh (for properly clothed persons)												

Note 1. – To temperature reproduced originally in °F, corresponding values in °C in brackets are added.
Note 2. – For wind values of ⩽ 1 m sec⁻¹, conditions are assumed to be calm.
The table indicates the limits of danger of frostbite even for appropriately dressed persons.

peripheral skin vessels can increase by an astounding factor of 7, compared to non-stressful thermal environment. This causes a rather dramatic increase in heartbeat rate if the core (rectal) temperature should increase by only 1°C (from normal 37° to 38°C). For a resting person the pulse rate may increase by 30 per cent, for a working person it can go up by 40 per cent. Very quickly hypothalamic regulation will initiate sweating. This too can reach extraordinary values, maximally as much as 1.7 litres per hour, or up to 10 litres in an 8-hour work day in the tropics. The increase in peripheral blood flow and skin temperature will cause greater heat loss by radiation from the body and by convection. Sweating will cause evaporative heat loss which will be assessed more quantitatively below.

The consequences, if the core temperature rises are very dangerous. They can lead to heat syncope (unconsciousness) because the brain does not get enough blood as a result of the peripheral vasodilation. Should the core temperature rise to about 42°C heat stroke (hyperpyrexia) will occur, characterised by a complete collapse of the cardiovascular system, often with fatal results. Excessive sweat production can result in dehydration and salt depletion. The loss of body fluids can lead to giddiness and ultimately delirium. The salt depletion will cause heat cramps, nausea, and vomiting. Unless adequate fluids are consumed and the electrolyte balance is restored death may result (Gilat *et al.*, 1963).

Atmospheric heat conditions are particularly dangerous to infants, whose heat regulatory mechanisms are not yet developed, and to old persons whose circulatory systems are impaired. Obese individuals also are endangered by heat. Persons with congestive heart disease are also among potential victims of hot weather or climates.

There are again a large number of indices attempting to assess the heat stress of the environment. These relate to the feeling of discomfort and, as such, have been frequently classified by votes of people exposed to a variety of environmental conditions. One of these indices which has been widely used is the so-called effective temperature. It is in fact a combination of air temperature and humidity into an equivalent temperature representing the prevailing conditions, the same sensation as felt for a temperature of the same value with calm air saturated with water vapour. It can be represented by

$$ET = 0.4\,(T_d + T_w) + 4.8 \qquad (10)$$

where T_d = air temperature measured with °C dry-bulb thermometer
T_w = temperature measured with a moistened (wet) thermometer. This is $\leqslant T_d$ and the difference $T_d - T_w$ is a measure of atmospheric moisture. The greater the difference the drier the atmosphere, because of the evaporation from the wet wick surrounding the thermometer, the heat of vaporisation being taken from the thermometer.

Figure 2.9 gives a comfort diagram based on temperature and humidity factors. It shows in a grid of dry-bulb air temperatures and water vapour mixing ratios (grams of water vapour per kilogram of dry air), lines of wet-bulb temperatures, relative humidities, and effective temperatures. A hatched area in the graph indicates the combination of values within which a majority of persons in light clothing and sedentary occupations feel comfortable. This clusters around effective temperatures of 20°C (or dry-bulb temperatures 20 to 24°C and relative humidities of 40 to 60 per cent). At effective temperatures above 30°, far into the zone of discomfort, the dangerous area of core overheating begins, and at 32°C effective temperature the physiological defences begin to break down, as shown in Figures 2.10 and 2.11. Hard work is not recommended for any effective temperature above 25 to 28°C, depending on degree of acclimatisation. The wise custom of a siesta during the hottest hours of the day in tropical and subtropical climates is clearly supported by climatic stress analysis.

The effective temperature concept was developed for indoor conditions and for assessment of needs for air-conditioning. For outdoor conditions one of the major modifications is the solar radiation load which in experiments (Lee and Vaughan, 1964) of persons exposed to full summer sun is about equivalent to a 7 to 9°C increase in air temperature.

Because of the great importance of heat stress in exposed occupations, a special piece of equipment is used which measures both the dry-bulb and wet-bulb temperature, and at the same time integrates the effect of radiation and wind on a black globe, measuring its temperature, Tg, too. A combination of these temperatures

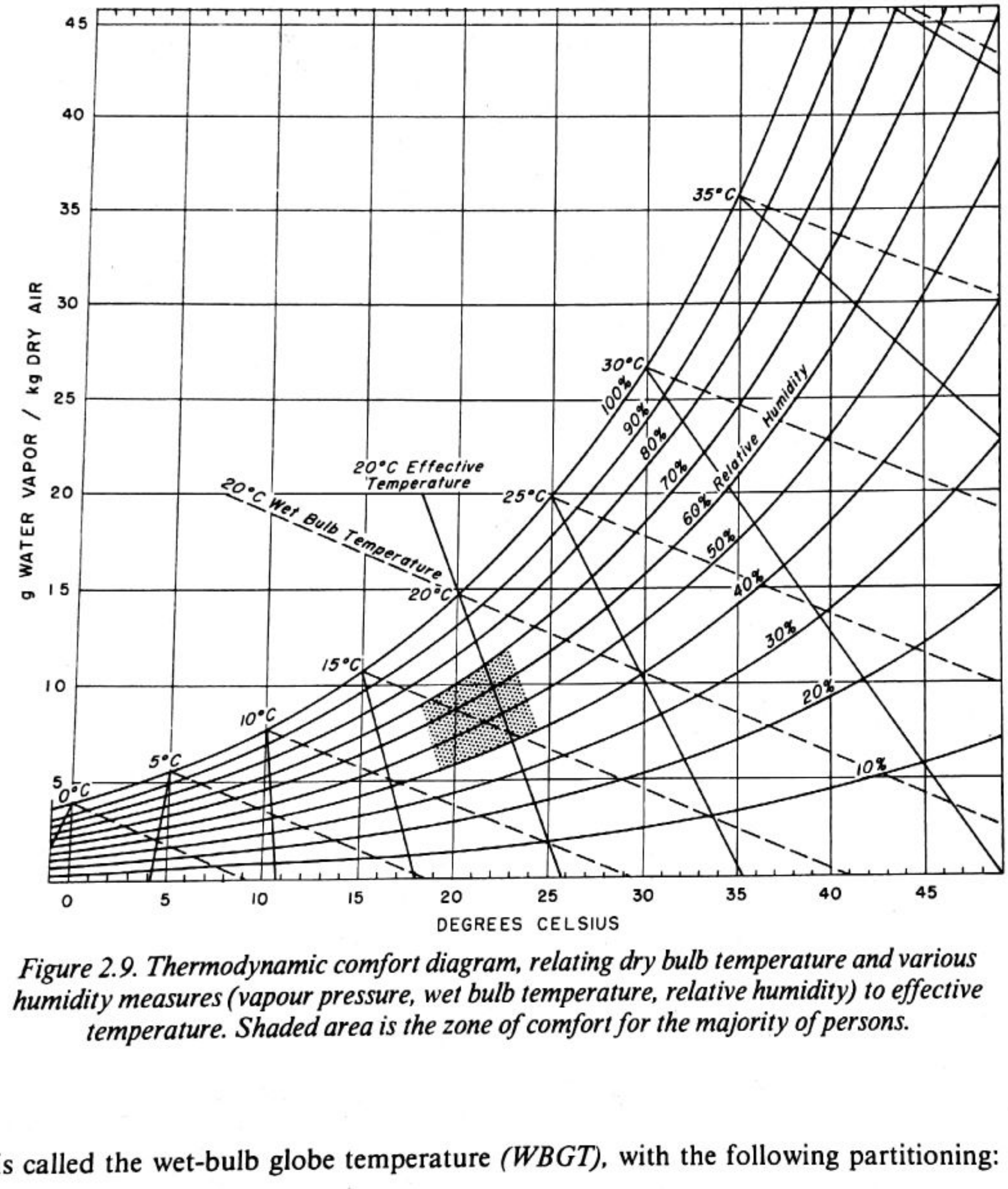


Figure 2.9. Thermodynamic comfort diagram, relating dry bulb temperature and various humidity measures (vapour pressure, wet bulb temperature, relative humidity) to effective temperature. Shaded area is the zone of comfort for the majority of persons.

is called the wet-bulb globe temperature (*WBGT*), with the following partitioning:

$$(11) \qquad WBGT = 0.2T_g + 0.1T_d + 0.7T_w$$

This indicates the great weight one has to attribute to the moisture-indicating wet-bulb temperature. For *WBGT* values of 31°C or higher it has been found wise to discontinue strenuous activities.

For the lay public indices such as effective temperature or wet-bulb globe temperatures have much less appeal than for scientists or engineers. A particular drawback is the fact that the uncomfortable or dangerous values are lower than the air temperature. Hence the Canadian Weather Service developed an index, in analogy to the equivalent wind chill temperature, which would be a better comfort (or

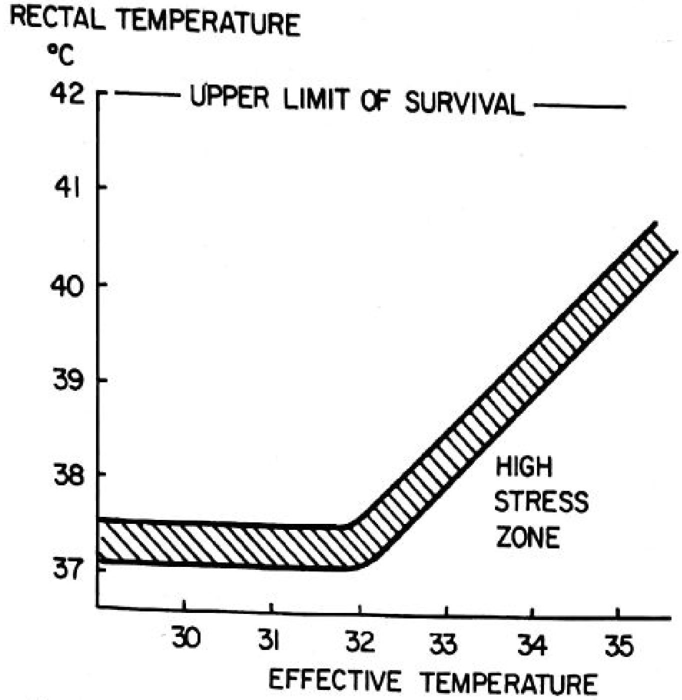
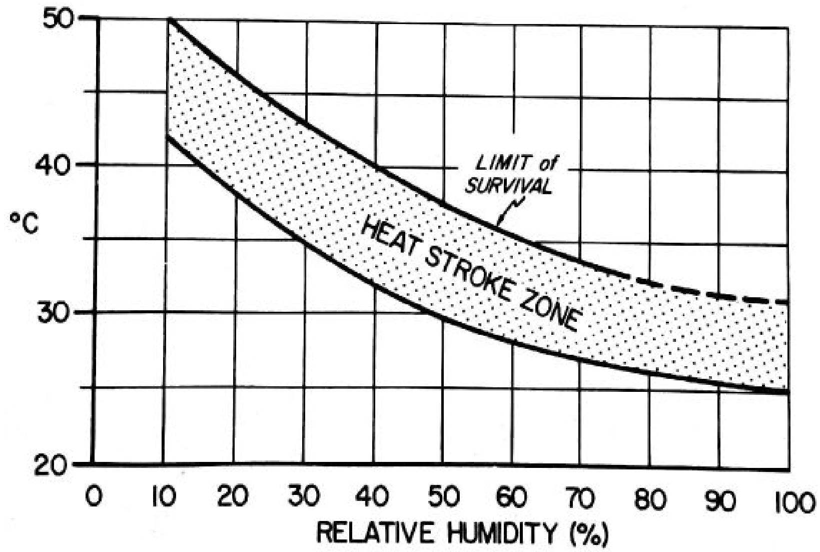


Figure 2.10. Rise in body core temperature as function of environmental effective temperature

Figure 2.11. Combinations of air temperature and relative humidity conducive to heat stroke



discomfort) representation of summer weather (Masterson and Richardson, 1979). This index, called humidex, is defined as

$$(12) \qquad H = T_a + h$$

where T_a = air temperature
h = 5/9 (e–10)
e is the vapour pressure in millibars (or kilopascals × 10).
e is determined from T_{dp} or dew point temperature, i.e. the temperature to which the air has to be cooled for dew to form.
T_{dp} is another measure of atmospheric moisture.

$$(12a) \qquad e = 6.11\left[\exp\left\{\frac{ML}{R}\left(\frac{1}{273.16} - \frac{1}{T_{dp}}\right)\right\}\right]$$

where M = molecular weight of water (18.016 g mol^{-1})
L = latent heat of vaporization (597.3 cal g^{-1})
R = gas constant (8.3144×10^7 erg mol^{-1} sK^{-1})
T_{dp} = dew point temperature, °K.

It is fairly clear that appropriate tables will greatly facilitate by-passing the fairly complex calculation to obtain H. Table 2.10 gives a brief excerpt from such tables.

Where dew point temperatures, T_{dp}, are available the value of h can be added to the air temperature. The conversion value has been determined by Canadian researchers, as shown in Table 2.11.

The degree of discomfort for various ranges of the Humidex have been described. They are shown here in Table 2.12.

While such indices may satisfy certain practical needs, for scientific work in human physiology and for quantitative estimates of energy consumption for air-conditioning

Table 2.10. Example of Humidex values as function of air temperature and dew point

Air temperature	Wet-bulb temperature T_w, °C		
T_{dp}, °C	15	20	25
20	22.3	27.6	—
25	25.5	30.8	37.2
30	—	34.0	40.4
35	—	37.2	43.6

Table 2.11. Conversion value of dew point temperature to factor h in Humidex formula

T_{dp} °C	15	20	23	25	26
h	4	8	10	12	13

Table 2.12. Comfort sensations associated with various ranges of Humidex

Humidex value	Sensations
20-29	Comfortable
30-39	Various degrees of discomfort
40-45	Almost everyone uncomfortable
⩾46	Work effort must be restricted

a more exact approach is needed. This can be done by an energy balance approach (Auliciems & Kalma, 1979), which defines the heat stress, *HS*, as follows:

$$(13) \qquad HS = (M + (1/A)(Q_s + Q_{sk})(A/f)$$

where M = metabolic rate
A = body area
$Q_s + Q_{sk}$ = solar and diffuse sky radiation
f = cooling efficiency of sweating,
l/c = $\exp(0.6 \frac{E}{E_{max}} - 0.12)$
C = actual sweating rate, $E = AM + (Q_s + Q_{sk}) - AD$:
D_i = dry heat exchange loss at 35°, when sweating = $h\,(35 - T_a)$;
h = heat transfer coefficient from body to air.
E_{max} = evaporative capacity of the air = $49.61u^{0.3}(31.5 - e)$ watts;
[u = wind speed m sec^{-1}, e vapour pressure (millibars)]

The investigators, by substituting the various heat gain and heat loss estimators, worked out a heat stress relation:

$$(14) \qquad HS = [132 + (Q_s Q_{sk}) - (12.3 + 16.2u^{0.5})(35 - T_a) \exp 0.6(\frac{E}{E_{max}} - 0.12)]\text{Watts}$$

using all previously explained symbols. In order to perform the necessary calculation, air temperature, wind speed, vapour pressure, solar and sky radiation must be known. Metabolic rates and body area can be assumed for various individuals and work loads. Using available climatic data, Kalma and Auliciems (1978) charted heat stress in Australia for various seasons and day times. They also estimated both heating and cooling energy requirements.

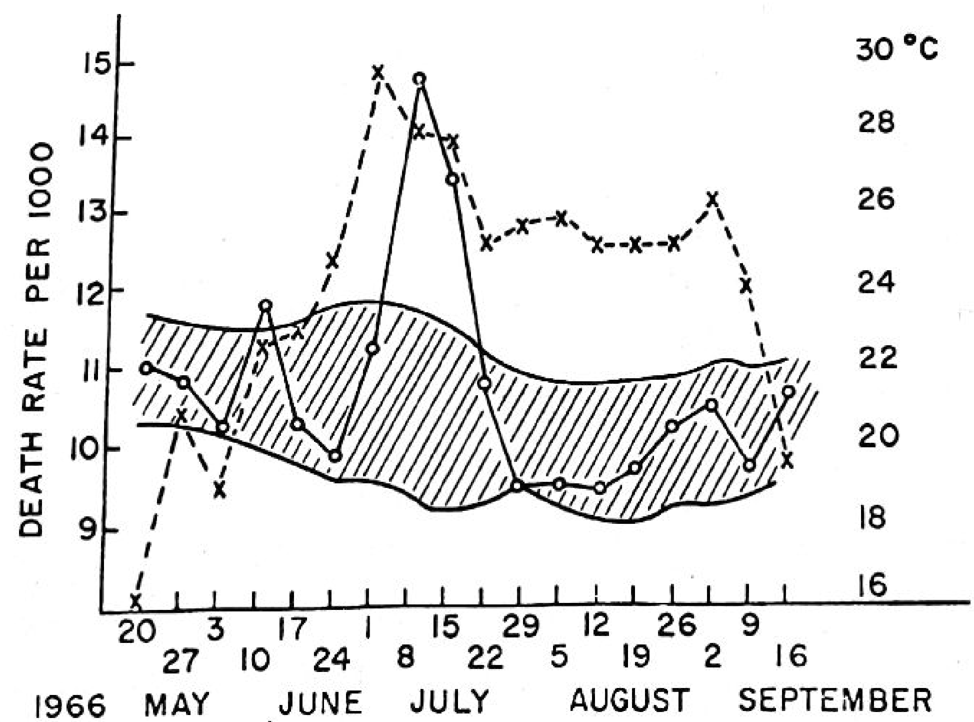
The need for air-conditioning in hot climates has been investigated in various contexts. Among the more interesting are performance and learning. Both suffer in hot environments. Tasks requiring memory are impaired also when the thermal equilibrium is disturbed. The evidence is overwhelming that the mental balance is upset by heat discomfort also. When persons cannot get rid of their metabolic heat they became irritable. Tempers flare, crimes of passion rise in frequency in hot weather and riots are more common than in comfortable weather. Hot desert winds, often laden with dust, whether called Chamsin, Sharav or Scirocco, seem to increase human aggressiveness.

But heat waves are not only reflected in the crime statistics; they also show clearly in the mortality statistics. About 500 persons per year die on average in the United States directly as a result of heat stroke. In 1936, one of the hottest summers on record, especially in the Midwest and Great Plains, 4,700 people were killed by the heat. These are only the direct victims. Many more die each year from other causes aggravated by excessive heat. The year 1966 was another of high mortality in the US coincident with high temperatures. St Louis and New York City showed, for example, suddenly high mortality rates. Figure 2.12 shows the weekly death rates for New York City during the summer of 1966. The hatched band shows the 95 per cent confidence limits of expected deaths, based on long-year experience. The dashed line represents the weekly mean temperatures, which rose in the last June week to 30°C. This was followed in the subsequent week by a 35 per cent rise in deaths, far beyond the expected values. Ailing elderly persons were the chief victims.

It is interesting to note that the upper confidence limit shows a notable bulge in June. This suggests that during that month somewhat higher death rates are not uncommon. In this transition from spring to summer people are not yet properly acclimatised to heat, and their clothing had not been adjusted to warm weather.

In 1976, London, England, experienced a similar startling rise in summer deaths among the elderly as had New York a decade earlier. The hot spell from June 23 to July 7 was the worst in the century. Temperatures were 10°C above the long-term average and maxima soared above the 30°C mark. Death rates among the population of 65 years or older rose steeply by 50 per cent.

Figure 2.12. Excess mortality in New York City during 1966 heat wave. Solid line shows weekly death rates (hatched area 95 per cent confidence limits), dashed line shows average weekly temperatures



There have been a number of attempts to relate incidence of criminal offences to weather and climate. Whatever the relationship may be, they are neither obvious nor simple. If the statistics show that there are more robberies in the cold season, does that indicate anything more than that the longer period of darkness offers better cover than short nights? On the other hand, aggravated assault and rape are more frequent in the warm season. The traditional folklore has it that hot weather leads to so-called crimes of passion. But some criminologists have raised the question whether the victims are in the season less careful and thus more exposed to criminal attacks (Kevan and Faust, 1976).

Accident statistics also suggest that hot weather renders many more accident prone. It has been argued that excess heat makes people sleepy and hence less alert. Thus both industrial and traffic accidents show increases in hot weather for no other obvious reasons, that are quite apparent when roads are slippery from rain or ice.

CONTAMINANTS OF THE ATMOSPHERE

The air, far from being a pure mixture of the life-sustaining gas oxygen (O_2) and the inert gas nitrogen (N_2), contains innumerable gaseous and solid admixtures. Some of these are harmless, others noxious. Many of them are produced by nature, but human activity has progressively added more and more. Amounts of these contaminants vary greatly with geography and climate. In urban and industrial areas they have become major elements of the local climate.

Among the natural contaminants are dusts from deserts and volcanic eruptions. The former are a regular feature in arid countries. Blown by the wind they can travel thousands of kilometres. For example, Sahara dust is a regular feature in the Caribbean and major dust clouds can be frequently noted over the South Atlantic on satellite pictures. Volcanic dust is more sporadic and generally restricted to the areas of active volcanoes. But the volcanoes contribute also to the sulphur dioxide (SO_2) content of the air. Other sulphur compounds, such as the evil-smelling hydrogen sulphide (H_2S) result from organic decay. But manmade SO_2 has been blamed for mortality and morbidity in major air pollution episodes. In many of these, when SO_2 exceeded 0.2 parts per million, acute respiratory distress ensues. It may result in acute bronchitis and pneumonia. Persons with existing respiratory ailments, such as emphysema, may die during a persisting air pollution episode.

These episodes are caused by meteorological conditions. They always involve a temperature inversion, in which a shallow layer of cold air is overlaid by warm air. This condition occurs in high pressure systems with often clear skies. Winds are weak and pollutants brought into the air from whatever source will tend to accumulate. Inversions are frequent in the valleys of mountainous areas and common in some subtropical coastal zones. Often geography and meteorology conspire to create stagnant conditions. Mountain barriers may block ready air exchange. The Los Angeles basin is a typical example.

In urban areas where pollution is endemic, chronic bronchitis, emphysema, and asthma are common ailments. In the most affected people continuous exposure may result in pulmonary fibrosis or emphysema. It is, however, difficult to relate death rates to the level of pollution, except for the major pollution episodes, because of the many other insults, such as cigarette consumption, and the great variability of pollutants even in different city quarters (Lipfert, 1980). Vital statistics tell us very little about shortening of life.

Air chemistry is exceedingly complex. No contaminant stays unchanged. With time and such energy input as solar radiation, photochemical reactions take place and create new compounds. Trace metals often act as catalysts in the promotion of chemical reactions. Thus SO_2 and NO_2, common in the smoke plumes of power plants, other industrial processes using fossil fuels, and car exhaust, are converted to sulphuric acid (H_2SO_4) and nitric acid (H_2NO_3). Photochemical reactions will produce from NO_2, nitrous oxide (NO) and O, which in turn produce ozone O_3, and peroxyacetylnitrate (PAN). The latter is a well-known eye irritant. Ozone in concentrations of 0.1 parts per million will lead to irritation of mucous membrances and some persons experience nausea and headache.

Another contaminant, prevalent in cities but encountered only in extremely low concentrations in nature, is carbon monoxide (CO). The culturally produced CO results from incomplete combustion of fossil fuel, most of it from car exhaust, but is also present in smoking material. Because of its affinity for the haemoglobin in blood it forms a compound carboxyhaemoglobin (COHb) and the blood molecules so transformed become useless for the essential transport of oxygen to muscle and vital organs. The blood transformation is directly proportional to the CO concentration. In 10 parts per million (rare in the atmosphere) 1.6 per cent of the haemoglobin is transformed into COHb.

Among the solid suspensions, often designated as aerosols, nature produces a wide share of particles that cause distress. Many of these are aeroallergens, with the most common being various types of pollen. For nearly the whole vegetative period of the year some of this flotsam is present in the air. In the spring tree pollen is prevalent and grass pollen is usually also common in that season in moderate latitudes. In many areas goldenrod and rag weed pollen saturate the autumn air where these plants grow. At the time of maximum production of a given pollen variety one can count from 10 to 300 such particles in a cubic metre of air. They are relatively large, about 30 μm in diameter and are intercepted in the outer respiratory passages. Yet they cause a large amount of misery, from runny noses and sneezing to asthma.

Pollen are larger and less numerous than other aerosol particles. These measure usually from 0.1 to 10 μm. Larger particles fall out close to the source, but the small ones are carried by the wind. Rainfall causes their release from the plants. Depending on the climatic rain regime their life time as atmospheric suspensoids may be from 5 to 30 days. The smallest variety is also the most numerous. Least are found over the ocean, where there are only a few hundred per millilitre of air (ml). In clean country air there are usually several thousand, and in city air less than 100,000 ml^{-1} are rarely encountered. While ocean air is unlikely to contain noxious substances and may, in fact, carry some desirable ones such as iodine, urban air has a large number of undesirable trace substances. Among them are asbestos, a carcinogenic mineral, cadmium, detrimental to the cardiovascular system, and others.

It should be noted here that the average human being circulates about 12 m^3 air through the lungs daily. This means that a staggering 10^{12} particles per day pass through the respiratory system of the average urban dweller. Many are exhaled, some are intercepted in the upper respiratory passages but many penetrate into the alveoli. It is known that on autopsy lungs of urbanites are dark, instead of pink, as found in the lungs of people living in clean air.

At this point we should look at the portion of the atmospheric contaminants which are radioactive. Here again nature exposes us to considerable radiation. Two gases Radon (Rn^{220}) and Thoron (Th^{222}). Both of them are decay products of the naturally occurring radioactive elements in the early's crust. They escape through the soil into the air where they continue to decay. In areas of granitic rock much more radioactive gas is emitted than from thick sedimentary layers. Radon has three radioactive solids as decay products and thoron six. These are part of the aerosols. They are almost absent over the oceans and a snow cover will prevent the diffusion of radon and thoron from the soil.

The radiation is about 0.16 nano-Curies[4] from each of the two radioactive gases. It is not known whether there is any repair in cells subjected to very minor doses of radiation or if the detrimental effects are cumulative. The biological effectiveness of these natural exposures are measured in a unit called a RAD (radiation absorbed dose), which is the energy absorption of an energy of 100 erg per grams of substance. It is estimated that most people are exposed to from 50 to 150 m rad yr^{-1}. But there is also an exposure to manmade radioactivity. Apart from weapon testing there is a small addition to the air from the nuclear and coal-fired power plants. The latter, using certain types of coal which contain uranium and thorium often release more radioactivity than nuclear fission plants, which are more closely controlled. Present (1980) exposure to manmade radioactivity of all types, including weapons, has been estimated at about 3 per cent of the natural radiation components.

Atmospheric radioactivity and cosmic radiation causes ionisation of air molecules and these air ions have been adduced as the cause of innumerable health effects. Observations show that there are usually between 500 and 2000 ions cm^{-3} in air. The positive charge prevails over the negative charge by a ratio of 5 to 4 (Wehner, 1969). There is a continuous recombination into the electrically neutral state. Many of the ions attach themselves to other aerosol particles. They then become inert and recombination with particles of opposite charge is slowed down. The initial ions are called small ions. They have high mobility in an electric field. Those attached to aerosols are called large ions and have slow mobility in an electric field.

There is some evidence that in certain weather conditions their concentration rises above the average. An example is the conditions preceding or accompanying the hot desert wind Sharav. Sulman *et al.* (1974) reported in Jerusalem a quadrupling of the ion number (4000 – and 4500+) prior to such winds. The adverse reactions of weather sensitive persons were attributed to "serotonin irritation syndrome." The neurohormone serotonin is an irritant. It inactivates an enzyme (monoaminooxydase) and reduces its metabolite 5-hydrooxindole. Excessive serotonin causes rise in blood

4. 1 nano-Currie corresponds to 37 radioactive disintegrations per second. Both Rn and Th decay by α-emissions.

pressure, as well as irritability and allergy symptoms. It is alleged that the offending serotonin is secreted in the intestinal tract and from there is pervasively transported through the body.

In the case of the Föhn,[5] a hot wind descending into the valleys when air masses are forced to cross a mountain range and in the process lose their moisture on the windward side, it is well documented that the surface radon content increases. It often marks the transition from anticyclonic to cyclonic circulation in the Alpine areas. Physiological symptoms in weather-sensitive persons are inability to concentrate, motor-unrest, sleep disturbances, occasionally migraine headaches, but occasionally result in euphoria (Swantes and Reinke, 1978). If all this can be ascribed to ionisation, increase or the prevalence of the positive sign over the negative is not yet adequately established, although the adherents of the serotonin hypothesis suggest that.

DISEASES AFFECTED BY CLIMATE

An examination of maps showing the geographical distribution of diseases clearly shows that pathological factors are quite unevenly distributed over the globe. The prevalence of certain diseases is so notable that they have been labelled "tropical". Although there are cultural, nutritional, and sanitary facets of disease occurrence and control, it is immediately clear that climate and weather play an important role (May, 1950; Stamp, 1964). Although the tropics have been singled out as the hotbed of a host of diseases, there are other diseases which are more prevalent in moderate or cold climates.

The association of various diseases with climatic factors is generally established only in a statistical sense. In many instances the exact pathway of the etiology is not well known. What complicates the tracing of causes and effects is the fact that climatic circumstances will not only affect the human body but also the microorganism or viruses causing the disease. However, in very many instances the effect is on intermediary hosts and transmitters. These vectors are almost always weather-sensitive at various stages in their life cycle. This accounts also for the very notable annual variation of diseases, especially at onset.

In those diseases where insects or snails act as vectors the limiting climatic conditions are fairly easily traced by comparisons of maps of disease distribution and climatological charts (Jusatz, 1962; Jusatz, 1977). This is particularly evident for the various disease-transmitting mosquitoes. Of all climate-affected vectors, the mosquito is by far the most noxious (Gillett, 1974). Of 3,000 mosquito species, about 40 to 50 are important as malaria transmitters. Their life cycles are intimately related to weather. Optimal for oviposition are, for example, temperatures of 30°C. Annual temperatures below an average of 12°C are generally limiting for survival. Ample rainfall for the production of stagnant surface waters is essential to keep the larvae alive. There is also evidence that the malaria plasmodium requires temperatures of the warmest month of

5. In the North American Rocky Mountains this type of wind is known by its Indian name Chinook.

the year to be greater or equal to 17°C. There is little doubt that malaria is the most prevalent disease afflicting humanity. There are estimates that 100 million cases occur annually and result in a million deaths (National Academy of Sciences, 1973).

Yet there are a large number of other diseases transmitted by insects such as Leishmaniasis (sandfly), sleeping sickness (tsetse fly) and yaws, which can also be transmitted from person to person. For nearly all disease transmitting bloodsucking insects the 10°C annual isotherm is the lower limit of viability.

Other insects important as vectors of diseases are ticks and fleas. Ticks, which are important in the transmission of meningitis, are generally hardy, although for hatching they need temperatures greater or equal to 22°C. Fleas ordinarily survive on warm-blooded secondary hosts, such as dogs, cats or rats, so that their sensitivity to environmental conditions is sharply reduced. Table 2.13 shows some of the established limiting climatic conditions for certain diseases or their vectors.

Other tropical diseases are transmitted by snails, such as schistosomiasis which is fairly widespread. The intermediate hosts, which carry the blood flukes causing the disease, are found in an aquatic environment. Hence ample rainfall feeding streams, swamps or puddles are essential climatic prerequisites.

There are some diseases which evidently do not follow the moist-warm environmental pattern otherwise typical of tropical diseases. Jusatz (1962) reported that the often epidemic cerebro-meningitis in the sub-Saharan area is bound to the dry season, January to April, when the notorious dry, dusty Hamattan wind from the desert sweeps the area. The epidemics cease with the start of the rainy season caused by the northward motion of the intertropical convergence zone.

In the eastern United States, however, epidemic encephalitis is invariably tied to wet weather. It can spread as far as southern New England. Hence the larvae of the transmitting mosquito *(Culiseta melanura)* must be fairly resistant to cold. Outbreaks of the disease are bound to years in which the preceding August to October had heavy precipitation, often caused by tropical storms. During the epidemic year June through August rains also have to be unusually heavy (Hayes and Hess, 1964). In Europe, acute cases of meningitis epidemica have been observed to occur with higher frequency when weather changes indicating the approach of a low pressure system (increasing cloudiness, increasing temperature and humidity, falling barometer) occur (Brezowsky and Menger, 1959).

Table 2.13. Climate dependence of selected diseases

Disease	Limit °C	Vector	Limits °C	
Leishmaniasis	Annual $\geqslant 10$	Sandfly	Annual $\geqslant 10$, low humidity	
Dengu fever	Annual $\geqslant 12$	*Aedes aegypti*	Annual $\geqslant 12$	large amounts of rain
Sleeping sickness	Warmest month $\geqslant 25$	Tsetse fly	Min $\geqslant 10$	
Yellow fever	Coldest month $\geqslant 15$	*Aedes aegypti*	Annual $\geqslant 12$	
Malaria	Annual $\geqslant 15$	Anophelidae	Annual $\geqslant 12$	
Amoebic dysentery	Warmest month $\geqslant 25$	*Entamoeba histolytica*	Insensitive	

Another tropical disease, classified among the rheumatic ailments is myositis tropica, an inflammation of the muscle fibres. It is common in the tropical rain forests and occurs in the savannah during the rainy season but is rare in the warm deserts.

In contrast, scarlet fever is a typical disease of the cold-moist regions of the world (von Bormann, 1960). In continental climates incidence of the disease rises steeply in the cold months and drops precipitously in the warm months. In oceanic cool climates the annual variation is quite smooth and the maximum may be reached at the beginning of the cold season in October. Epidemic outbreaks have been noted in cold winters. In the tropical rain regions and deserts this disease is almost unknown.

In some diseases a meteorological connection can only be suspected because of the annual variation. Thus mortality from certain diseases shows distinct seasonal peaks (Brezowsky, 1964; Haase and Leidreiter, 1975). This is particularly pronounced in cases of cardio-vascular and respiratory diseases. In many areas of the world with moderate or cool climates these show notable cold season peaks and one can see an inverse correlation to the annual march of temperature (Figure 2.13). The amplitude of respiratory disease mortality is much greater than that for cardiovascular disease. This has been ascribed to the greater exposure to contact infection in enclosed areas during the heating season. Meteorologically it must be considered also that physiological stresses are induced by the great temperature contrast indoors-outdoors to which many persons are exposed, the very low humidities indoors which dry the mucous membranes of the respiratory system, and the frequent abrupt weather changes during winter. This variability is clearly shown for the average day-to-day changes of the maximum daily temperatures during the month of February over the contiguous United States (Figure 2.14). Clearly certain areas, especially in the Central Great Plains and Mid-Atlantic States, are subjected to many rapid air mass changes

Figure 2.13. Average annual variation of mortality from diseases, as a percentage departure from average, for respiratory ailments R, and cardiovascular ailments C, as related to mean environmental temperature

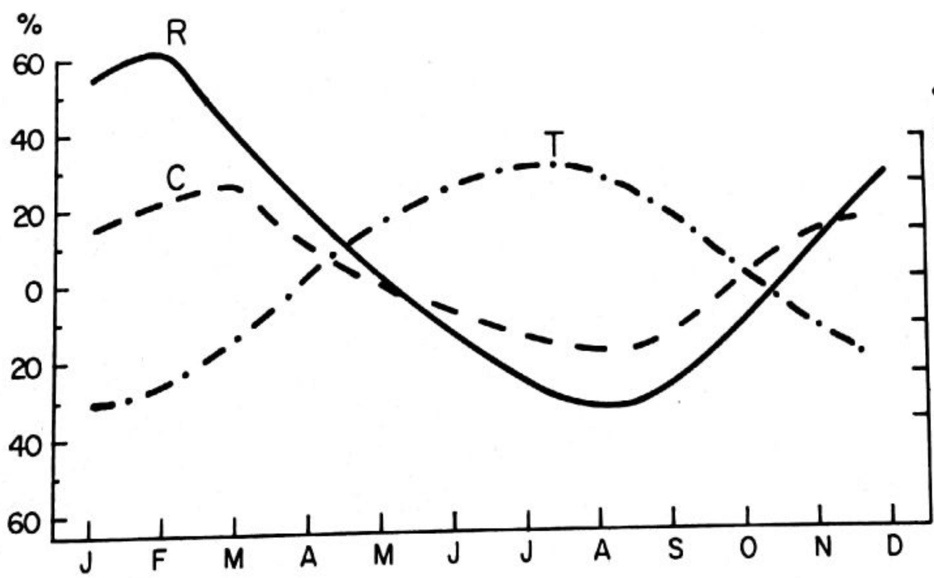
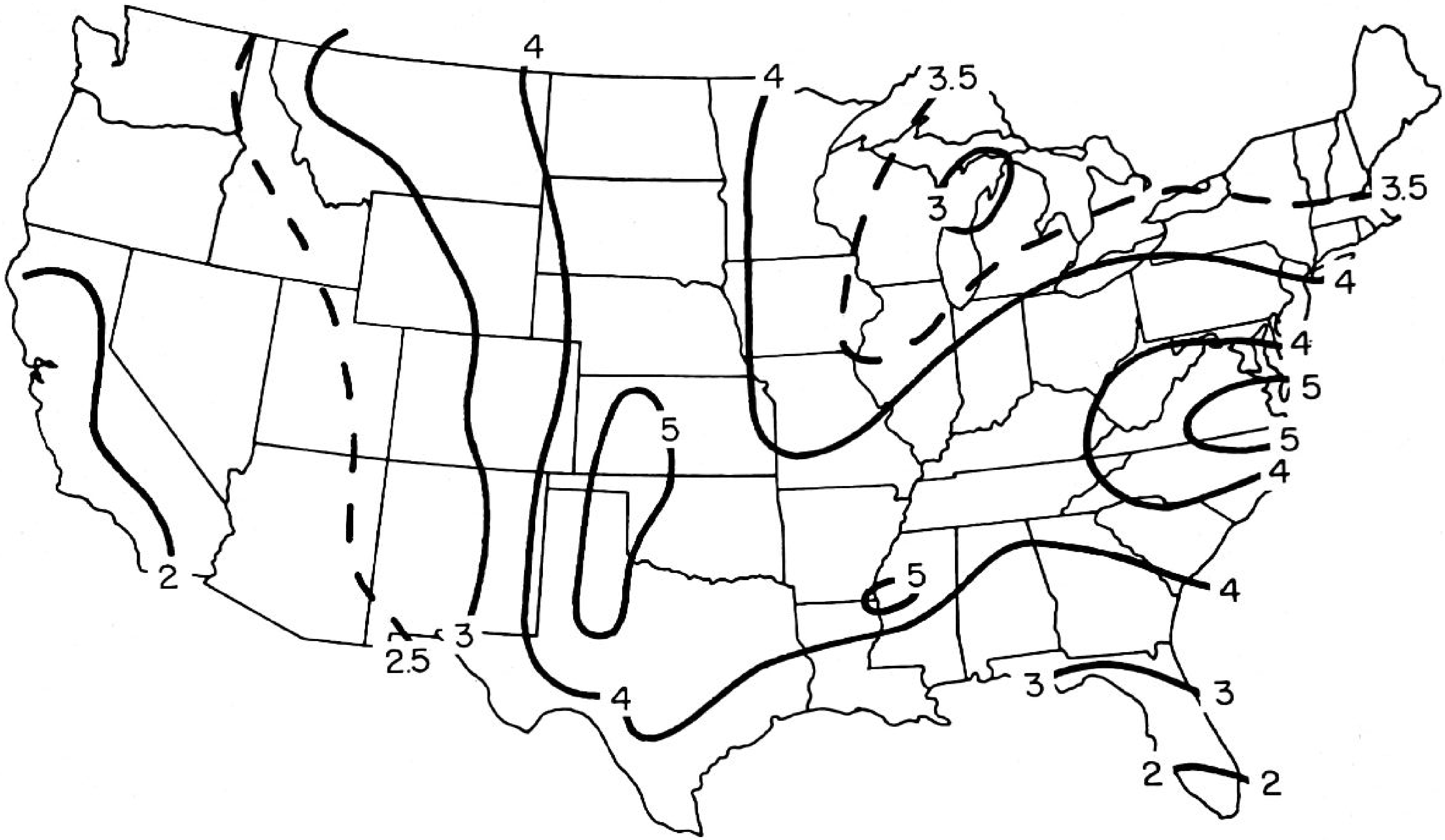


Figure 2.14. Mean interdiurnal change of daily maximum temperature in degrees Centigrade in February over the contiguous United States



with frequent frontal passages. In regions such as these persons with chronic ailments are subjected to atmospheric changes faster than they can adapt. This applies particularly to the older age groups. A number of studies in Central Europe suggest that large-scale circulation systems — passage of marked cyclones and troughs — are associated with increased numbers of coronary occlusions and strokes (Jäger, 1968).

A disease symptom traditionally associated with weather and climate is arthritic pain. Persons especially afflicted with arthritic joint disease appear to react adversely to cold. The incidence of rheumatism and arthritis is about four times as great in a cold-moist climate as in a warm-dry subtropical area. The pain-causing sequence of events has not yet been unravelled but both statistical evidence and some chamber experiments indicate that falling pressure and increased humidity bring about swelling of afflicted joints and pain (Lawrence, 1977). One gets the impression that these joints appear to react like an aneroid barometer.

Weather as a pain-provoker is also encountered by persons with extensive scar tissue, such as those having had a limb amputated. They experience pain when atmospheric humidity rises and sometimes when temperatures change rapidly. Differential reactions of the normal skin and the scar tissue apparently lead to the pain sensations (Swantes, 1971).

One more disease should be mentioned as being weather related in some instances. That is the lung disease, histoplasnosis, which is provoked by a soil fungus. Strong winds can dislodge this organism and carry it along, exposing people to its invasion of the respiratory tract.

CLIMATIC CHANGE BY TRAVEL AND FOR THERAPY

In the modern world air travel enables people to span wide geographic areas in a very short time. The term jet-lag has become a familiar phrase. Ordinarily this refers to the upsetting of physiological circadian rhythms, such as diurnal body temperature variations, hormonal secretions, sleep patterns, and digestive processes. But often overlooked is the sudden change in climatic conditions which can be equally traumatic. Trips to the polar or tropical regions can expose a traveller to sudden temperature changes of 20 to 30°C. This is more than the change from winter to summer in many regions. The latter is a gradual transition and permits physiological adaptation. The change during a trip is abrupt in contrast. The seasoned traveller will be prepared to compensate in part for the change by bringing appropriate clothing along. Yet only the healthy will have the physiological reserve to counterbalance the climatic shock. Fortunately, there are many sources of climatological information available which can be consulted prior to embarking on a trip.

Problems are more likely to be encountered when persons from cold or moderate climates make rapid moves to warm and humid areas. The adjustments to heat stress affect the body generally more than cold because it is easier to counteract cold by clothing. Older persons in particular are adversely affected by fast change to sultry conditions. A quick trip for them may aggravate circulatory ailments and even cause heart attacks or strokes. Individuals who have slight cases of hyperthyroidism are also jeopardized (Tal and Sulman, 1973). Even healthy recreational travellers from countries with moderate climate have been warned to avoid certain areas during periods of seasonal high sultriness. Harlfinger (1975) using the readily available climatic data has pointed out the extraordinary contrast in comfort conditions that exists between the central European countries and their favorite vacation spots around the Mediterranean, especially in summer. Incipient or hidden ailments can flare acutely during sudden climatic transitions, which can expose persons also to unaccustomed foods and unfamiliar microbes.

Slower moves or moves at seasons when the climatic contrasts between two regions are minimised are usually better tolerated. There is a fair capacity for acclimatisation in humans, especially younger ones. Aside from the change in life habits, especially food and fluid secretions and of electrolyte balance, in hot regions thyroxine (a secretion of the thyroid gland) turnover is reduced, hence metabolism is slowed. This is aided by lower calorific intake. Aldosterone, an adrenal gland hormone, rises to act as a regulator of the sodium-potassium ratio, activated due to sodium loss in perspiration. Adequate intake of lightly salted fluid will help (Macfarlane, 1974). Cold acclimatisation brings about increased metabolism, usually quite voluntarily accompanied by greater calorific intake. Apparently there is also a change in the ability to shiver, a reaction to increased metabolic heat production by muscular activity. However, the ability of the human body to adapt by physiological responses to cold climatic conditions is far more restricted than to cope with warm climate. The genetic heritage of human origin in the tropics is not readily overcome (Edholm, 1966).

The role of climate in the treatment of disease has been known for a very long time. In fact one of the most common devices is to create an artificial climate to isolate a sick person from the demands of atmospheric changes. As a fairly stress-free climate, therapy has used the bed. It not only provides rest to a stricken body but permits by suitable covers or thermostatically controlled devices to regulate temperature and humidity (Spangenberg, 1954).

However, in general, when consideration is given to climate therapy it is usually an attempt to correct imbalances and gradually return bodily malfunctions back to normal. In order to enable physicians in the field of physical medicine to assess the appropriate climate for a patient a careful analysis of various climatic environments needs to be made. There have already been some promising starts in that direction. Using the available climatological data, whole areas have been charted. A notable example is Becker's (1972) system of assessment. This author distinguishes three atmospheric influence complexes: thermal, radiative, and air-chemical. Each of these is then appraised separately in three categories: stress factors, taxing factors, and protective factors.

Stress factors are:

1. high values of chill factor or cooling power; also large diurnal, seasonal, or annual fluctuations of these;
2. high intensity of radiation on a horizontal surface, including high values of ultraviolet radiation;
3. decrease of partial pressure of oxygen (elevations > 1 km);
4. intense diurnal variation of the temperature-humidity environment.

Taxing factors are:

1. temperature and humidity combinations causing sultry conditions and feelings of discomfort;
2. continued lack of radiation (including ultraviolet radiation);
3. moist-cold and frequent fog;
4. frequent or sustained high levels of air pollution either through photochemical smog or effluent accumulations under inversions and stagnant circulation conditions.

Protective factors are:

1. low values of cooling power with temperatures of 14 to 25°C, low wind speeds (<4 m sec^{-1}), small diurnal, seasonal and annual fluctuations;
2. adequate solar and sky radiation but not too intense; shadow effects in parks and forests;
3. clean air, free of dust and pollutants from traffic or industry.

Actual meteorological values in these categories are to some extent arbitrary but some guide lines can be gathered from figures 2.5 to 2.9 in earlier sections of this chapter. Becker and Wagner (1972) have used such criteria to chart the bioclimate of the Federal Republic of Germany. The Federal Health Office of Switzerland (1965) has published, based on similar criteria, a guide to climatic resorts with indications of what ailments are thought to be beneficially influenced at various localities.

The therapeutic exploitation of various climates has been extensively explored since the last century. At one time desert climates or high altitude climates with their intense radiation and low humidities were the only remedies for pulmonary tuberculosis until replaced by chemotherapy. But even now such climatic conditions are used for recovery from respiratory ailments.

Emphysema, bronchitis and asthma can be alleviated by choice of proper climate. Certain forms of arthritis can also be beneficially influenced by a move of the sufferer to another climate. However, this is not a universal experience and individual trial periods must precede a permanent move. Circulatory ailments including high blood pressure, can be occasionally successfully treated by low-stress climatotherapy. In many instances reconvalescence from operations and severe disease is aided by a suitable sojourn in an appropriate climatic environment. Rules for climatotherapy, as a subdiscipline of physical medicine, have been worked out by physicians (Amelung, 1970; Schmidt-Kessen, 1977).

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