ENVIRONMENTAL HEALTH SERIES
Air Pollution

SEMINAR ON HUMAN BIOMETEOROLOGY

U.S. DEPARTMENT OF HEALTH
EDUCATION, AND WELFARE
Public Health Service

SEMINAR
ON HUMAN BIOMETEOROLOGY

Sponsored by
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and
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PREFACE

This seminar on biometeorology was intended for presentation to a relatively small group. The Division of Air Pollution (National Center for Air Pollution Control) and the Environmental Science Services Administration arranged the seminar to introduce professional personnel of the Division to current biometeorological problems and practices, particularly emphasizing the techniques that can be applied in air pollution investigations.

The persons invited to speak are nationally and internationally recognized authorities in their fields. Several were unable to attend because severe weather immobilized air and rail transportation in many areas across the nation. By rescheduling and substitution, the co-moderators of the seminar, Mr. James Dicke and Dr. Robert J. M. Horton, provided a cohesive program that evoked enthusiastic response from the participants.

Because many of the attendees proposed that the material be made available for more careful review and more widespread distribution, Mr. Dicke undertook the task of compiling the papers for publication. This volume is the result of his efforts.

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ABSTRACT

This volume is a collection of papers presented at Cincinnati, Ohio, January 14-17, 1964, at a seminar on human biometeorology. Subjects discussed include physiological and climatological instrumentation, climates of the United States, altitude, microclimatology, indoor and outdoor weather, ultraviolet light, heat exposure, air ions, and ecology.

INTRODUCTION TO HUMAN BIOMETEOROLOGY: ITS CONCEPTS AND PROBLEMS

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SUMMARY

Human biometeorology studies that portion of the whole environment designated as the atmosphere, taking into account the cultural environment of man; his adaptability to the atmosphere as evidenced in the tanning reactions to ultraviolet radiation, in habituation to cold and heat, and in acclimatization to heat, cold, and hypoxia; and his modification of the atmosphere by controlling and by polluting it. By adopting the ecological viewpoint and focusing attention on the broad problems of phenotypic plasticity and genetic individuality, the biometerologist can achieve a better understanding of the human organism-environment system and of man's capacity to manipulate his environment to serve his future biological needs.

INTRODUCTION

The invitation to participate in this seminar on human biometeorology and to introduce the subject has stimulated me to begin a task to which I have given much thought in recent years. I plan to scrutinize human biometeorology, critically examine its working assumptions, and delineate some of its major unsolved problems. I have conducted biometeorological research for almost 30 years. I have taught graduate students about biometeorology for more than a decade. This experience has been combined with 7 years of intensive and exciting work as chairman of a University Committee on Human Ecology. It is against this background that I want to draw my introductory sketch.

ECOLOGICAL PROPOSITIONS

ORGANISM-ENVIRONMENT, A SYSTEM

The organism and its environment constitute a system. The life science that investigates this system is ecology. The environment of ecology is really a concept, for that environment is a matrix of conditions and circumstances, of spatio-temporal configurations, which can be identified for analytical purposes as material or physical, biotic or biological, and cultural or social. Biometeorology studies that portion of the whole environment designated as the atmosphere. Since biometeorology, in a sense, abstracts the organism from its total environment, a basic assumption underlies its investigations, viz. that non-atmospheric environmental influences are controlled or inconsequential. This assumption may be justified for biometeorological studies of animals, but because human biology is not merely an extension of the principles of animal biology to man, the assumption, insofar as man is concerned, is not valid.

NATURE OF HUMAN BIOMETEOROLOGY

The orientation and content of human biometeorology are different from those of general biometeorology. From the strictly biological viewpoint man possesses few characteristics that can be identified as unique. To be sure, he can be distinguished morphologically. Functionally, however, human beings differ from other animals more in degree than in kind. We may then ask, what are the differences between animals and man? Medawar(*28*) concludes that man is unique among animals because culture has come to provide a continuum for many of those properties to which man owes his biological fitness. Indeed, culture has become so much a part of man that it is difficult to separate it from his biology(*13*). Thus it can be argued that human biometeorology is distinctly different from general biometeorology because of the very nature of human biology. It is distinctive because human biometeorology must be cognizant of the cultural environment.

BIOLOGICAL FITNESS

Organisms demonstrate "biological fitness" if they are endowed with organs, systems, and processes that enable them to sustain themselves in and prevail over their environments(*28*). For man there are inborn endowments and the technological creations of his culture. Both have exhibited evolution, but cultural evolution has been the more rapid(*7*). Both contribute to his biological fitness. Medawar(*28*) views culture as "a biological instrument by means of which human beings conserve, propagate, and enlarge upon those properties to which they owe their present biological fitness and their hope of becoming fitter still."

Biological fitness is greater among organisms that are adaptable than among those that are adapted. Man is adaptable. His adaptability arises from his genetic individuality, his phenotypic plasticity, and his culture. This biological fitness must be measured against man's total environment, not merely the atmospheric milieu(*22*).

Genetic Diversity

Each human being is a unique combination of genetic traits. One individual is anatomically and functionally, with the exception of monozygous twins, unlike any other(*28*). Paracelsus intuitively appreciated, more than 400 years ago, the significance of this individuality. According to him, "man is constellated in himself mightily" (*33*). This inborn diversity and the genetic system responsible for maintaining that diversity allows selection to happen with the result that evolution proceeds.

Phenotypic Plasticity

Phenotypic plasticity is the alteration in the individual with change in the environment. The degree of plasticity is genetically determined. It is the norm of reaction that the individual or the species is capable of making to environmental change(*12*). To a large extent the norm of reaction measures the sum total of selective environmental experiences that the species has survived during its evolution. The norm of reaction, therefore, is past-oriented. Biometeorological expressions of phenotypic plasticity in the human being are the tanning reaction to ultraviolet radiation, habituation to cold and heat, and acclimatization to heat, cold, and hypoxia.

Culture

Culture constitutes the sum total of traditions and institutions that man has created to regulate himself and the technology by which he provides for himself and dominates the biota. By these means he had brought under his control a large reserve of nutrient energy and nutrient raw materials as domesticated plants and animals, and he has extended his mechanical capabilities by the utilization of fossil fuels and atomic energy. He has exhibited great capability of profoundly modifying the atmospheric environment and its impact on him. On the one hand, he has at his disposal numerous devices for supporting and maintaining his health and comfort, e.g. medical technology, clothing, housing, heating and ventilating machinery, and air-conditioning. On the other hand, particulate and gaseous discharges from his technological establishments have polluted the atmosphere of urban population centers and have damaged the biota. The industrial atmosphere has become a constant threat to the health of the laborer. Man's domesticated plants and animals demand the use of insecticides and pesticides that are potential hazards to the health of the plants, the animals, and man himself. The impact of these cultural devices on man's continued biological fitness is a moot point that demands the most careful ecological scrutiny. Since the problems stemming from man's control of his atmospheric environment, indeed of his total environment, are complex and have multiple causation, one must attack them on all fronts simultaneously; "in fact," as Aldous Huxley(*23*) emphasizes, "nothing short of everything is enough".[a]

MAN'S ADAPTABILITY AS PHENOTYPIC PLASTICITY

The starting point of human biometeorological theory is this concept of biological fitness. The essence of man's fitness is his adaptability; its main elements, genetic individuality, phenotypic plasticity,

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[a] Reference 23, p. 63.

and culture, have been defined. Determining how each of these elements contributes to biometeorological theory is our next task. Consider phenotypic plasticity first.

From the biological viewpoint man is a regulator(*35*). A regulator maintains, despite external environmental vicissitudes, a steady state among the physicochemical properties of its internal environment. This internal environment is aqueous; it is the fluid which bathes the cells, tissues, and organs. The steady state is called homeostasis. Basically the steady state is a state of limited variability of the properties of the internal environment. The limitation of the variability is accomplished by regulatory processes or homeostatic mechanisms. Because the organism is an open system that derives nutrient energy and nutrient raw materials essential for its continued existence from its external environment, one can conceive of homeostatic mechanisms as comprising both internal and external regulations. For example, the control of blood sugar comprises equally the internal regulation of the neuroendocrine system and the external regulatory behavior of searching for sources of nutrient energy. Together such internal and external processes permit organismic self-regulation.

The limitation of variability of the internal environment depends upon the effective operation of homeostatic mechanisms. In turn, however, the effective operation of these mechanisms requires that the internal environment exhibit some variation. The organisms possess sense organs, which detect alterations in their surroundings. The changes are deviations from set points. As a consequence of the detection of deviation, reactions, both physiological and behavioral, are set in motion to correct the deviation. The deviation is never corrected completely. There is constant variation about the set point. This variation constitutes an inherent variability of the organism that might be designated as system variability.

PRECISION OF REGULATION

The limits within which the physicochemical properties of the internal environment vary is a function of the precision of physiological regulations. The variability that characterizes the steady state is both hierarchical and lawful. It is hierarchical because there is a rank-ordering of the precision with which the properties are regulated. It is lawful because the variation of the physicochemical properties exhibits distinctive circadian, menstrual, and seasonal rhythms; the variation is not random.

The precision of physiological regulation may be measured in terms of inter-individual variability. There is demonstrable a hierarchy of preciseness with which the chemical composition of the blood is regulated(*41*). Certain constituents of the blood particularly essential for the normal functioning of the body cells, for example osmolarity, pH, sodium, and potassium (Figure 1), are precisely regulated or closely guarded. Other constituents not so essential for the normal functioning of the body are less closely guarded. In this category one finds intermediary metabolic substances such as glucose and cholesterol and metabolic waste products (Figure 1). Furthermore, the homeostatic processes that regulate the composition of the blood, for example functioning of the lungs and kidneys (Figure 2), are more variable than the properties of the blood(*41*). The regulatory processes show more variance than do the properties regulated. These hierarchies of inter-individual variability apply equally to intra-individual variability, even though a single individual generally exhibits much less variation than does a group of individuals(*41*).

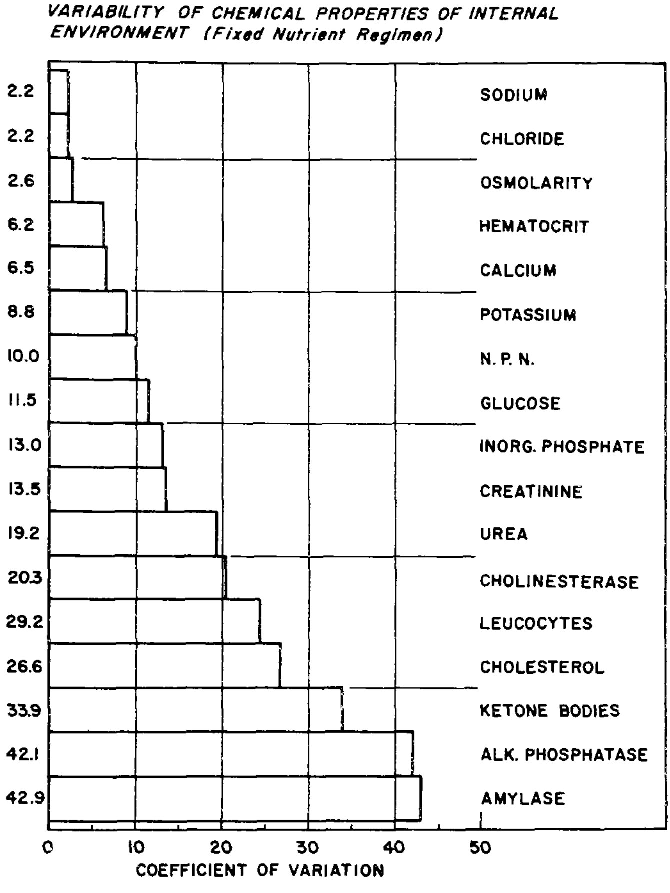

Figure 1 — Hierarchy of precision of regulation of chemical composition of man's internal environment. (Reference 41. Reproduced with permission of McGraw-Hill Co.)

Season and Precision of Regulation

The season of the year when measurements are made of the physicochemical properties of the internal environment and of the regulatory processes does not alter the hierarchy of precision of regulation, but season does markedly influence the degree of precision (Figure 3). The chemical properties of the blood exhibit appreciably greater inter-individual variability in winter whereas the physical properties, such as temperature and blood pressure, and the functioning of the homeostatic mechanisms show much greater inter-individual variability in summer. These facts suggest that the winter season may have a particular impact on bodily metabolic processes, whereas the summer season may have an especial impact on the physiological functions of major organs and systems such as thermoregulation, renal function, and the cardiovascular system. Although the full meaning of this seasonal influence is not immediately apparent, a more detailed consideration of the impact of season on man will be presented after the concept of effectiveness of regulation has been described.

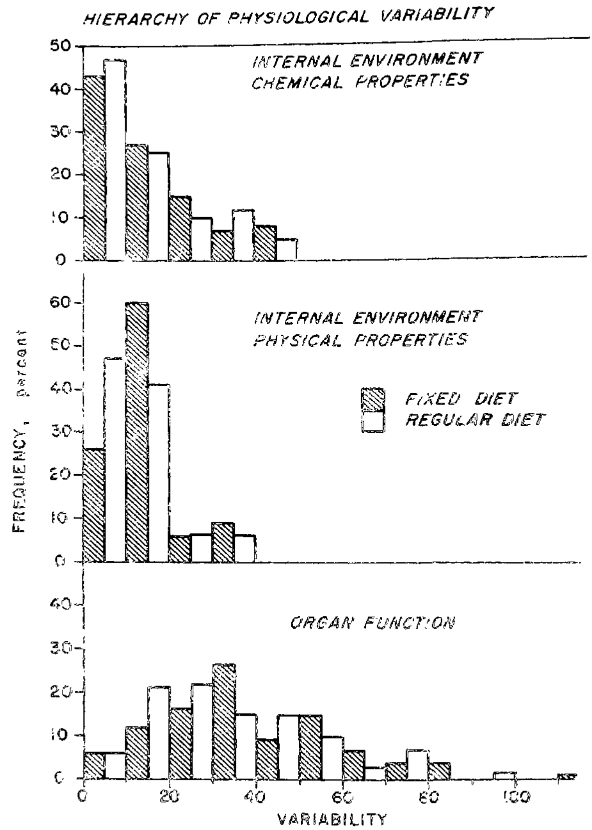

Figure 2 — Comparison of inter-individual variability. (Reference 41. Reproduced with permission of McGraw-Hill Co.)

EFFECTIVENESS OF PHYSIOLOGICAL REGULATION

Effectiveness of physiological regulation may be measured by the capability of the organism to limit change when the environmental circumstances are altered. The ability to maintain the chem-

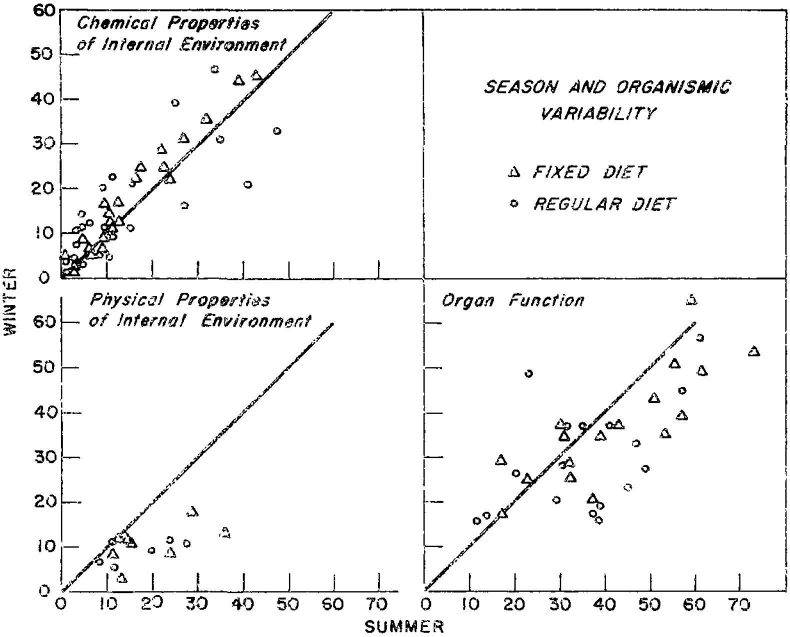

Figure 3 — Season and inter-individual variability among young men on fixed and regular diets. Summer and winter compared for chemical and physical properties of internal environment and for functioning of organs and systems. Line at 45° is line of no seasonal effect.

ical properties of the blood and the body temperature in the face of external environmental change is a function of the adaptability of the organism. Effectiveness and precision of regulation are closely related(42). When human beings are abruptly exposed to under-nutrition, unaccustomed diets, and restricted allowances of water, the properties of the blood that are most closely guarded change least; those least precisely regulated change most (Figure 4).

Effectiveness of physiological regulation appears to be hierarchical. The evidence for this thought comes from investigations of the physiology of sweating. When a dehydrated man is exposed to a hot atmosphere in which thermoregulation is mainly achieved through sweating, continued sweating will accentuate dehydration. With increasing dehydration maintenance of body temperature is disturbed. Will sweat loss, at this point, decline so as to conserve body water? With severe dehydration, the decrement of sweating is physiologically inconsequential(2, 37, 42). The organismic "decision" is to maintain heat loss at the expense of body water. Thus, thermoregulation seems to be dominant over processes of water regulation. Its dominance creates a vicious circle that will be fatal if external regulation cannot be achieved.

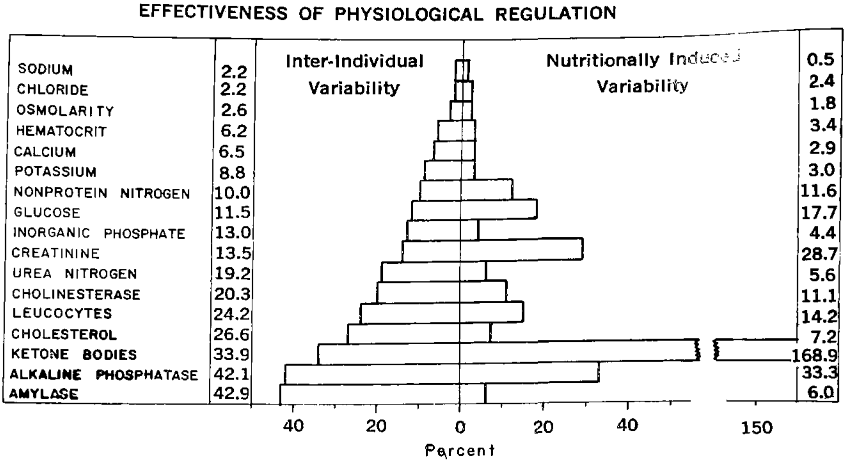

Figure 4 — Comparison between precision and effectiveness of physiological regulation of chemical properties of internal environment. Rank-order correlation coefficient = +0.78. (Reference 42.)

Season and Effectiveness of Physiological Regulation

The fact that inter-individual variability in the chemical properties of the blood is greater in winter than in summer suggests an inherent metabolic instability at this season. When the nutritional condition is abruptly altered—the diet is changed from a customary one to an unaccustomed one consisting of insufficient nutrient energy, unusual amounts of protein, carbohydrate, and fat, and restricted water—the effectiveness of the physiological regulation is critically taxed. If such a nutritional stress is imposed in both winter and summer, a distinctive metabolic syndrome becomes manifest in winter but not in summer (Figure 5). In winter there is hypoglycemia, hyperketonuria, azotemia, and symptoms consistent with hypoglycemia. The syndrome is particularly marked among individuals on regimens high in fat. In summer these biochemical changes and symptoms are absent(*42*).

In summer, the inter-individual variability of the physical properties of the blood and of organ functions is greater than in winter. When these same nutritional stresses are abruptly imposed on subjects in summer, disturbances of thermoregulation and cardiovascular function appear. There is hypohidrosis, anhidrosis, hyperventilation tetany, orthostatic hypotension, and heat exhaustion. The clinical disturbances are more common among dehydrated than adequately hydrated individuals(*39, 40*). Comparable alterations of diet do not elicit these disturbances in the winter. Effectiveness of water conservation is a most important adaptive reaction in summer. The summer syndromes are thus not so unexpected and problematical as the winter syndromes.

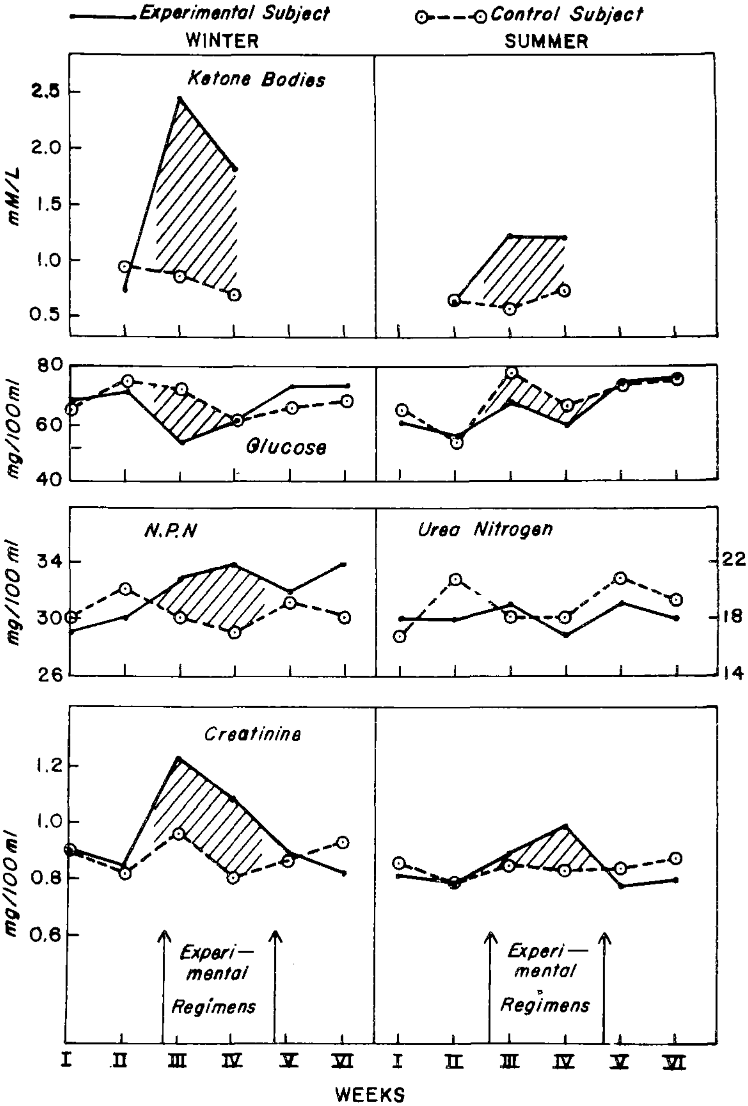

Figure 5 — Influence of season on metabolic reaction of young men to change of nutrient regimen. (Reference 42.)

TEMPORAL VARIABILITY, A FUNDAMENTAL PROBLEM OF HUMAN BIOLOGY

Our general ecological proposition is that man and his environment constitute a system. Both "man" and "environment" exhibit temporal variability. For each, two rhythms are distinctive: one runs its course in 24 hours; the other is seasonal. For the organism the 24-hour rhythm has been identified as circadian (*15*). Both rhythms have been demonstrated at all levels of biological organization (*14, 48*). They appear to be fundamental characteristics of life. Twenty-four hour and seasonal rhythms are moreover as characteristic of the cosmic terrestrial environment as they are of life processes. Two deductions have been made from these parallel rhythms. First, biologists have subscribed to a causal relation between the environmental events and the biological (*3, 8, 11, 17, 44, 48, 49*). Second, the existence of these rhythms has led to the speculation that an exogenous biological clock times life processes (*49, 59*).

I suggest that these biological rhythms are actually an expression of the adaptive plasticity of living organisms to the restrictions imposed on them during their evolution in the cosmic-terrestrial environment. This hypothesis is really an extension of L. J. Henderson's concept of fitness of the environment. According to this concept,

> "The fitness of the environment is one part of a reciprocal relationship of which the fitness of the organism is the other. This relationship is completely and perfectly reciprocal; the one fitness is not less important than the other nor less invariably a constituent of a particular case of biological fitness . . ."[a]

> "The properties of matter and the course of cosmic evolution are . . . intimately related to the structure of the living being and to its activities; they become, therefore, far more important in biology than has been previously suspected. For the whole evolutionary process, both cosmic and organic, is one, and the biologist may now rightly regard the universe in its very essence as biocentric."[b]

When one attempts to deal logically with either Henderson's concept of fitness or the parallel rhythmicity of organism and environment, an identical problem arises, namely the problem of circular reasoning. As Blum (*6*) states it, ". . . fitness partakes of the nature of uniqueness, and this uniqueness of the earth as an abode of life is a matter that strikes one more forcibly the more he tries to break out of the circle."[c] Perhaps one of the most basic implications of space technology is the opportunity it gives the biologist to break out of the circle. If the temporal-spatial configurations of the cosmic-terrestrial relations of living organisms sets the clock that times the

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[a] Henderson (1913), p. 271 (Reference 19).

[b] Henderson (1913), p. 312 (Reference 19).

[c] Blum (1962), p. 73 (Reference 6).

functioning of their cells, tissues, and organs, a major reorientation of the time-space relationships of the organisms should seriously disrupt the functioning of the organism.

EVIDENCE OF ADAPTIVE NATURE OF TEMPORAL VARIABILITY

Health may be viewed as a state in which the physiological regulations are operating most effectively. In this state the organism's integrative functions are harmoniously blended so that the individual can meet and cope with his environmental challenges(*14, 18*). With dysfunction or ineffectiveness of physiological regulation, disease occurs(*14, 20*). The conclusion has been reached that circadian and seasonal variation in the precision and effectiveness of physiological regulation is a manifestation of adaptive plasticity of the organism. This conclusion is consistent with the prevalent view that circadian and seasonal variations are "physiological."

Numerous observations support the view that these rhythms are adaptive reactions to the external atmospheric environment. A few examples will illustrate my point. The seasonal rhythms in man may be viewed as acclimatization to heat in the summer and cold in the winter(*54*). In summer people are comfortable at higher temperatures than in winter. In summer the sweating mechanism is more reactive than in winter—the latent period for induction of sweating is short and for a given stimulus the output of sweat is greater(*25*). In winter a longer period is required to induce shivering than in the summer(*10*). In summer the output of urinary antidiuretic hormone is greater than in winter(*54*). The summer tanning reaction and the thickening of the stratum corneum protect against the damaging influences of ultraviolet radiation(*5*).

TEMPORAL VARIABILITY OF DISEASE

If circadian and seasonal rhythms are indeed expressions of adaptive plasticity, why then does human disease show circadian and seasonal variation? Death, for example, comes to man more often in the early morning hours than at other times, and most diseases display clear seasonal variations in morbidity, prevalence, and mortality. These facts suggest that man's susceptibility to disease is different at different phases of the circadian and seasonal rhythms. Tetany and rickets, for example, are most prevalent in the spring. At this season the healthy population shows low blood calcium and phosphate and high alkaline phosphatase, negative calcium balance, and maximal sensitivity to galvanic stimulation(*24, 36*). These "physiological" alterations constitute a *formes frustes* of the clinical disease. Some 10 years ago I advanced the hypothesis(*36*) that there are different degrees of effectiveness of physiological regulation within the population. Some people exhibit only the biochemical and functional alterations; others, whose regulation is less effective, develop dysfunction and clinical symptoms. Now I am convinced that the explanation is more complex, for the following additional elements must be taken into account: (1) the environmental conditions for which adaptive plasticity evolved, (2) the age-structure of the population, and (3) physiological individuality. At the present time just a glimmering of the basic significance of these factors is emerging.

Evolution of Adaptive Plasticity

The norm of reaction or the adaptive plasticity of an individual or a population is a function of the genotype. The adaptive potential of a genotype depends upon the past experience of the species(*12*) Selective screening, in other words, is past-oriented. For man and other primates, indeed for mammals generally, this selection has been stabilizing, for it gave rise to homeostasis. Since the adaptive potential is past-oriented, adaptiveness that has been adequate for former generations will not necessarily be adequate for future generations, particularly if those generations create environments that are beyond the norm of reaction of the genotype.

Health is sustained by preserving the adaptive capacity. Adaptive capacity is maintained by repeated environmental challenge from *such forces as the organism prevailed over in its evolution*, viz., weather and climatic change, scarcity of food and water, predation, and disease(*45, 46*). Man's present biological fitness, however, also depends upon cultural tradition and cultural innovation. Increasingly he lives, works, and plays in a constant physical environment regulated technologically so that he is comfortable all the time. This cultural innovation which began with the discovery of fire, has increasingly come, as Dubos(*14*) expresses it, "to place him outside the order of things."[a] The fundamental problem for human biometeorology cannot be better stated than in the words of Dubos(*14*). "By changing the physical world to fit his requirements—or wishes—he has almost done away with need for biological adaptation on his part. He has thus established a biological precedent and is tempting fate, for biological fitness achieved through evolutionary adaptation has been so far the most dependable touchstone of permanent success in the living world."[a]

None would gainsay that man has become a significant ecological factor. He has rapidly molded the total environment to suit his own wishes. Has he, at the same time, modified the environment in conformity with his biological needs? Cultural evolution has been so rapid—exponential, in fact—that it is valid to question whether man has not overstressed his adaptive plasticity. As Dubos(*14*) states it, "The one characteristic of our civilization is the rapidity with which it changes all our ways of life, without too much, if any, concern for the long-term effects of these changes. Man can eventually become adapted to almost anything, but adaptation demands more time than is allowed by the increasing tempo at which changes are presently taking place."[b]

[a] Reference 14, p. 49.

[b] Reference 14, p. 140.

To answer these questions one must be able to piece together the conditions and circumstances for which man exhibits adaptiveness. Perhaps the fact that man exhibits seasonal disease results from his living outside his adaptive capacity at certain seasons, living at these seasons under conditions that are widely divergent from those that the basic organismic reactions expect(*21*).

The Life Sequence and Seasonal Disease

There is an intriguing interaction among culture, adaptive capacity, and season, which expresses itself in the seasonal variation of disease at different stages of the life sequence. This interaction provides some clues regarding the problem of season and disease.

There is an ontogeny of physiological regulations (*1*). Precision and effectiveness of regulation mature and decay during the life sequence. The newborn exhibits immaturity of physiological regulation. During the reproductive period adaptive capacity is maximal. After this time, as aging begins, precision and effectiveness of regulation are reduced(*43*). During the stages when the homeostatic mechanisms are maturing and again when they exhibit deterioration, mortality from all disease varies seasonally(*26*). Both in the young and the old, moreover, mortality is maximal in winter (Figure 6). When the homeostatic processes exhibit maximal precision and effectiveness, the total mortality shows no seasonal variation. Comparable findings have been reported by Panhorst(*34*) for mortality from diabetes mellitus. These striking observations suggest that age must be taken into account to arrive at a clear understanding of the nature of season and disease.

Momiyama(*30, 31, 32*) has found that during the past 50 years the mortality among Western cultures has become increasingly restricted to the winter months (Figure 7). Diseases with a formerly characteristic peak in summer, e.g. gastrointestinal disease and beriberi, now show a winter maximum. For winter diseases, particularly cardiovascular and degenerative disease, the mortality of that season has shown a relative accentuation (Figure 8). These changing patterns of disease have coincided with two phenomena of advancing civilization: cultural innovation in the form of medical and sanitary technology, and aging of the population.

Why winter should become a season of maximum mortality with advance of culture is not at all clear from the facts now in hand. Perhaps a few speculations might be offered to stimulate thought on this intriguing problem. First, we might view senescence as an accidental byproduct of evolution — a byproduct of an adaptation that had survival value for the organism and the species during infancy and childhood(*45, 46*). Second, man is physiologically(*27*) and ecologically(*4*) a tropical animal. Man's migration into cold climates from the original tropical niche was made possible by cultural innovation. The norm of reaction of modern man still carries this tropical bias. With senescence, effectiveness of regulation deteriorates(*43, 50*). Some adaptive capacity for heat remains; capability of dealing with the winter season rapidly declines. The consequence is an increasing winter mortality as continued cultural innovation becomes increasingly capable of supporting an aging population.

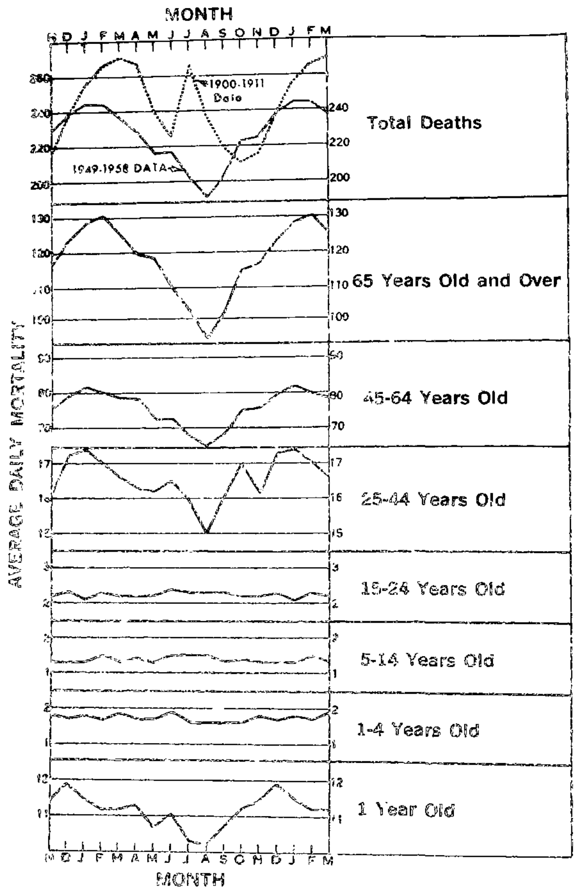

Figure 6 — Seasonal variation in mortality in New York City among different age groups. (Reference 26.)

MAN'S ADAPTABILITY AS GENETIC DIVERSITY

Genetic diversity as expressed in biochemical and physiological individuality is another fundamental factor in human adaptability. Only in recent years have human biometeorologists studied this matter systematically. Almost 40 years ago Sundstroem (47) foresaw how important the study of individuality would be for an understanding of this field. He observed that

> "The disparity in the observed responses to a tropical climate . . . would probably become intelligible if we were enabled, in an

individualizing way, to fit each separate functional effect into its proper place in the adaptation process at large. It is conceivable that individuals may not be all alike in their choice of the acclimatization mechanisms which nature has placed at their disposal. Some may succeed in striking the medium road, pre-

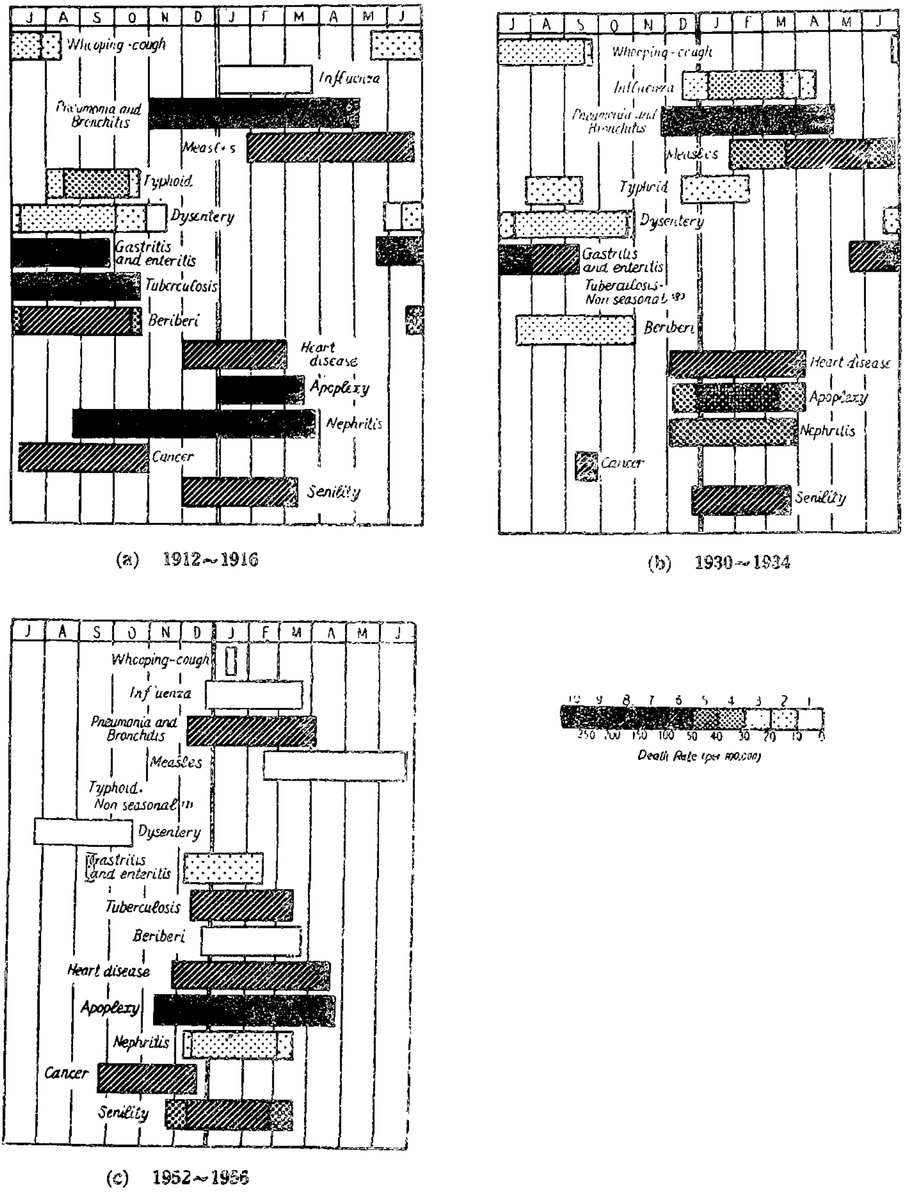

Figure 7 — Calendars of seasonal diseases in metropolitan Tokyo for three periods 1912-1916, 1930-1934, and 1952-1956. (Reference 32.)

ferring to divide up the burden imposed by a trying environment on several functions without unduly taxing any one of them. In such cases it may be difficult by our as yet imperfect methods to detect any measurable deviation from accepted standards. On the other hand it appears to be fairly well established that others may exhibit abnormalities as a consequence of their failure to equilibrize the acclimatization process."

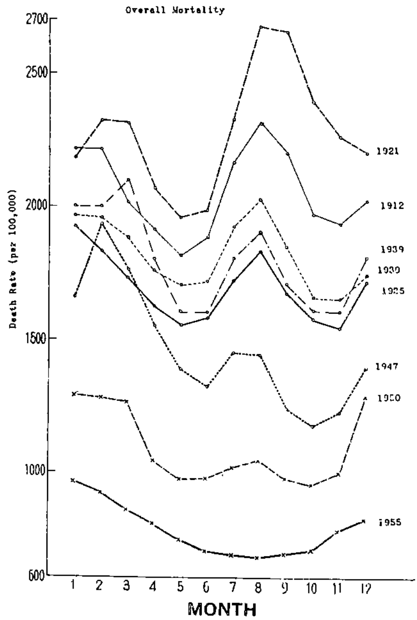

Figure 8 — Seasonal variation in total death rate for Japan for various years from 1900-1955. (Reference 32.)

BIOCHEMICAL INDIVIDUALITY

Within the relatively narrow limits of the steady state defined earlier, there is a distinctive biochemical individuality (*42, 51*). When a variety of biochemical measurements is made repeatedly under standardized conditions, each individual in the group under study exhibits a unique pattern of mean values (Figure 9). The hierarchy of the precision of regulation is imposed on these patterns. Biochemical individuality is more evident among the properties that are less closely guarded than among the properties that are precisely regulated.

PHYSIOLOGICAL INDIVIDUALITY

Physiological individuality may be shown in two ways: in patterns of mean values of organ function measured under standard conditions and in patterns of physiological response to stressful con-

SUBJECTS ON REGULAR DIET: WINTER

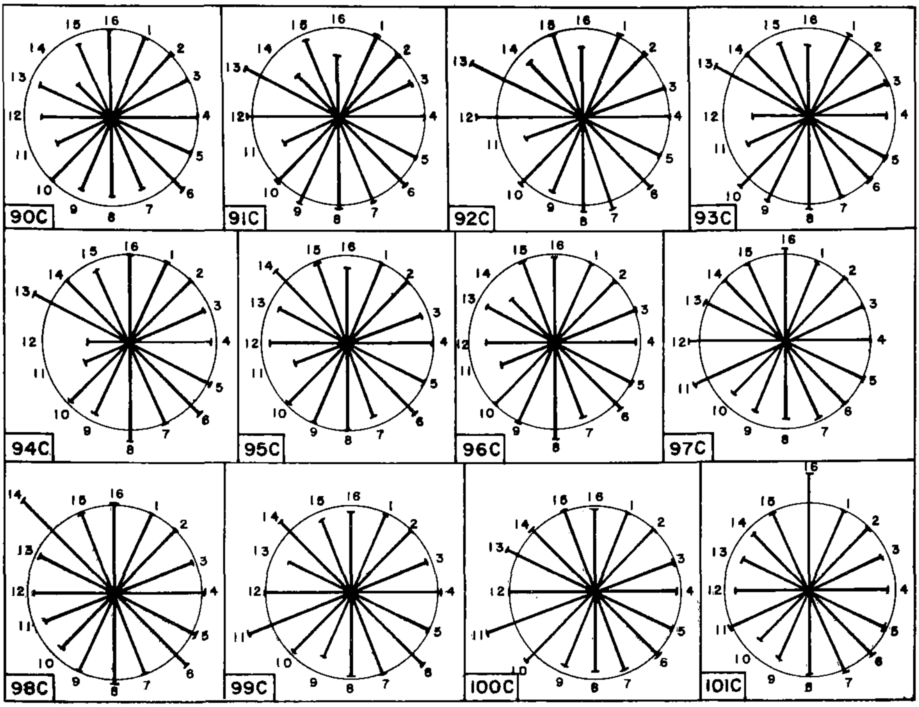

Figure 9 — Individual patterns of chemical properties of internal environment. Circles represent group mean for each chemical property measured. Radial lines represent individual mean values for each chemical property measured. Chemical properties measured were serum osmolarity (1), serum sodium (2), serum potassium (3), serum total calcium (4), serum chloride (5), serum inorganic phosphate (6), serum nonprotein nitrogen (7), serum creatinine (8), whole blood glucose (9), serum total cholesterol (10), serum total ketone bodies (11), serum cholinesterase (12), serum amylase (13), serum alkaline phosphatase (14), whole blood hematocrit (15), and whole blood total leucocyte count (16). (Reference 42.)

ditions. When the mean values of a variety of organ functions are calculated from six separate tests on the same 12 fit young men shown in Figure 9, unique patterns again emerge (Figure 10). The level at which the temperature and blood pressure are maintained and the tempo at which homeostatic mechanisms operate is a distinctive characteristic of the individual.

Eight other fit young men marched 6 hours in an hot, moist environment on four or five occasions. The walks were spaced at intervals of 2 to 3 weeks so that acclimatization would not develop. During the walks the thermoregulatory and cardiovascular responses were measured. When the mean and extreme values of these measurements were assembled graphically, it was found that each man reacted to the march in moist heat in a reproducible and characteristic manner.

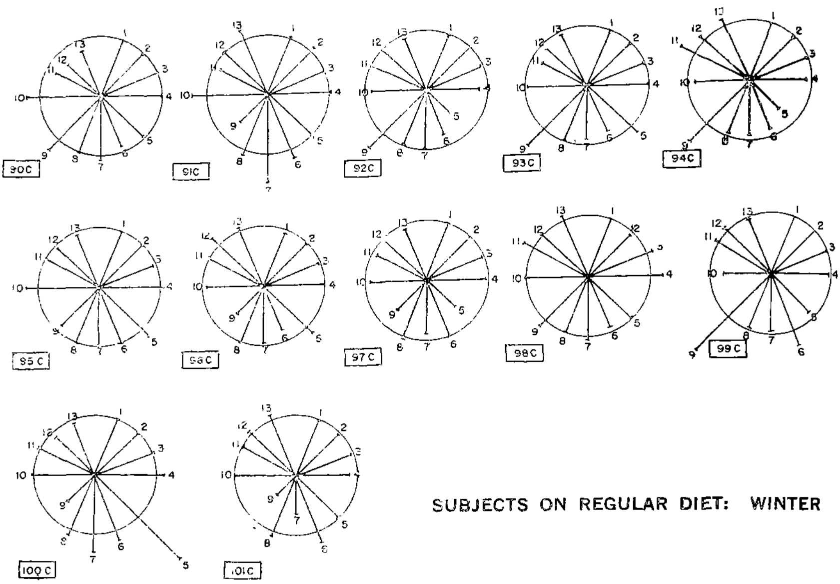

Figure 10 — Individual patterns of organ function. Circles and radial lines calculated as described for Figure 9. Organ functions represented are reclining systolic blood pressure (1), reclining diastolic blood pressure (2), reclining pulse pressure (3), reclining pulse rate (4), minute urinary volume (5), creatinine clearance (6), osmotic clearance (7), urinary pH (8), urinary titratable acidity (9), pulmonary ventilation (10) and estimate of passage of time: 20 seconds (11), 45 seconds (12) and 70 seconds (13).

Figure 11 illustrates the thermoregulatory reactions. Note that in most cases, the extreme values closely parallel the means. Under the standardized conditions of these experiments, these men responded to the heat in eight distinct ways.

Figure 12 demonstrates a comparable individuality for the cardiovascular reaction to work in heat. These two charts amply confirm the wisdom of Sundstroem's remarks quoted above.

EVIDENCE OF GENETIC ORIGIN OF BIOCHEMICAL AND PHYSIOLOGICAL INDIVIDUALITY

These patterns of individuality may be genetic in origin. The genotype of an individual probably determines not only his pattern of mean values of biochemical and physiological measurements but also the norms of reaction to environmental change. For instance, monozygous twins exhibit less individuality in biochemical and physiological measurements than do unrelated persons(*52*). Within large populations individuals can be found whose measurements deviate by more than three standard deviations from the population mean. These deviations are disconformities(*53*). There is ample evidence that many disconformities are genetic. Much additional research on human biology will have to be undertaken, however, to demonstrate whether patterns of individuality characteristic of most persons are also genetic.

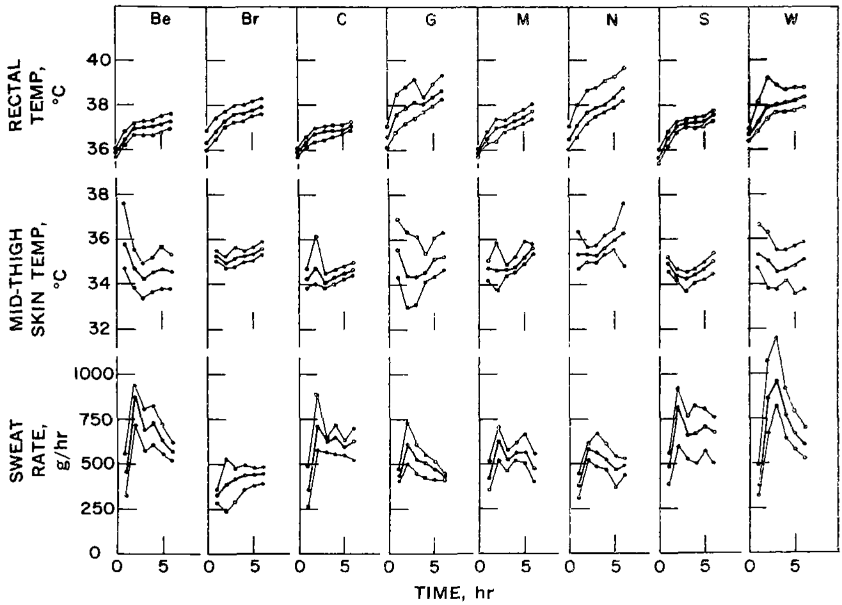

Figure 11 — Individual patterns of thermoregulatory response by eight men to marching 5.6 km/hr at 31°C corrected effective temperature. Heavy central lines represent mean hourly values of rectal temperature, mid-thigh skin temperature, and total body-sweat rate. Light lines represent range of individual hourly observations.

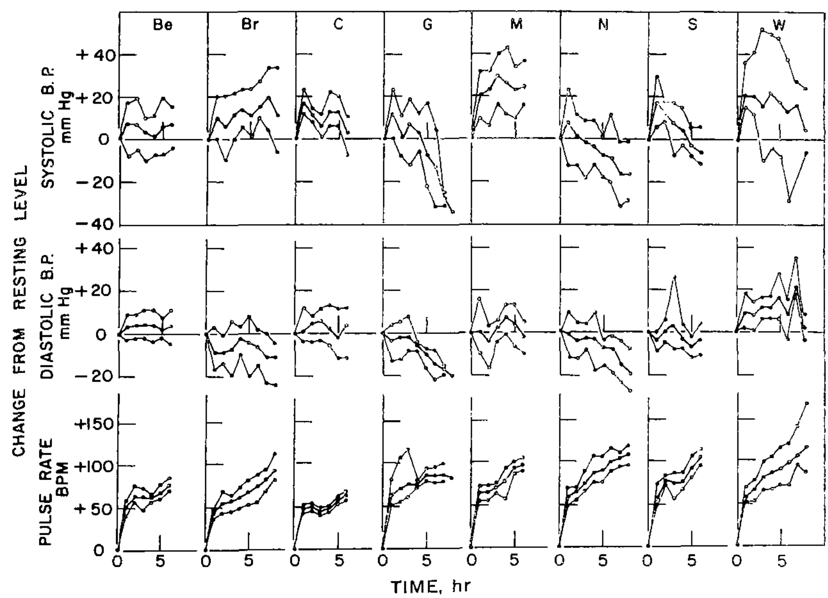

Figure 12 — Individual patterns of cardiovascular reaction to marching 5.6 km/hr at 31°C corrected effective temperature. Deviations from resting (control) observations of blood pressure and pulse rate represented in same fashion as described for Figure 11.

SUMMATION

The primary object of study by the human biologist is the system composed of the organism and a matrix of environments. The two elements of the system are inseparable. The organism of itself is an open system with needs for specific forms of matter and information. The organism functions to maintain in equilibrium a number of variables in different subsystems of its total self(29). The environment is equally complex; it is comprised of the material, biotic, and cultural components. This system, in spite of its great complexity, must be investigated holistically if deep understanding is to be realized. This viewpoint does not gainsay the specialized study of limited aspects of this system; the productivity of the biological sciences attests to the value of such study. My point is that the discrete bits of information contributed by the specialists must finally be fitted into the broad picture to arrive at a general knowledge of the system. The human biological scientist must ever think in terms of multiple causation of the processes he studies. He must relate to the more general concept of the system with which he deals.

Human biometeorology specifically must focus its attention on the broad problems of phenotypic plasticity and genetic individuality. Human biometeorology must adopt the ecological viewpoint as it investigates man and his atmospheric environment. Only by this approach can the human biometeorologist ever achieve an understanding of the organism-environment system and fully appreciate the implications of man's capacity to manipulate his environment for his future biological fitness.

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PHYSIOLOGICAL INSTRUMENTATION

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SUMMARY

Physiology covers such a wide range of biological functions that instrumentation required for one type of function cannot work for another. Some of the difficulties encountered in biological instrumentation of man are due to the variability of biological material, the unattainability of some sorts of data, the necessity of using indexes instead of the measurement itself, the difficulty of standardization, the variety of items for study, and the complexity of relationships of functions. For example, to measure skin temperature, one can use thermocouples, thermistors, or radiometers. The various methods of measuring other functions (such as sweat rate, oxygen consumption, pulse rate, blood pressure, and distribution of water), and a formula for quantitatively expressing man's relative strain are given.

The assignment to speak on physiological instrumentation for biometeorological studies is somewhat unusual for a physiologist. Physiologists don't think in terms of a field of instrumentation as peculiar to themselves. Physiology covers such a wide range of biological functions that the types of instrumentation required for one type of function or one set of circumstances just can't work for others. I doubt that you will find any textbooks on physiological instrumentation as I am sure you will on meteorological instrumentation. Instead of trying to deal with this subject on a systematic basis, I am going to stress principles underlying physiological measurement — the kind of things that one aims at, the kind of difficulties one gets into.

PROBLEMS — PRINCIPLES

Physiologists are a solemn lot. About the only amusement they can get is when somebody who is trained in the so-called exact sciences tries to apply the principles of measurements learned in the exact sciences to biological material. Now biological material just doesn't behave like most physical material and remain relatively constant; it is extremely variable. It is very frustrating indeed for somebody who is used to having his materials stay put to find that this doesn't happen at all. Many other difficulties arise in physiological

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measurement, or biological measurement in general. One is that the datum you want is very often completely unattainable. For example, I would very much like to have some method of estimating the net strain developed in an individual when he is exposed to a certain stressful situation. I don't know how to measure it; I even suspect that it is virtually unmeasureable. It is a concept and not a thing that can be measured; it is a very useful concept and one that we would like to quantify.

Then again, one may wish to know something about a certain function in the body, but getting an estimate or a measurement of that function with a person still alive may be difficult. How would you go about measuring the blood flow in the kidney of the person sitting next to you and still leave him intact and functioning? So many of the things you would dearly like to know just are not measurable, and you must put up with a second or a third best. You take some measurement that is only an index—an indication of what's going on, and not the thing itself.

PULMONARY FUNCTION

Just now we are very much concerned with pulmonary function and various measures of pulmonary function, particularly in relation to dust diseases. Now there are all sorts of "pulmonary function measurements," but these are really measurements of some *aspect* of pulmonary function. For example, we measure the degree of obstruction presented in the respiratory tree as the air goes in or comes out; the extent to which some parts of the lung are shut off and are not participating in the gaseous exchange; or some loss of permeability in the membrane between the alveolus and the blood stream. These are only special aspects of pulmonary function; they are not pulmonary function itself. I like to think that the only measure of pulmonary function would be a measurement of the facility with which it gets oxygen across to the arterial blood in the face of increasing demand. If you want to measure this, and if the patient will let you, you can catheterize his right heart and his arterial system, take samples of blood, and estimate the extent to which oxygen is really getting through. But this is a somewhat restricted procedure. You can't just haul in a coal miner, shove catheters into his heart, and then send him back to work. The measurement is possible under certain conditions but by no means under all conditions. And yet we need measurements of pulmonary function. How can we obtain them? Again, only by indirection and by some sort of mental integration of the results obtained by different procedures.

A further difficulty is that with all biological material there is the danger that what you are looking at becomes changed by your process of looking. We are reminded of the Heisenberg Uncertainty Principle, but in a different guise and a much wider sphere. One hopes to find ways of looking at a biological system without disturbing it.

Further, the circumstances under which the observation is made may exert far more influence on the result than the things you are trying to study. For example, you may be measuring small differences in pulse rate as a response to a given situation or a given stress. For a reasonably stable subject the change in pulse rate brought about by relatively high temperatures is quite small in relation to the change in pulse rate brought about by other things. Just the prospect of being the subject of an examination or the fact that a man is still mad at his mother-in-law may have much more effect on his pulse rate than shoving the temperature up 15 or 20 degrees. Again, you are frustrated in your attempts to measure the reaction, unless, and this is a very important "unless", you can thoroughly standardize your material.

STANDARDIZATION

Standardization is probably the most important single condition for physiological measurement, but physiologists are not always certain how far they must go. Recently I attended a meeting, related to a proposed International Biological Program; this meeting was to set up the conditions for making comparable measurements in different parts of the world on different groups of people. The recommendations fell far short of requirements and omitted numerous areas that need to be standardized. If the expert physiologists are not fully aware of the needs, those who are not so experienced certainly will overlook this very important principle. Standardization is probably the most important single principle for physiological instrumentation.

SELECTION OF MATERIAL

Another major difficulty arises in selecting material for study. Because so many variables are involved, it is virtually impossible to obtain measurements on the total system. You cannot, in one lifetime, set up enough different experiments to take in all of the different variable aspects of the system that will yield a complete line on the total system. You must simplify. You say to yourself, "This very limited number of variables I am going to study. The rest I am hopefully going to hold constant and leave out of my further consideration." This selection must be done consciously and not by default. Unless the experimenter knows that these are the variables he is going to standardize, he will find himself involved in purposeless arguments with others who are working in a similar field but with a different selection of variables. In my work, for instance, I may decide to standardize, and therefore ignore, the effect of nutrition. The fellow next door may decide to make nutrition one of his primary variables. We will never get together, and there is no point in arguing about our results, since my results are comparable with his at only one point. If you standardize your conditions and state them clearly, your position will be obvious and argument will be unnecessary.

COMPLEXITY OF RESPONSE

The relationships between the response of the organism and the stress that is applied to it are by no means simple functions. These relationships are generally complex; very seldom do you find a straight-line relationship, except over a very narrow range. For example, if you measure the rectal temperature response to increasing temperature, you will find at first no detectable change, then a slight increase, and as the temperature goes up, a more and more rapid increase in rectal temperature. You have a continually rising but by no means linear function. If you measure something like sweat rate, however, you will first get no sweat; then the sweat will increase rapidly for a while, stay constant over the next phase of rising temperature, and then taper off. Finally, if you insist on going further, the sweat rate very probably will start to fall again. Here we have anything but a simple function. Any extrapolation you made on the first half of your curve as to what would probably happen on the second half of the curve would be completely wrong. Unless you have been over the ground and know what the function is likely to be, you cannot extrapolate more than a very short distance from the range that you have studied.

Furthermore, if you apply two stresses to a biological system—first separately and then together—you do not get a simple additive response. If, for example, you increase the air temperature and measure the rise in pulse rate, you'll get a certain increment. If you increase the work rate of the individual and measure the pulse rate, you'll get a certain increment. If you expose the person to a high temperature and give him work, the resulting increment in pulse rate will bear no predictable relationship to the other two. There is no rational basis for integrating these values. Again, unless you know from experience, what the summation is likely to be, you have no clues.

After one has accumulated enough data, perhaps, one could go to a computer for assistance. But remember that the computer works only with the data it is given. If the data are inadequate, or very limited, then the computer will come up with some fancy answers that won't mean anything. You'll still have to go back and find out whether the computer was even in the ball park.

In Occupational Health we are plagued by our awareness that the subject is only part of a very complex system—a family system, a social system, an industrial system, an economic system, and so on. The examination you want to make may be quite incompatible with the system. We would very much like to have very extensive records of changes in rectal temperature, core body temperature, skin temperature, pulse rate, blood pressure, and so on, for a man doing his work in a hot industry. Well, you can just imagine the reception you would get if you went to the plant manager and said you wanted to hitch up 79 cords to this man, with a whole truckload of equipment trailing after him measuring all these things while he does some complicated job. A measurement system may be technically feasible, but totally impossible to carry out. When we want to measure the man on his job, we must usually content ourselves with very simple measurements that can be read without complex instrumentation. These are some of the difficulties that one encounters in biological instrumentation and particularly in the instrumentation of man.

MEASUREMENT OF HEAT

So much for the general principles. Now let me take one set of circumstances by way of illustration and run through the kinds of instrumentation that are involved. I'm going to discuss heat because this is the subject I know most about. Someone else could very well talk about instrumentation of human responses to toxic gases or the instrumentation of human responses to noise. For every kind of environmental stress that you might postulate, one could develop a set of measurements of human responses that are fairly peculiar to that particular stress.

I mentioned the basic importance of standardization. A second important principle of even higher priority is answering the question, Why make the measurement at all? It is very easy to run around making measurements simply to be making measurements—without a very clear idea of how they are to be used. I've done this myself. Over a period of three summers I devised a good system of measuring skin temperatures under working conditions. I took a lot of readings. I still have them, but I don't really know what to do with them. They don't really add to the story I was trying to investigate.

BODY TEMPERATURE

In discussing instrumentation for heat physiology, we start with purpose. What is it one is measuring for? What is it about the person's response that you need to investigate? This immediately determines the scope of your attempts to measure. Body temperature has attracted man's attention ever since there were methods of estimating temperature, certainly from Galileo's time on. Yet we still have no really satisfactory method of measuring body temperature. Over the last 5 years I've been to three or four fairly high-level conferences in physiology at which the measurement of body temperature has been discussed, always with vigor and sometimes with bitterness. Again, it is largely a question of definition: what do you mean by "body temperature"? Do you mean the average temperature of all the bodily tissues? Or do you mean the temperature of the central core of tissue in the body, which may be quite different from that of the periphery and therefore different from the mean temperature of all the bodily tissue? Or do you mean the temperature of the blood going to the chief heat-regulating centers in the brain?

SKIN TEMPERATURE

Let us say that you want to measure skin temperature; how do you do it? To measure skin temperature you can use thermocouples, thermistors, or a radiometer. The difficulty about a thermocouple or a thermistor is to place it in close contact with the skin without interfering with that skin. During the war it was fashionable to slap thermocouples all over the skin and cover each thermocouple with several layers of surgical adhesive tape. This procedure gave marvelously constant temperatures. But they weren't skin temperatures; they were temperatures under several layers of surgical adhesive tape. Nowadays we do it a little better. We can put the thermocouple on the skin without covering it with foreign material and so obtain what we think is a good skin temperature.

MEASURING DEVICES

You may be interested in a device, recently invented, called the Radio Pill. It is a very thick-walled capsule containing a transmitter with a temperature-sensitive element. As the temperature of the Radio Pill changes, the frequency of the emission from the transmitter changes also. The subject swallows the pill, while you stand with a little box and tune in to the frequency, reading from the frequency setting the temperature of the pill at that time. You can follow this pill all the way down, and if you are ingenious enough you can even recover the pill and use it again. (I'm told that the average number of uses is five.) This procedure gives you a core temperature. If you want a mean temperature you must average out the core temperature with the skin temperatures obtained according to an accepted formula.

Another new gadget is a thermocouple put into the ear canal so that it is almost in contact with the tympanic membrane. Some swear that this device gives the body temperature; but as you see there are a number of body temperatures, and one must decide which it is that one wants.

SWEAT RATE

Suppose you want to measure sweat rate. Sweating is a means of adjusting body temperature, and you can measure sweat rate in various ways; the most common is by weighing. If you weigh the subject clothed, before and after a period of exposure, you find the amount of water evaporated from his skin. If you weigh him nude, before and after, you get the amount of water lost from his skin. Now these methods may give two different figures, but each is an acceptable way of measuring sweat rate.

You may be interested, not in the total weight loss, but in the sweat rate from a particular body area, or from different body areas. For this measurement one generally uses a capsule. You can measure the water loss from the capsule in various ways. You can pass dried air through it and measure the water content of the air coming out, or you can measure the difference in water content of the air going in and that going out. Everybody has his own pet method; I object to all except mine, of course. Again, you can see that with a dozen of these things on, a worker wouldn't be of much use to the plant manager.

OXYGEN CONSUMPTION

You may need to measure oxygen consumption. Why oxygen consumption? Because by measuring the oxygen consumption one can get a measure of the metabolic rate—the amount of energy being generated by the individual and therefore the amount of heat being produced by the individual. This is one side of the heat-balance picture. To measure oxygen consumption, one hitches a man up to a tank of air and measures the amount of oxygen used over a period of time. From this one calculates the heat production. We are beginning to believe that a lot of the long-term adjustment of individuals to heat situations lies in learning how to do work with less heat production.

CONSEQUENTIAL MEASUREMENTS

So far I have discussed the measurement of items in the heat-regulating mechanism of the individual. But since in a complex body you can't do any one thing without upsetting a lot of other things too, other consequential disturbances are apt to develop in the course of heat regulation. If you want to investigate these, then you need a different set of techniques.

CARDIOVASCULAR SYSTEM

One of the systems that is very likely to become upset during exposure to heat is the cardiovascular system. You just may not have enough blood to fill up all those dilated blood vessels in the skin, to keep up with the loss of water in the sweat, to keep up, perhaps, with an undue consumption of food or alcohol, and at the same time to keep up the supply of blood to the head. The simple things that you can measure, like pulse rate, unfortunately, are open to all sorts of influences other than the one you are investigating; such measurements are to that extent suspect. One would like to measure blood pressure, but the conventional way of measuring blood pressure is a little crude. The most you can get are values at separate points of time. You cannot follow rapid changes in blood pressure. About the only way to follow rapid changes in blood pressure is with a catheter in a blood vessel. You are very restricted in what you can do with a catheterized man; you will be restricted as to the men that will let you do it, too.

WATER SYSTEM

You may be interested in the amount of water in the body and the distribution of water about different parts of the body. One speaks of three compartments in the body—the blood stream, the tissue fluid, and the cells. Water moves by a very complex set of laws from one compartment to another. As a result of changes in blood vessels and the loss of sweat, it's quite possible for one compartment to be without water or not to have enough. Measurements of the distribution of water among these three compartments are not simple. Fortunately, some substances will pass into one compartment but not into another. If you inject a known quantity of one of these substances into the blood stream, its rate of disappearance from the blood stream, as shown by successive samplings, gives a measure of the volume of the compartment into which it is going. By using a suitable battery of substances and by measuring at a suitable time after the injections, you can get a fairly good indication of where the water is in the body or where it isn't, which is usually the problem.

PULSE RATE

If, in spite of its drawbacks, you are interested in the pulse rate, you can measure it by palpation at the wrist, which of course is the common way. You can also measure it with a stethoscope placed over the heart. But both are difficult when the man is marching, partly because neither your finger nor the stethoscope will stay put, and partly because the rate at which the pulse is beating is usually so close to the rate at which the man is marching that you find yourself counting the marching and not the pulse. One can also use the electrocardiogram. If you put one lead on the chest and another on the back, you can get an electrocardiogram without too much interference from the muscle action currents; then pick off the top of each R wave to serve as a pulse counter.

Another method that is frequently advocated, especially by instrument manufacturers, involves an oximeter, which records variations in the blood flow through the ear lobe. It works very well for determining the saturation or desaturation of the blood going through the ear, but we have not found it very satisfactory as a pulse counter. Others claim much more success.

RENAL FUNCTION

Renal function is something we would like to measure, but it is very hard to get at. It can be estimated only indirectly by measuring the volume of the urine, and the amount of a particular substance like urea excreted in the urine, and then calculating the quantity of blood that is cleared of a substance like urea in a period of time. This is only a partial measure of renal function, however. Obtaining a real measure of renal function is quite complicated and involves a lot of induction from this kind of partial evidence.

NERVOUS FUNCTION

A consideration of nervous function is, of course, limitless. You can divide and subdivide nervous function and devise all sorts of measurement methods. Psychomotor tests are being used more and more frequently for this purpose, particularly to determine speed of reaction, accuracy of reaction, and vigilance. During the war we developed an experiment, in which we placed a trained gunner in a mock tank, with the job of picking up a target and training his gunsight accurately on it. We measured the time that elapsed between the appearance of the target on the screen and his actual accurate sighting of the target. This was a measure of speed, accuracy, and vigilance. We tried this under various conditions of heat and also of heat plus noise. When we put the subject in very hot conditions his efficiency dropped about 10 percent. When we applied noise through ear phones, even up to 110 decibels, his efficiency did not drop any more. But when we took the noise off, his efficiency increased by 15 percent. He was better when we took the noise off than he had ever been before, for a short while. After about an hour he slipped back to the 10 percent decrease again. So you see there is some point to the adage about knocking your head against a wall because it is so pleasant when you stop.

Cellular metabolism is now engaging our attention more and more. We would like to know what goes on in the cells, particularly what disturbances occur. If you are interested in this type of measurement, you'll find increasing literature on it.

Earlier I mentioned an apparently insoluble problem: we would like to have some measure of the total effect on the individual; not what happens to his pulse, or his body temperature, or his sweat rate, but what happens to him—the real him. Various formulas and charts have been devised to approach this problem; they all give only partial or very unsatisfactory answers. I will run through our attempts to solve this problem, acknowledging in one gesture the 25 or 30 years of work by dozens of people. A full account will appear in a forthcoming volume of the Annals, New York Academy of Sciences, on Biology of Human Variation.

QUANTITATIVE FORMULA

The quantitative expression of man's reaction to his thermal environment poses a complex problem. Three sets of variables, each containing several items or sub-sets, must be considered:

1. Environmental—temperature, humidity, air movement, radiant heat, clothing insulation, and contiguity;
2. Individual—age, sex, body build, disease, hydration, level of activity, acclimatization, and individual variability;
3. Evaluational (criteria for assessment of effect)—comfort-discomfort, sensation of distress, functional failure, pathological developments, aggravation of previous defects, susceptibility to other stresses, water requirements.

The problem of handling such a multiplicity of variables in meaningful fashion can be logically dealt with in five steps:

1. From heat-transfer equations devise expressions of interrelationship between appropriate variables (activity level, temperature, humidity, radiant heat, air movement, clothing insulation) and their net significance for man.

Using Burton's(*1*, *2*) equations and the concept of relative strain introduced by Belding and Hatch(*3*), Henschel and I(*4*) developed the following approximate relationship:

$$RS = \frac{M(I_{cw} + I_a) + 5.55\ (t_a - 35) + RI_a}{7.5(44 - p_a)}$$

where RS is relative strain (dimensionless); M is metabolic rate in kcal/sq m,hr; R is radiant heat gain in kcal/sq m,hr; t_a is air temperature in °C; I_a is insulation of air (inversely proportional to square root of air movement) in clo units; I_{cw} is insulation of wet clothes in clo units; p_a is vapor pressure of air in mmHg.

2. By postulating convenient "standard" values for metabolic rate (M), air movement (I_a), clothing insulation (I_{cw}), and radiant heat (R), reduce expression to effect of two independent variables (temperature and vapor pressure) on the dependent variable (relative strain); and draw lines of equal strain on a psychrometric chart.

3. From the expression for RS (relative strain), calculate the changes in air temperature that would produce the same changes in the value of RS as deviations from the "standard" values assigned to the variables of metabolic rate, air movement, radiant heat, and clothing insulation; and prepare tables to show "corrections" to actual air temperature which, if made after entering the chart, would compensate for such deviations.

4. From the data available in the literature and elsewhere, determine the probable effect of successive degrees of relative strain upon a defined "standard" person, in terms of selected evaluative criteria, and express in graphical form.

5. Prepare similar graphic expressions of probable effects for nonstandard persons.

The limited amount of useful data in the literature makes this last step difficult. Evaluation charts will be found in the references. The actual use of the scheme is comparatively simple:

a. From the appropriate table, determine any "correction" to the actual air temperature needed to compensate for other than the "standard" values assigned to metabolic rate, air movement, radiant heat, or clothing.

b. With air temperature and whatever measure of humidity is being used (wet bulb temperature, relative humidity, or vapor pressure), enter the psychrometric chart. From the point so obtained move horizontally to make the adjustment obtained in (a) and read off the corresponding value of relative strain.

c. From the chart of effects appropriate to the persons under consideration read off the probable effects indicated for that value of relative strain.

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DISCUSSION

Question: On your last slide you showed "discomfort", which sounds something like the Weather Bureau's "discomfort index". Is it true that you can get only so uncomfortable and then it is just constant?

Dr. Lee: Yes. One of the troubles about using discomfort as a criterion is that once you have reached a certain degree of discomfort, any more does not count. From there on you're getting into more serious changes. I might say that the word "comfort" presents a philosophical difficulty. From my point of view, comfort is the vanishing point of discomfort. There are no degrees of comfort.

Question: Dr. Sargent, you said that senescence is an accidental byproduct of evolution. I'd like an explanation. By accidental you don't mean "random"?

Dr. Sargent: No. If we look at the mechanism by which natural selection operates, we find that this process is operative only during the reproductive period. There is no natural selection for the aged. The fact that we do age beyond the reproductive period can be argued as an accidental byproduct of adaptive processes that have selective advantages for the reproductive period.

Question: What do you think is the most effective measurement of body temperature?

Dr. Lee: An argument is centered on whether one should measure the tympanic membrane's temperature, which is supposed to be the closest you can come to measuring the brain; whether one should measure the esophageal temperature as being closest to a core temperature; or whether one should measure the rectal temperature, which is much more easily obtained. It really depends entirely upon what you are after. Recently in London I saw a chart with simultaneous plots of the temperature in the right heart, which is the temperature of the mixed blood coming back from all parts of the body, the temperature in the esophagus, the temperature in the tympanic membrane, and the rectal temperature. No two curves agreed; they were all different. You just have to decide which one suits your purpose.

Question: You say they don't agree in value or shape?

Dr. Lee: Well, if a person were locked up in a room at the same temperature all the time they would agree. But if there are any changes in environment, these curves may not agree at all.

Question: I'd like to hear some comments on stress levels. Some popular articles have been written on this. It seems to me there are two sides. There is an advantage to an individual to be put under stress, and then we've heard of disadvantages.

Dr. Lee: Complete isolation from external stress does not result in an optimum condition of the body. The optimum condition of the body apparently occurs with at least some external stress. After that, one begins to pay for additional stress, first of all by the decline of the advantages of mild stress and finally by negative values.

Question: Would you call that mild stress a stimulant, then?

Dr. Lee: Yes. If you take 20 people sitting down and measure their pulse rates, you'll get a pretty wide range of pulse rates. If you have them standing up, you'll get slightly higher pulse rates and still a wide range. If you have them walking, say, at 2 miles an hour, you'll get still higher pulse rates but the range will be narrower. At some moderately high value, perhaps at 3½, you'll get a comparatively narrow range of pulse rates. If you start putting the stress to them hard—getting them running up hill at something like 5 miles per hour—then obviously the rates are going to spread out again, and some people will drop by the wayside. So here one finds a range of stress in which people become more uniform.

Dr. Sargent: Some people are improved, in a way, by these stresses. Sir Joseph Barcroft discussed another aspect of this some years ago in his book *Architecture of Physiological Functions.* Most physiologists measure human beings under quite unusual conditions. The standard conditions that we use are conditions of vegetation—we are lying on a bed without having eaten anything for the past 18 hours, etc. These are not the conditions in which we are physiologically expected to get along. We should measure people under circumstances that are as consistent as possible with ordinary living conditions. This bears on what Dr. Lee is saying. In a study at Harvard University, the medical investigators used representative Harvard students and put them through an experiment that involved sitting, standing, standing on a treadmill, and running on a treadmill; recovery from this work was also followed. If one plots the coefficients of variation, a measure of the interindividual difference of the subjects, one finds that the interindividual variabilities were quite wide when the students were sitting and standing. Then as they went through the treadmill run the variability became narrow. As they recovered, the variance widened out again. This particular experiment did not push the subjects, so some stress tends to reduce inter-individual variance. What physiologists have to do is measure human beings under realistic stresses rather than under extreme stress.

Question: Dr. Sargent, you mentioned the problems of a body maintaining its chemical stability in winter. Have you any information showing that there seems to be a time when certain diseases tend to attack an individual because of this lack of chemical stability or of a certain chemical which goes awry?

Dr. Sargent: The evidence that I showed from Dr. Momiyama suggests that a great many diseases are beginning to concentrate in the winter, that we're losing the summer maxima. The slide I showed is from her data for Tokyo, but she found this true of all important western countries where statistical data are reasonably good. The generalization thus seems to apply to metabolic disturbance, infectious diseases—to practically all diseases.

Dr. Lee: There's one exceptional case in regard to summer. The highest mortality rates occur in a period of exceptionally hot weather. The mean summer figures are much lower than the mean winter figures, but an exceptionally hot period gives the highest figures of all.

Dr. Sargent: The biochemical reaction that we showed was uncovered in our studies on survival rations for the Air Force. The increase of ketone bodies in the blood and the decrease of blood sugar, the increase of nitrogen that developed in the winter is exactly equivalent to an injection of insulin. We were even able to demonstrate a negative phosphate balance in our subjects. I don't know what this metabolic reaction means yet. The insulin reaction is really an analogy. There must be some very important fundamental metabolic change that occurred.

Question: Do you find that the first onset of winter—the first cold spell—tends to cause cardiovascular problems or some other type of illness to emerge?

Dr. Lee: Not necessarily. About 30 years ago Johns Hopkins analyzed the relationship of respiratory morbidity to changes in temperature. They found that a rapid change in either direction was associated with increased morbidity. It didn't matter much whether it was going up or going down. Of course, the changes in winter are more rapid than in summer.

Question: Is this tendency toward increased mortality in winter a world-wide trend or is it just in the United States?

Dr. Lee: It's world wide among the advanced civilizations, the Western civilizations.

Question: Do you think that the increase in the use of air conditioning could have anything to do with this? In ages past, or at least

20 or 30 years ago, people were keeping relatively warm in the winter, so there hasn't been any great change there; but in the summer we have arrived at this mechanical means to cool our environment.

Dr. Lee: There isn't much air conditioning in Britain.

Dr. Sargent: The trend applies to France, to England, to the Scandinavian countries, and to the United States.

Question: Does it wash out as you go into more temperate climates?

Dr. Sargent: Dr. Momiyama hasn't studied this particular aspect, as far as I know.

Question: What do you mean by more temperate?

Dr. Sargent: More moderate winters as you go south.

Question: Are her figures percentages?

Dr. Sargent: No, they're death rate—by months.

Dr. Horton: Some of your changes in the seasonal pattern of illness are due not to an increase in the winter but to a decrease in the summer. The shape of the curve simply changes. The whole pattern of intestinal illness in bottle-fed babies, which killed hundreds and hundreds of infants every summer, particularly in August, in urban United States back before about 1920 is essentially this. The disease was found only in rural areas until 1946. When the Public Health Service was about ready to study the problem, it disappeared. But that is not a phenomenon of air conditioning. It's due to elimination of flyborne intestinal illness largely in young babies.

Dr. Lee: We could put it this way: summer mortality is very largely due to vector-borne diseases; whereas the winter mortality is largely due to more contact with the disease.

Dr. Horton: It always has been. But at least the mortality of the disease has been reduced, either naturally or through treatment. I'm not sure that one could say that these diseases have been reduced. Some of them have become less severe, such as scarlet fever, and others have become more treatable, such as pneumonia.

Dr. Sargent: This same trend applies to cardiovascular disease and cancer.

Dr. Horton: Part of this is due to the fact that some of these diseases are due to terminal infection.

Question: Dr. Sargent, concerning the adaptability of the body, has any attention been directed to this increase in stress by going through the cycles of winter and summer year after year, so that the aged person reflects this more, say, than the younger person? Would this occur more in the temperate zone than with someone who is always in the winter season, such as in the arctic, or someone who is always in the summer season and doesn't have to endure the cyclical changes?

Dr. Sargent: Very little has been done on this subject. You find that some seasonal curves, such as for poliomyelitis and rheumatic fever, are flatter in the tropics than in temperate regions. But we have very little good information on the arctic regions.

Dr. Lee: There has been a lot of argument over the years about the desirability of having change in climate. I think it is like a stress situation. Complete lack of change is undesirable. A moderate change is desirable. When the change becomes more than moderate, then you start getting a stressful curve again.

Dr. Horton: I don't know that one can say that people living in a place like Honolulu, for instance, which has about as little variation as one can find, are any worse off than in other locations. Huntington, for one, made a great point of the fact that the only people who amounted to anything much were the people brought up in what some people call the intemperate climate. This is a complex question.

Dr. Sargent: I think that the study of Kutschenreuter showing the different effects of seasons on the various age groups should be repeated. As far as I know, season and mortality were studied only in New York City. I think this is probably a very important thing—the fact that the seasonal variation of the mortality rate is different for different age groups. [Recently Momiyama* has confirmed Kutschenreuter's findings.]

Dr. Larsen: Some air pollutants seem to be about 5 times as concentrated in the winter as in the summer. Have you any good suggestions for filtering out the stress from air pollutants as opposed to the stress from changes in meteorology?

Dr. Sargent: They go together. If it is nice and warm, there won't be as much air pollution because you won't have to heat so much. I think the effects of air pollution are quite frequently very closely tied up with the effects of the weather. I don't have any suggestions for filtering them out.

Question: Do you find that some of these seasonal adjustments the body makes may throw off other functions of adaptation in the body? Do you find that keeping a close regulatory effect on some of the chemicals in the body can throw off other functions of the body adaptation to the changes in the weather or climate?

Dr. Sargent: No. I don't think that is the right way to look at it. The fact that we can keep certain aspects of our physiology so closely guarded has great survival advantage for us because it keeps the very essential functions of the cells, the systems, operating. We don't find things getting out of gear in just the way you've asked.

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* M. Momiyama and H. Kito. Papers in Meteorology and Geophysics, 14: 190-200(1963).

Question: You mentioned low calcium in the winter time. Would that be something related to, say, lack of sunshine or lack of vitamin D?

Dr. Sargent: This gets us into this problem of seasonal variation in the physical environment versus seasonal variation of the body. The two are beautifully correlated. The literature gives some lovely graphs, with correlation coefficients up to around 0.9 between calcium and galvanic stimulation and incidence of tetany. They all go beautifully together, and we know from independent physiological research that there is an important interrelationship between the ultraviolet component of the sun and the calcium and phosphorus metabolism.

Question: Could we say that if pollution causes decreased sunshine it causes vitamin D deficiency?

Dr. Sargent: Well, theoretically. But as Dr. Giel pointed out, we get our vitamin D by other means now. By technological inventions of man, in milk.

Question: Dr. Lee, is there any information on whether people born and raised, let's say, in a southern climatic area are performing a different physiological function from people in other areas? I was with an occupational health group in Brazil, and my Brazilian colleagues never sweated the way I did. They never seemed to have any visible sweat. Now these people—one was a boy of French extraction, one was a chubby Italian, some were of Negro extraction, and others were Portuguese—but they always seemed to be cool and comfortable.

Dr. Lee: Such investigation that has been carried out shows virtually no effect of race; this has been a very disappointing field. You'll find lots of statements in the older literature, but in most cases they looked at only one side of the balance. For example, they would see that this racial group sweated more than another racial group without recording how much work they were doing, or the way in which they went about doing the work. Remember I said that we are beginning to realize now that a large part of the long-term acclimatization is learning to do the job with less expenditure of energy. This is very important. The man who sweats less may do so because he's just not doing the same amount of work or because he is working more efficiently.

Question: One of the remarks that the physician made was that Brazilians develop small pores. Is there such a thing?

Dr. Lee: No. I heard Dr. Weiner, who is probably *the* authority, talk on this subject a couple of months ago, and he is very disappointed. He can't find any racial differences. He has not looked at very many racial groups, but so far he has not been able to find any differences.

Dr. Sargent: I would like to comment on the question of heat tolerance in the white versus the Negro, found in the literature in the last few years.* In our survival studies a third of our subjects were

Negroes. The boys all went through identical procedures. To make the analysis of our data more elegant, we matched them for body size, height, weight, surface area, and lean body mass, within 10%; we found 19 matched pairs. We compared about 20 different measurements made on these men while they were resting and while they were walking on a track for an hour in temperatures of 95 to 105°F, dry bulb; there were no significant differences in the physiological reactions. We also observed heat illness among these subjects. Only one case of heat illness of any kind occurred among the Negro subjects, and 21 cases of heat illness occurred among the whites. Our physiological measurements showed nothing but that the Negro showed more stamina. This is somewhat the conclusion that Wyndham arrived at in comparing Bantus and Zulus with white people in South Africa. The same conclusion was reached by Sid Robinson in a study of share croppers years ago. I would agree with Dr. Weiner on these differences of race: they are very difficult to establish. We also have the very important question of how long these people have been in a hot environment. We don't know how long it takes an individual to acclimatize. We're doing a lot of research in chambers, but you can't get anybody to live in a chamber for 10 years. You can get them to live in a chamber for a couple of hours every other day for a few weeks. We find that the rectal temperature and pulse rate go down and the sweat rate goes up, so we say "Now he's acclimatized." But evidence now shows that with continued exposure to heat the sweat rate actually starts to go down again. Such a finding came from the Singapore lab of the Royal Navy, where they studied people for 25 weeks. Maybe what we are studying in the chambers is not "acclimatization" but "acclimatizing." The newcomer to the hot areas shows high sweat rates and the natives in the tropics show low sweat rates. We might look on this really as an overreaction with a very long time phase. The homeostatic mechanisms have a large variety of time sequences.

Question: When you spoke of these matched pairs and you said there were no physiological differences in response, how did you interpret this heat illness in the 18?

Dr. Sargent: By the vague term "stamina".

Question: It was a psychological response?

Dr. Sargent: No. We had total cessation of sweating, heat exhaustion, hyperventilation tetany, and things of this sort. There was only one case of reduced sweating among the Negroes, but 21 cases of heat illness occurred among the whites. This wasn't a feeling of unhappiness or distress or discomfort.

Question: Weren't these measurable things then?

Dr. Sargent: Yes, they were measurable, but at the clinical level rather than the physiological level. Maybe we weren't measuring the

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* S. K. Riggs and F. Sargent, II. Human Biology, 36:339-352. 1964.

right things physiologically to bring these differences out. Sundestrom realized this years ago. The ways people put together all their adaptive reactions are quite different. Some people put them together one way, and some another. Maybe you can't measure it all at once. By using the standard procedures that most physiologists use today, you couldn't see any difference. Other people have arrived at some very interesting conclusions on the basis of similar measurements where they found differences. Baker of Penn State has written some delightful articles on "Climate, Culture, and Evolution," which you all ought to read. He has studied Negroes at 85°F, which he called moist heat stress, and then found some regressions between sweat rate and temperature. He then extrapolated from his curves to explain racial differences in sweat rate all over the world. He found only small differences.

Question: Do the results on the paired study on physiological response suggest that it might be well to measure some of the more sensitive variables, such as hyperventilation or sweat rate, or some of these other things that seem more touchy or clinical?

Dr. Sargent: We measured sweat rate, pulse rate, rectal temperature, skin temperature, and blood pressure at rest and standing. We also measured oral temperature, blood pressure and pulse standing and sitting, and metabolic rate.

Dr. Lee: Hyperventilation is a bit hard to measure because people are extremely sensitive to observation.

Dr. Sargent: We measured the maximum ventilatory capacity as well as pulmonary ventilation and tidal air.

Question: What was the nature of the heat illness of the whites?

Dr. Sargent: One was anhidrosis, total cessation of sweating. Another was a marked reduction of sweating, which we call hyperhidrosis. Neither of these was associated with a rise in body temperature. And then there was hyperventilation tetany, which has been ascribed to the heat, although it might be partly due to anxiety because of the circumstances or to a panic reaction. We had one case of heat exhaustion.

CLIMATES OF THE UNITED STATES

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SUMMARY

As a result of the interacting effects of the wedge-shape of the North American continent, the large land mass in northern latitudes, the warm oceanic areas and currents in the south, the north-south mountain ranges, and the large urban areas, distinct and different air masses develop in appropriate source regions producing unique types of climates in the United States. The temperature-humidity index (THI), a climatic variable calculated from air temperature and moisture and expressing the integrated effects of temperature and humidity on human effort, is discussed.

INTRODUCTION

My topic is indeed a very, very broad area of study. Since I teach a 3-credit course at Rutgers University entitled "Climates of the United States," it was difficult for me to decide what specific aspects of United States and North American climatology to deal with. I finally decided to discuss the uniqueness of the climates of North America and some of the main controlling factors that produce the particular type of climate to which we are subjected. The second part of my talk will deal with the distribution of two important climatic parameters, temperature and precipitation, and the distribution of a measure of human comfort, the temperature-humidity index or THI.

CLIMATIC FACTORS

LATITUDE

Among the most important controlling factors of the climate of any particular area, latitude must be included. The word "climatology" or "climate" is from the Greek word "klimas," which means angle of inclination. This refers to the angle of inclination of the sun above the horizon, which is latitude-dependent and one of the main factors of climate. Thus, the early Greeks knew that if one proceeded north or south from a particular location a corresponding change in climate would be observed. North America is a very long continent latitudinally, extending from about 10°N to 70 or 80°N. As you might expect, on the basis of latitude alone, there are broad differences in climatic types.

TOPOGRAPHY

A second controlling factor of climate is the geographic setting or the topography of the continent. Figure 1 indicates that the general shape of the North American continent is that of a wedge, with the broad anvil portion of the wedge in northern latitudes, narrowing down considerably in southern latitudes. This shape has important ramifications in the type of climate we experience. Notice also that most of the mountains in North America are oriented north and south, in particular the Cordillera in the West and the Appalachians in the East. Considering the rest of the continental land masses, one may recall that aside from South America, which is also a wedge but inverted latitudinally, all other major mountain ranges appear to be oriented east-west, in particular the Alps and the Himalayas. Thus, as a result of this factor alone, the climate of North America is strikingly different from that of Eurasia.

OCEAN CURRENTS

A third controlling factor is the ocean currents. Two current systems, shown in Figure 2, affect the climate of North America. One is the North Pacific drift, which comes across the central Pacific and bifurcates when it strikes the North American Continent at about 40°N. This bifurcation results in a current moving from south to north along the coast of Washington, Oregon, and British Columbia—the Alaska current. The other current moves to the south—the California current. Since these two currents travel from middle latitudes to either higher or lower latitudes, they tend to modify the corresponding coastal climates. Thus, the Alaska current moving from south to north is essentially a warm current; it warms the air about it and tends to increase instability. The California current moving to the south is relatively cold; since it is moving from higher to lower latitudes, it tends to cool the air immediately above and has a general stabilizing effect. These air-sea interactions are of noticeable importance in the general climate of the area.

In the Atlantic, we have the Gulf Stream system, emanating from the Florida straits and paralleling the North American coast in a northeasterly direction just off the continental shelf. This system becomes the North Atlantic drift and moves across the North Atlantic ocean. Since the general movement of winds in mid-latitudes over North America is from west to east, the currents in the Pacific have a more profound effect upon the general climate than does the Gulf Stream in the Atlantic.

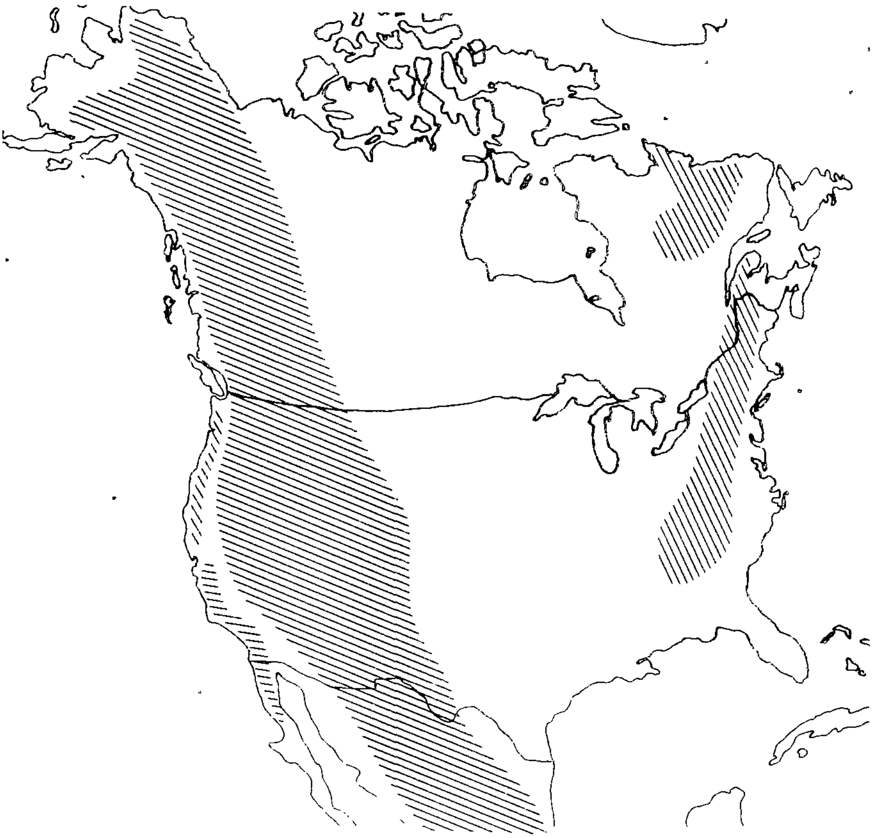

Figure 1 — Orientation of major mountain ranges of North America.

PRESSURE SYSTEMS

The next factor controlling climate is the existence of the atmospheric semipermanent pressure systems. The Bermuda High, the semi-permanent high-pressure system off Southern California, the Aleutian Low, and the Icelandic Low are examples of such systems. These semipermanent pressure systems, which are statistical in nature, perform the very important function of distributing moisture, momentum, and heat energy in the atmosphere. If these giant rotors did not exist, the earth, which receives most of its energy from the sun in low latitudes, would tend to become overheated in low latitudes and supercooled in higher latitudes.

URBAN AREAS

The fifth controlling factor is urban areas. You may think it strange to consider this factor, but urban areas do produce a pronounced effect on their climate. Such an area tends to influence its local climate as a result of changes in albedo, evaporative surfaces, heat capacity, and so on. Since this subject is more properly a function of microclimatology, let it suffice to mention that cities in contrast to non-urban areas tend to have generally higher temperatures, greater amounts of rainfall, greater amounts of fog, and lower relative humidity.

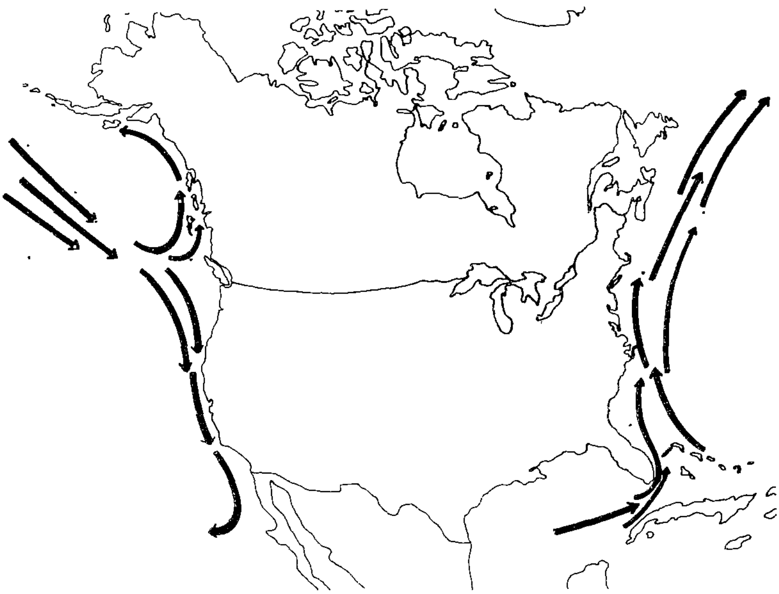

Figure 2 — Major ocean current systems affecting North America.

AIR MASSES

Before we discuss the distribution of precipitation, temperature, and the temperature-humidity index over the United States, let us briefly consider a combination of these factors to describe the uniqueness of the climate of North America. As a result of the wedge-like shape of the continent, with a large land mass in northern latitudes and warm oceanic areas to the South, combined with north-south mountain ranges, we have perfect conditions for the development of distinct and different air masses in appropriate source regions. Figures 3 and 4 show the source regions and trajectories for some of the major air masses that affect the North American continent during the two extreme seasons, winter and summer. The arrows indicate the general trajectory of these different air masses. Several major air masses affect, at least, the greater portion of the country east of the Rocky Mountains. Two are the cP (continental polar) and cA (continental arctic) air masses originating in the north; these are usually cold, dry, and unstable. These air masses move in roughly north to south trajectories. Another important air mass is the Gulf mT (maritime tropical) air mass, which generally moves from the Gulf of Mexico, its source region, to the north. Other air masses that affect mainly the coastal regions of the Atlantic and the Pacific are the mT in the Pacific and the mP (maritime polar) in the North Atlantic and North Pacific.

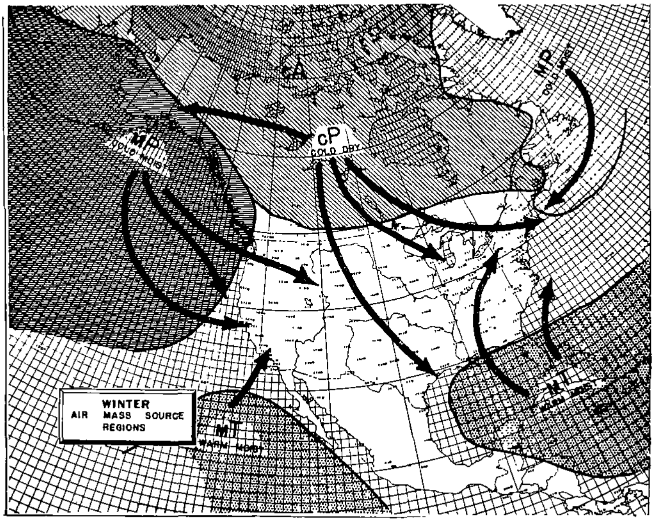

Figure 3 — North American air mass source regions and trajectories (winter).

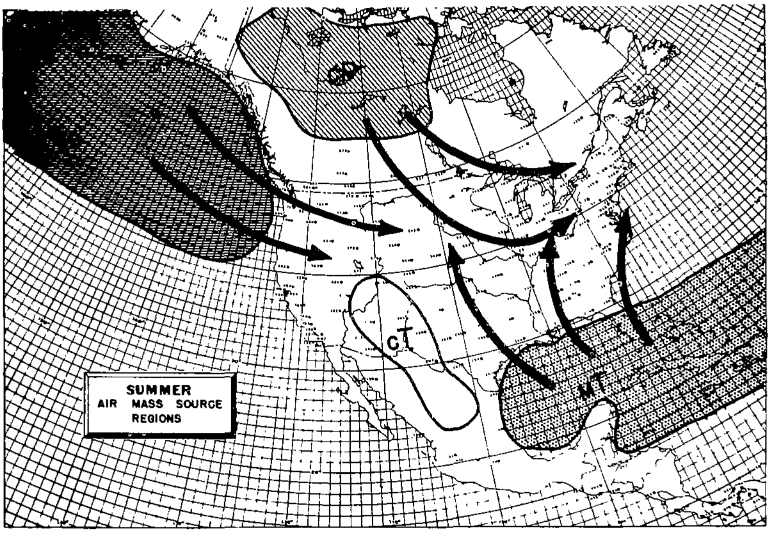

Figure 4 — North American air mass source regions and trajectories (summer).

LOW PRESSURE SYSTEMS

Air masses are distinguishable according to peculiar and distinct characteristics and are separated from each other by frontal surfaces. According to the Norwegian theories of cyclogenesis, fronts are usually associated with traveling low-pressure systems or cyclones, which are the main producers of inclement weather. The movement of these low-pressure systems, with their attendant fronts, cold and warm, provides the mechanism for the movement and distribution of these various air masses over the United States. Figure 5 indicates the general paths or trajectories of these traveling cyclones or low-pressure systems, as well as those of some of the major anticyclonic or high-pressure systems. Note that the general path of these pressure systems is in a west-to-east direction, which is in line with the general movement of winds in midlatitudes. Note also the general convergence of storm tracks over the northeastern United States. Some of these paths include that of the Alberta low, Colorado and Texas low-pressure systems, Gulf lows and east-coastal low-pressure systems. It appears that lows are most intense and are associated with the greatest amounts of precipitation when they are moving in a south to north direction. This is in line with the fact that the main sources of moisture for these storms are the Gulf of Mexico and the Atlantic Ocean.

As a result of these factors North America, the United States in particular, is blessed with an abundance of unusual climatic phenomena; unusual because of their great frequency of occurrence and intensity. Such climatic "delights" include tornadoes, blizzards, dust storms, thunderstorms (with and without hail), and abundant rain.

TEMPERATURE

One way of getting a good feeling for the climate of an area is to take a detailed look at the distribution of certain climatic elements. As I indicated earlier, we will consider temperature, precipitation, and the temperature-humidity index. Let's start with the distribution of temperature and consider the two extreme seasons, in particular the months of January and July.

DISTRIBUTION IN JANUARY

Figure 6 shows the patterns of isotherms, lines connecting equal temperatures, over the United States during January. Notice the effects of the oceans. The isotherms appear to reach their southernmost extent in the interior of the country and are bowed upward to the north along the Atlantic and the Pacific coasts. This effect is most pronounced along the Pacific, where isotherms parallel the coast for considerable distances. The change in temperature with latitude varies considerably from one part of the country to another. The temperature gradient from Maine to Florida corresponds to about 2.5°F per degree latitude. This means that someone in the northern part of the United States traveling south along the eastern seaboard for his winter vacation at approximately 70 miles per hour on the new interstate highway systems, could expect to gain 2.5°F for each hour of travel. This, of course, refers to mean or average conditions. In the interior of the country from Minnesota, say Duluth, to New Orleans, the change in temperature or temperature gradient is approximately the same. Along the west coast of the United States, because of the moderating effect of the ocean and general onshore breezes, the temperature gradient is only about 0.8°F per latitude degree.

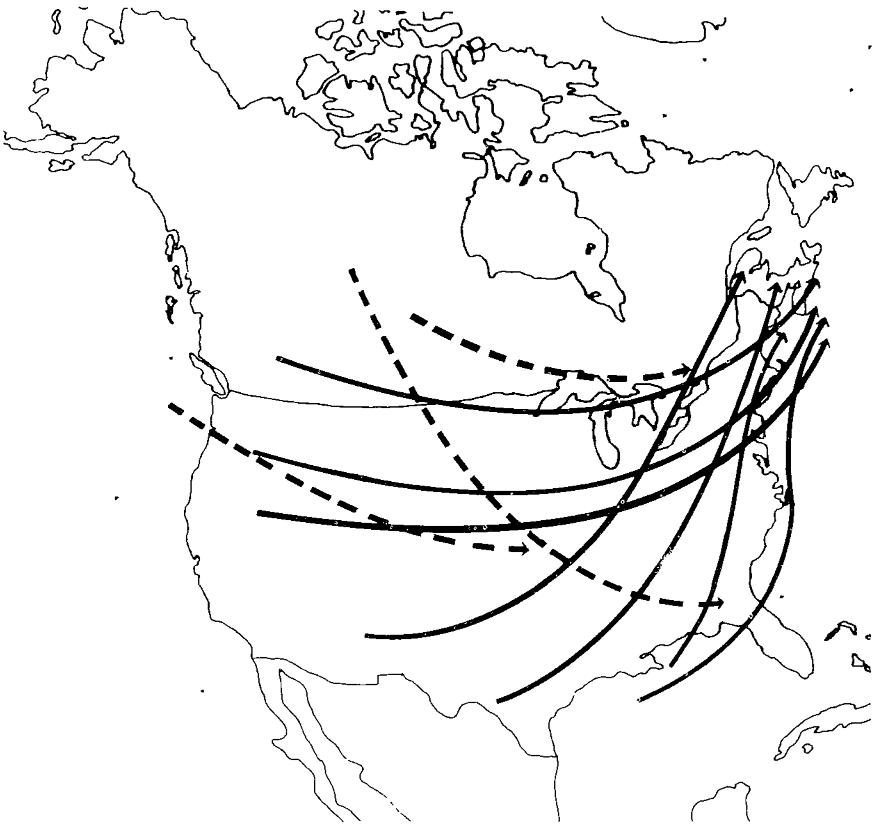

Figure 5 — Main cyclone tracks (solid lines) and anticyclone tracks (broken lines) over North America.

Look at two particular isotherms, the 0° isotherm and the 30° isotherm. The 0° isotherm enters the country in the northcentral plains in the vicinity of eastern North Dakota and northwestern Minnesota, quickly returning to Canada. The 30° isotherm, however, has a considerable traverse across the United States. It enters the eastern seaboard in the vicinity of New York City, progresses to the south and west, bows toward the equator in the Appalachian mountains, then proceeds through the Ohio valley in the vicinity of Cincinnati, through the Mississippi valley a little north of St. Louis, and into the plains in the vicinity of Denver. At this point it becomes extremely erratic because of the effects of the mountains. It reappears in northcentral California and generally parallels the coast (notice the effect of the Columbia River valley), never actually touching the ocean until southern Alaska. Once again, this contour is due to the modifying effects of the Pacific Ocean.

ROCKY MOUNTAINS

Also noteworthy in Figure 6 is the barrier that the north-south Rocky Mountains present to the marine air from the Pacific moving in from the west, and its subsequent effect on the isotherms. Note also that in the immediate lee of the Rocky Mountains temperatures are somewhat warmer than in the Plains farther to the east. This is due to what is known as a Chinook effect, in which air comes over the tops of the Rocky Mountains, descends the lee side, and warms adiabatically—that is, in a thermodynamic sense without the addition of heat. These Chinook winds are thus warm and dry, and result in the evident modified isothermal pattern.

GREAT LAKES

Another interesting point in Figure 6 is the effect of the Great Lakes. The Great Lakes generally do not freeze during the winter. The only one that does freeze with any consistency is Lake Erie, which freezes because of its shallower depth. As a result of open water, air passing over the Lakes in a general west-to-east direction becomes modified with increased moisture and warmer temperatures. This net effect is seen when we compare the temperatures of several cities in central Wisconsin on the windward side of the Lakes and other cities in central lower Michigan on the lee side of Lake Michigan but at approximately the same latitude. For example, the mean January temperatures for such cities as Madison, LaCrosse, and several other smaller stations in Wisconsin, such as Richland Center, are between 15 and 18°F. Cities in Michigan, such as Muskegon, Flint, and Grand Rapids, which are affected to a much greater extent by the proximity of the Great Lakes, record mean January temperatures that range from 23 to 26°, considerably warmer. Occasionally, local and smaller topographic effects are evident on the mean isothermal pattern. One case in point might be the Hudson Valley and Lake Champlain. This area appears somewhat warmer than the surrounding countryside, mainly because of differences in elevation.

ABSOLUTE MINIMUM

Figure 7 indicates the extreme isotherms for the winter season. These values are the coldest temperatures ever recorded regardless of time of observation. Absolute minimum temperatures occur in the mountain states of Montana and Wyoming, where values of —60°F have been recorded. The —40°F isotherm is found in the Great

Plains, in isolated portions of New England, and in northern Wisconsin and Minnesota. At —40°F and below, mercury freezes and observers must use spirit thermometers to record these temperatures. Notice further the effects of the Great Lakes on the extreme isotherms. Absolute minimums along the shore are considerably higher than those recorded some distance inland; this temperature difference has an important effect on the economy of the region, with fruit belts along Lake Michigan and Ontario. Fruit trees that normally

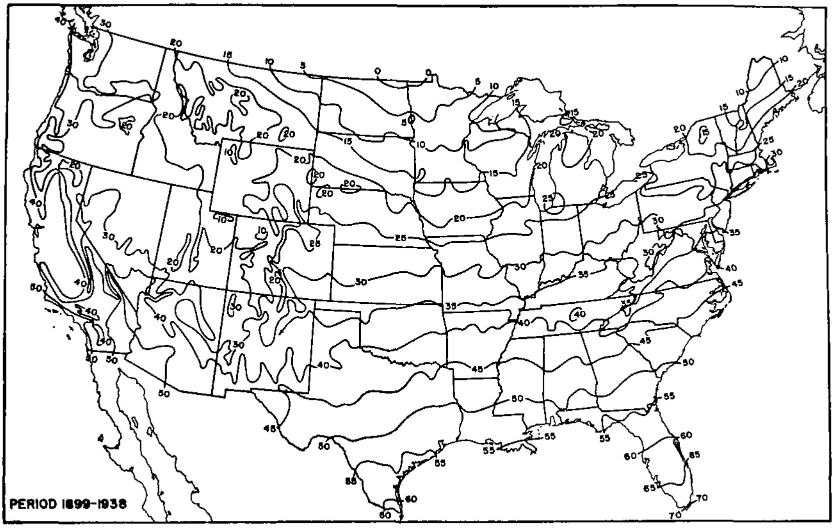

Figure 6 — Average January temperature in the United States (°F).

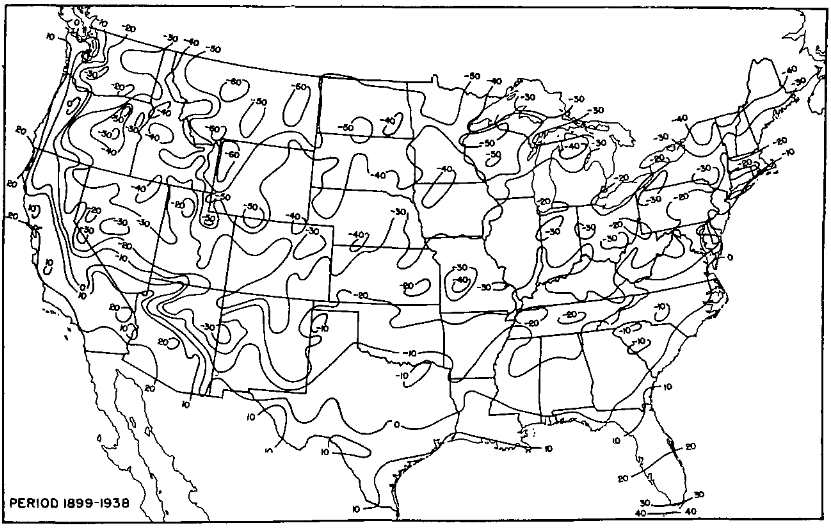

Figure 7 — Lowest temperatures ever observed in the United States (°F).

could not exist in such areas because of poor tolerance for low temperatures flourish in the vicinity of the Lakes.

DISTRIBUTION IN JULY

Let us now turn to the mean or average temperature distribution over the United States for the month of July, generally the hottest month, as shown in Figure 8. Note first the more uniform distribution of the isothermal pattern. Take a look at the 70° and 80° isotherms and track them as they traverse the country. A goodly portion of the United States falls between these two lines. Also the north-south temperature gradients are considerably less than during the winter. The change of temperature with latitude is now greatest in the central part of the country, where the temperature gradient from Duluth, Minnesota, to New Orleans, Louisiana, is approximately 1°F per degree latitude. Along the East Coast from Eastport, Maine, to Key West, Florida, the gradient is approximately 0.8°F per degree latitude. On the West Coast the temperature gradient is still smaller; from northern Washington to San Diego it is approximately 0.7°F per degree latitude. As indicated in Figure 8, most of this gradient occurs south of San Francisco.

As before, the effect of topography is evident in that somewhat cooler temperatures are experienced in the mountains of the East and particularly in the Rocky Mountains. The hottest portion of the United States occurs in the desert Southwest, where mean temperatures approaching 100°F are found in some isolated spots. Another interesting point is the extreme temperature gradient of the southwest coast. The immediate shoreline is quite cool in association with the cool ocean currents and the general west-to-east flow of air. The interior is exceedingly warm for several reasons. The rain shadow effect of the mountains causes the interior areas to be dry and support little vegetational growth. Hence little plant moisture is available for evaporative cooling. Also, because of the decreased amount of cloudiness, the sun's rays are allowed to strike unimpeded on the surface, producing the very warm temperatures. This sharp east-west temperature gradient results in the very great frequency of sea breezes.

Figure 9 indicates the pattern of the extreme isotherms of maximum temperatures for the summer. As with the mean isotherms, one is struck by the relative uniformity of the pattern. Most of the United States has had temperatures above 100°F. This is true except for a few isolated and exceedingly maritime areas, such as the coastal northeast in Maine, in the immediate vicinity of the northwestern Great Lakes, and the coast of extreme northwestern United States. As before, the effects of topography are evident in the deflection of isotherms due to the mountain areas and the modifying effects of the Great Lakes. Highest temperatures ever reached in the United States occur in the desert Southwest, where absolute maximum temperatures of greater than 125°F have been attained. In Greenland Ranch, California, a temperature of 134°F has been recorded.

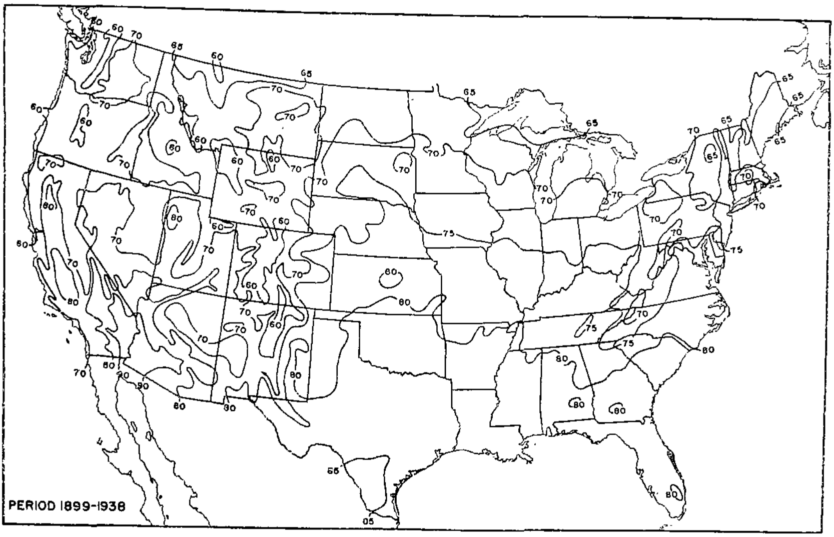

Figure 8 — Average July temperature in the United States (°F).

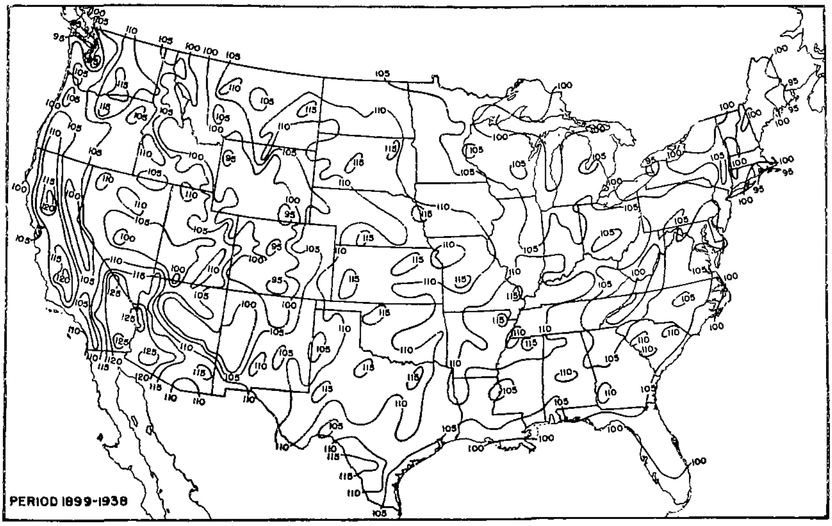

Figure 9 — Highest temperatures ever observed in the United States (°F).

PRECIPITATION

The second climatic parameter we will discuss is precipitation. Figure 10 shows the distribution of annual precipitation over the United States. This distribution is shown by the pattern of isohyets or lines of equal annual precipitation. The most remarkable thing about the precipitation of the United States, the eastern third of the nation in particular, is the abundance of well-distributed precipitation. The 40-inch isohyet which encompasses a land area with very adequate precipitation covers the southeastern third of the country. The 20-inch isohyet, generally taken as the dividing line between semi-arid and sub-humid types of climate, proceeds from central Texas, in a north-south direction, approximately along the 100th meridian before it enters into Canada.

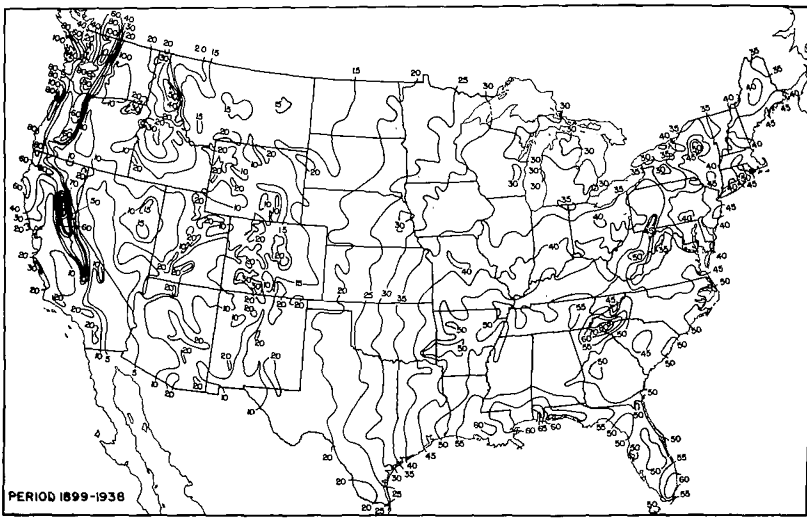

Figure 10 — Average annual precipitation in the United States (inches).

SOURCE

As indicated earlier, the main source of moisture for the greater portion of the United States is the Gulf of Mexico; the Atlantic Ocean is a secondary source. Evidence of these moisture source regions is seen in the general pattern of the isohyets which are oriented north-south in the central part of the country and east-west across the northeastern tier of states. Thus, the general moisture gradient is from southeast to northwest. This is further illustrated by the moisture differentials between selected points. For example, between St. Paul, Minnesota, and New Orleans, Louisiana, the precipitation differential amounts to 30 inches, indicating a pronounced decrease in precipitation from south to north. From St. Paul, Minnesota, to Eastport, Maine, the precipitation differential amounts to 15 inches; thus although precipitation increases from west to east, this increase is not as great as that from south to north.

GREAT LAKES

As we have noted, the Great Lakes have an important effect on the distribution of temperature in the immediate area; their effect on precipitation, however, is a minor one. Although, during certain portions of the year, particularly in the fall when cold air from the

Northwest traverses the warm waters of the Great Lakes and produces instability snow showers, the Great Lakes generally act as a very weak source of moisture. In fact, the stabilizing effect of the Great Lakes during the summer season, and the resultant inhibition of thunderstorms, usually reverses any tendency toward higher annual precipitation.

ROCKIES

Very evident in Figure 10 is the rain shadow effect of the Rockies. Air moving in from the West is forced to rise over the Rockies, and loses much of its moisture in the ascent; it descends exceedingly dry. Hence a great portion of the land immediately to the lee of the Rockies can support no major vegetation other than grass. Other orographic precipitation effects are seen in the various highlands of the East. For example, in northern Georgia, in the Catskill and Adirondack Mountains of New York, and the White Mountains of New Hampshire. The driest portion of the United States is the desert Southwest—in Nevada, southeastern California, and southwestern Arizona. The extreme aridity is due to the rain shadow effects of the Rockies acting in combination with other dynamic factors.

WEST COAST

The precipitation profile of the West Coast of the United States is interesting in that the precipitation gradient is reversed in comparison to those of the interior of the country and the East Coast. That is, precipitation is least in the southern portions and increases to the north. Two controlling factors determine this precipitation regime. One is the existence of a subtropical high-pressure system, with its associated subsiding and stabilizing air flow, situated off the southern California coast. This system affects the southern part of the coast to an extent, the effect diminishing to the north. The second factor is the ocean currents. The California current moves from north to south, allowing cooler water to be brought in, which further inhibits precipitation over the area. Furthermore, because of the rotation of the earth, the north-to-south-flowing current is affected by the coriolis force, which causes a net offshore transport of water. This allows cold bottom water to upwell along the immediate coastline, lowering the temperature of the surface water and adding to the general stability of the air immediately above.

PRECIPITATION REGIONS

Figure 11 indicates more adequately the seasonal distribution of precipitation on a month-to-month basis over the United States. Certain portions of the United States can be characterized by the similarity of precipitation profiles. Thus, the United States could be divided into some seven different areas that have similar precipitation regimes.

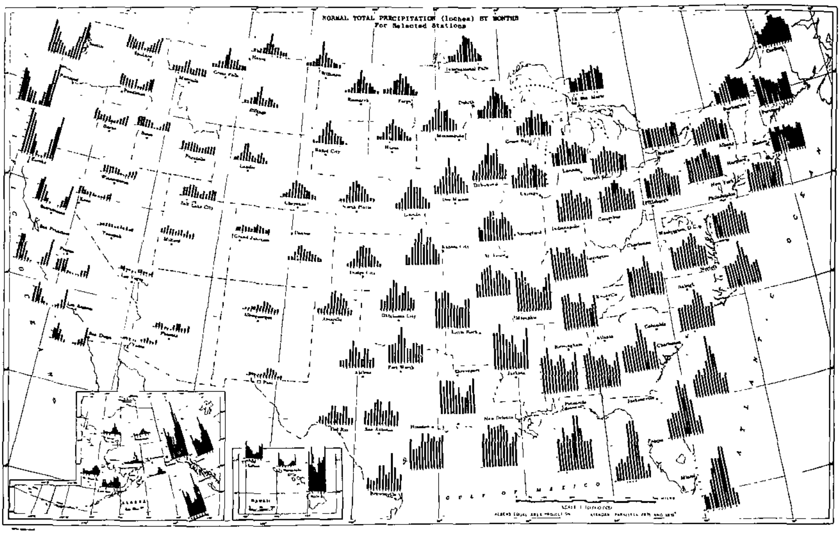

Figure 11 — Normal total precipitation by months for selected stations in the United States.

CENTRAL UNITED STATES

The first area, denoted as the central United States regime, includes Iowa, Minnesota, Missouri, and Wisconsin. This region is characterized by a single pronounced maximum of precipitation in the growing season (note the tendency in certain portions for a weak double summer maximum). In fact, 80 percent of the precipitation occurs during the time of vegetative growth, when precipitation is needed most. The summer maximum of precipitation is due to the depth of penetration of Gulf air with its associated moisture and thunderstorm activity. During the winter the prevalent cP air is dry, associated with surface anticyclones, and tends to inhibit precipitation.

OHIO VALLEY

The second precipitation regime is that of the Ohio Valley and vicinity. In this area a single precipitation maximum is still evident. In most cases it is equal to that of the central United States, the main difference being that there is more abundant precipitation in the winter season. Thus, while the general outline of the curve is similar to that for the central United States, the 'tails' of the curve are higher due to the resultant greater total precipitation.

NORTHEAST

The third distinct precipitation regime is found in the Northeast, including New England and New York State. Note the uniformity of the month-to-month precipitation. This abundant, well-distributed

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precipitation is due, as we have seen, to the convergence of the storm tracks over this portion of the country. This area may be further divided into the subregions. In one, along coastal New England, there is a slight tendency for maximum precipitation in the winter, as in Boston, Massachusetts, and Portland, Maine; in the interior and southernmost sections, although uniformity is maintained, there is a tendency for a summer precipitation maximum.

SOUTHEASTERN

Another general precipitation regime is the sub-tropical type located in the southeastern United States. This area is characterized by large total amounts of precipitation, in some places from 50 to 60 inches, with a pronounced summer maximum due to thunderstorms. Florida has an unusually high incidence of thunderstorms during the summer because of a double seabreeze effect. Since Florida is a peninsula, sea breezes are possible on both its Atlantic and Gulf coasts. When this double sea breeze effect is in operation, the air along the surface converges in the central portion of the peninsula. When this convergence occurs, there is no pluace for the air to go but up. As the air lifts, the vast amount of moisture available and the general high temperatures allow the formation of frequent heavy thunderstorms, resulting in the abundant summer precipitation.

TENNESSEE

Another rather distinct precipitation regime is the Tennessee precipitation type, which shows a pronounced winter precipitation maximum but also abundant precipitation during the summer. The high winter precipitation is probably due to local topographic effects and the relative closeness to the main storm tracks. Also the greater distance from the Gulf decreases the summer thunderstorms.

PACIFIC COASTAL

Turning to the far West, we have the Pacific coastal precipitation regime which is characterized by a strong winter maximum of precipitation and, perhaps more noteworthy, by the migratory nature of the time of maximum. In northern British Columbia and coastal Alaska, the wettest month of the year occurs in late October and November. As one proceeds south along the coast, there is a progression in the time of the precipitation maximum. In the southern British Columbia and Washington area the precipitation maximum is in December. Southward, in Oregon and northern California, the time of maximum precipitation is in January. In San Francisco, Los Angeles, and San Diego the maximum is further delayed, occurring from January through the end of February. The controlling factor is the migratory nature of the subtropical high-pressure system located off the coastal part of southwestern United States. In response to the seasons this high-pressure system migrates north and south, with its resultant effect on the precipitation pattern of the area.

ROCKY MT. AREA

The last general precipitation regime is in the Rocky Mountain area. This region is a transitional zone between the areas of pronounced summer maximum precipitation in the plains and the central United States and the noteworthy winter maximum along the West Coast. There is a general uniformity although not a great abundance of precipitation. In the southern part of the mountain regime, in Arizona, for example, there is a double precipitation maximum; a weak summer maximum associated with thunderstorms and air moving in from the Gulf of Mexico and a winter maximum associated with Pacific air and the movement of cyclonic storms across the region.

TEMPERATURE-HUMIDITY INDEX

Temperature and precipitation are directly measureable climatic elements and are important determinants of human activities. The temperature-humidity index or THI is a compound climatic variable, calculated from air temperature and moisture, and is directly associated with human comfort.

Values of the THI may be calculated with any one of the following linear equations; the choice of equation depends on the ease of its application to available data. The equations are,

1) $THI = 0.4\ (T_D + T_W) + 15$

2) $THI = 0.55\ T_D + 0.2\ T_{DP} + 17.5$

3) $THI = T_D - (0.55 - 0.55RH) \times (T_D - 58)$

where the dew point temperature (T_{DP}) is in degrees fahrenheit, as are the dry bulb (T_D) and wet bulb (T_W) temperatures. RH is the relative humidity in percent. Nomograms have been devised to simplify the calculation of THI data.

According to the developers of this index, when the THI reaches 70, 10% of the population will be uncomfortable; when the index passes 75, more than half will be uncomfortable; when it reaches 80, just about everyone will be uncomfortable. Figure 12 shows the distribution of the THI over the United States for the month of July and indicates areas of relative maximum, moderate, and minimum discomfort. The THI values are calculated from monthly mean values of temperature and humidity recorded at 12 noon, local time.

Regions of maximum discomfort occur in the south-central and south-eastern part of the United States; in the area to the south of the 80 isoline a combination of high temperature and humidity are the cause. Another area of maximum discomfort exists in the desert southwest, centered in southern Arizona. Here it is not the humidity, as the popular expression would have it, but the heat, at the time of observation, that causes the discomfort.

Much of the country lies between the 70 and 80 isolines, indicating moderate discomfort, with increasingly better conditions to

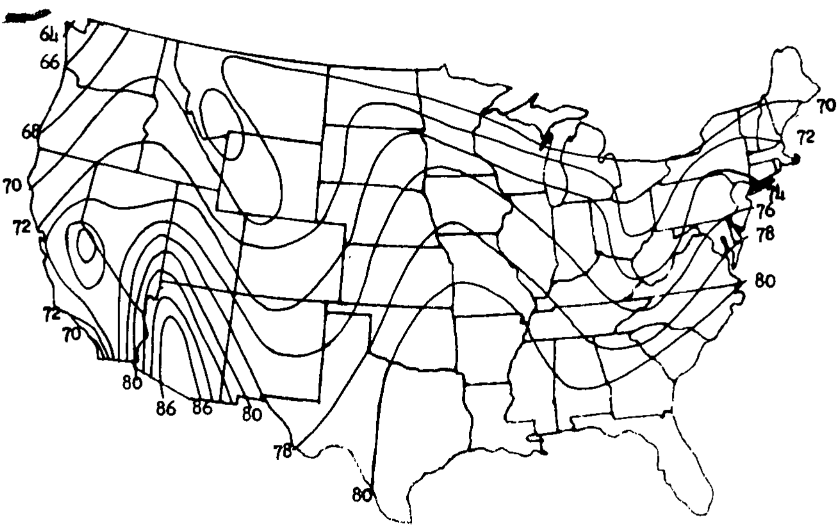

Figure 12 — Distribution of THI in the United States during July.

the north. Areas of "comfort" include the extreme northern portion of the United States, including a goodly portion of the higher elevations of the northern Rockies, much of the State of Washington, and the western half of Oregon. Not to be neglected, in all fairness, is the extreme coastal region of southwestern California. The 'comfort' of this last area may be due to the relative coolness of the offshore waters in association with the dynamic factors discussed earlier.

CONCLUSION

In concluding this discussion, I would like to reiterate my objectives. One was to discuss the main controlling factors of climate influencing North America, the United States in particular. These factors working together produce certain distinct climatic "types" that have no specific counterparts anywhere else in the world. The distribution of temperature and precipitation, often considered as the most important of the many climatic parameters, were evaluated in detail. The THI, a compound climatic element expressing the integrated effects of temperature and humidity of human comfort, was discussed. Its distribution over the United States for the month of July was presented and briefly analyzed. It is hoped that this presentation of the distribution and general pattern of these elements helps give a general picture of the climate of the United States.

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MICROCLIMATOLOGY

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SUMMARY

This discussion of microclimatology is concerned with the boundary layer of air where the earth's surface energy exchange is effective. In this area, which may vary in height from a few hundred feet to several thousand feet, the relationships of pressure gradient, coriolis effect of the earth's rotation, and wind speed and direction as expressed in classical principles do not apply. The microclimate is modified by various activities of man (e.g., crop-protection techniques of heating and windbreaks, construction of structures, and the build-up of urban areas) and by topography, including all variations in altitude and slope, however slight. Figures are given that illustrate the inversion temperature phenomenon, important in any study of air pollution.

INTRODUCTION

We have heard a great deal in recent years about efforts to modify the weather and climate. This subject has been abused in the press and in other writings perhaps more than any other topic in the field of meteorology. To be sure, some very interesting and very good legitimate research is being done in cloud physics and in other topics related to man's efforts to modify weather and climate. But we are certainly a long way from being able to influence or control the weather on a large scale. What is often overlooked is that we can and we do, practically every day of our lives, modify the microclimate, the small-scale atmospheric environment in which we live and work. I shall mention just three examples.

EXAMPLES OF MODIFICATION

Probably of greatest importance to agriculture are the efforts to prevent frost damage to crops, an ideal example of modification of the microclimate. The entire purpose of all types of frost-protective equipment or techniques,—whether they are orchard heaters, or wind machines or the flooding of a cranberry bog—is to modify the immediate atmospheric environment of the crop so as to prevent serious frost injury.

Farmers modify the microclimate in another way by erecting windbreaks. In contrast to the various methods of protecting a crop from frost, a windbreak has just the opposite effect. To prevent frost we often try to create wind—we stir up the lower layers of the atmosphere. When we erect a windbreak we do just the opposite—we reduce air movement. This creates a somewhat more excessive microclimate, but it also alleviates some of the unfavorable aspects of strong winds, particularly when accompanied by low humidity.

Whenever we erect a building of any kind, we modify the microclimate in the immediate vicinity. All of you are very familiar with the effects of a building on the immediate microclimatic environment. I have lilacs planted on both the north and the south sides of my house; this difference of exposure causes a difference of as much as 2 weeks in the date of blossoming of these lilacs.

One of the best experts on the effects of building and landscaping on the microclimate that I have observed was a pet cat. In the winter this cat invariably sought out a place that was protected from the wind and fully exposed to the sun; she seemed perfectly comfortable in temperatures well below freezing. In the summer the cat found the breeziest spots around the house, or stayed underneath the shrubbery, where the soil was moist and temperatures much cooler than in the open. Wild life of all sorts instinctively construct nests or shelters to alter the immediate microclimatic environment in a manner that is beneficial.

APPROACHES TO MICROCLIMATOLOGY

We can distinguish two different but closely related approaches to microclimatology. At Rutgers University, because of our affiliation with agricultural research, we are interested in what might be called the vertical viewpoint of microclimatology, closely aligned with the approach discussed by Dr. Geiger in his book "The Climate Near the Ground." Certainly the climate very near to the soil surface or near to the vegetative surface is quite different from that which we measure in a standard instrument shelter at a height of 5 or 6 feet above the ground.

If we are concerned with human microclimatology, the standard instrument shelter is quite useful for indicating the climate as it affects humans. This has been referred to as the horizontal view of microclimatology because in using these measurements made at a height of 5 or 6 feet above the ground, we record sizable differences in climate at nearby locations. Many other aspects of local exposure conditions influence the microclimate. Topography is the most obvious one. As Dr. Dill has indicated, there are tremendous atmospheric variations with altitude. But on a much smaller scale than the great heights that Dr. Dill discussed, the slope of the ground, the exposure with regard to surrounding buildings and trees—all exert a definite influence on the microclimate.

BOUNDARY LAYER

In this discussion of microclimatology we are dealing exclusively with the boundary layer of the atmosphere. I shall not attempt to put strict limitations on this boundary layer. Under certain circumstances it may extend upward several thousand feet. Under other circumstances the boundary layer, the layer in which the friction of the earth's surface influences the atmosphere significantly, may be limited to a few hundred feet. Whenever we talk about microclimatology, we are talking about this boundary layer in which the flow of the atmosphere is turbulent and in which nonadiabatic heating and cooling processes take place. These are points at which microclimatology departs from classical meteorology.

In classical meteorology, particularly when we deal with the free atmosphere above the boundary layer, we think of air flow as being almost entirely horizontal, and to a large extent this is true. We can mathematically describe the relationship between pressure gradient, the Coriolis effect of the earth's rotation, and wind speed and direction. The weather analyst and weather forecaster use these principles continually. In the boundary layer when we deal with turbulent flow near the earth's surface, these relationships become much more complex. Anyone who attempts to predict surface wind mathematically on the basis of the various forces involved is bound for frustration. Also in analyzing the stability of the atmosphere, the meteorologist deals with processes that are assumed to be essentially adiabatic, meaning that no heat is gained or lost from the surroundings. To a great extent the free atmosphere does fit this description. It is nearly adiabatic, and so we can use adiabatic principles in analyzing the stability of the atmosphere above the boundary layer. In dealing with the boundary layer, particularly the layer immediately adjacent to the ground in which heat is exchanged between the earth's surface and the atmosphere, nonadiabatic processes make all the difference. Our classical meteorological principles simply do not apply to this layer of the atmosphere.

Microclimates deviate most strongly from our standard climates during periods of fair weather with very little wind. Strong winds, which bring about a great deal of vertical mixing in the lower layers of the atmosphere, are quite effective in destroying microclimates. Weather reports during a period of stormy weather with extensive cloudiness and strong winds, indicate that temperatures over a large area are uniform. Changes from daytime to nighttime are very slight. The boundary layer of the atmosphere under these circumstances is greatly disturbed, mixing is good, and conditions are uniform. For all practical purposes microclimate is virtually eliminated under these conditions. In periods of clear skies with relatively light winds, microclimate is greatly exaggerated. At Rutgers University we are only 30 miles from New York City, and so we are keenly aware of the tremendous differences that can exist between the city and the suburbs. Minimum temperatures at the Agricultural Experiment Station in New Brunswick are often 20 degrees lower than those recorded in Central Park in New York City. And Central Park is much more exposed than some of the heavily built up areas in the city. In contrast, during periods of strong winds and cloudy skies the temperatures in New Brunswick and New York City may differ only 1 or 2 degrees.

SOLAR RADIATION

Dr. Geiger introduced the concept of active surface. Though somewhat of an oversimplification, it is a useful concept. Geiger described the active surface as the primary receiver of solar radiation and the primary emitter of terrestrial infrared radiation. Geiger conceives of this as the surface at which our radiative exchange takes place. I call it an oversimplification because we know that in forests or in other types of complex natural vegetation or crops one surface is not the primary receiver of solar radiation or emitter of terrestrial radiation. Many different surfaces are involved and the whole subject of radiative exchange at the earth's surface is very greatly influenced by the complex surfaces that exist.

In regard to human bioclimatology man has been modifying the active surfaces that influence our microclimate for a long time, and I'm afraid is doing so at an increasingly accelerated rate. An extreme example of this occurs when a park or woods or other natural surface is replaced by a flat black-top parking lot; the temperatures and the other aspects of the microclimate in that location are greatly altered. City planners should consider these matters thoroughly. One recent state-wide conference on city and regional planning lasted for 5 days and was attended by experts from all over the state. Yet not a single word was mentioned about climate or about air pollution. Microclimate and man's influence on it were completely ignored.

ATMOSPHERIC STABILITY

Meteorologists work with charts called pseudoadiabatic charts for analyzing the stability of the atmosphere. Lines on the chart represent the adiabatic rate of temperature change with altitude. If we force a layer of the atmosphere to rise, it will cool according to this adiabatic rate as long as it is the free atmosphere away from influences of the earth's surface. Similarly, if we force a layer of the atmosphere to subside or sink, it will warm according to the adiabatic rate of the temperature change, which is about 5.4°F per thousand feet. If the actual temperature lapse rate exceeds 5.4°F per thousand feet, the atmosphere will be unstable. Since any slight vertical displacement is capable of releasing this instability, it is extremely rare to measure in the free atmosphere a lapse rate greater than 5.4°F per thousand feet. When it occasionally happens, it does not persist because the instability very soon results in convection and vertical mixing, which realign the temperature distribution to a more stable condition. In the boundary layer of the atmosphere, however, where nonadiabatic heating takes place when the surface of the earth is being strongly heated by the sun, the temperature lapse rate often far exceeds our theoretical adiabatic rate of temperature change. If we were to plot the distribution of temperature from the surface of the earth upward, we would find an extremely rapid decrease of temperature upward (assuming clear skies and strong heating of the earth's surface by the sun) and then an alignment that more or less parallels the adiabatic rate once we get 150 to 200 feet above the earth's surface. Theoretically we cannot have a lapse rate of this kind for more than a brief instant because the atmosphere undergoes convection and realigns itself according to a more stable temperature distribution. Actually, we can measure a lapse rate of this kind in the lower few feet of the atmosphere on any bright sunny day with light kinds; heat is being added to the surface layer of the atmosphere more rapidly than it can be distributed by convection.

RADIATION

All the time that the earth is receiving solar insolation during the daytime, it likewise is radiating some of this heat back into the atmosphere and into space in the form of infrared radiation. As long as our radiation balance at the earth's surface is positive, this type of temperature distribution will prevail, with the surface layer of the air being strongly heated. When the sun goes down, our radiation balance changes signs. We have a negative radiation balance, and the earth's surface cools rapidly. The earth is still radiating its heat outward in the form of infrared radiation, but now nothing is coming in. The temperature distribution undergoes a drastic change, and temperature actually increases as we go upward through the boundary layer under these circumstances. This is an inversion of temperature, a reversal of the normal distribution. This condition, so important in air pollution, is not nearly so rare as some people believe. At the Brookhaven National Laboratory on Long Island the study of micrometeorology in relationship to diffusion of the atmosphere has been in progress for many years. Records of hourly temperature observations, 24 hours a day, 365 days a year, indicate that an inversion is present 44 percent of the time. Brookhaven has level topography. In areas with steep slopes and sheltered valleys, an inversion may be more common than the usual decrease of temperature upward. Later we shall see an extreme example, in which the persistence of a temperature inversion causes an inversion of the vertical stratification of vegetation on the slopes.

ILLUSTRATIONS

Figure 1 is a plot of the mean daily temperature range against wind speed. This figure shows a very clear relationship between wind speed and the daily variation of temperature, again illustrating the fact that strong winds tend to thoroughly mix the boundary layer of the atmosphere and smooth out temperature differences not only from day to night but from place to place. With light winds this effect of the active surface in heating the lower layers of the atmosphere in the daytime and cooling it at night has a much greater influence.

Figure 2, taken from Geiger's book "The Climate Near the Ground," is an attempt to illustrate the effect not only of buildings but also of dense forests in preventing the drainage of cold air down slope in areas of hilly terrain. These two examples illustrate effects of the natural and man-made environments on the microclimate.

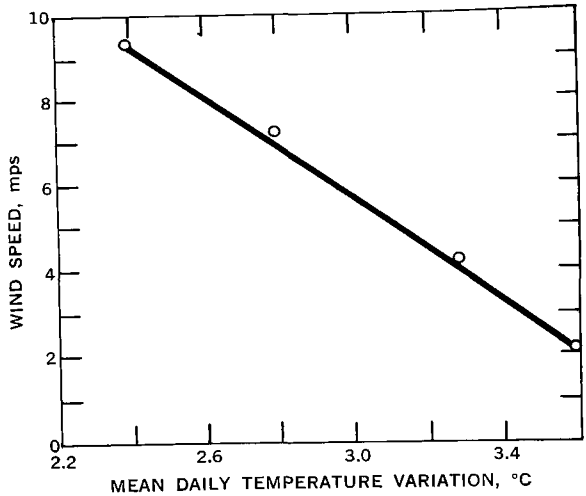


Figure 1 — Relationship between mean diurnal temperature range and mean wind speed on clear days. (After Geiger)

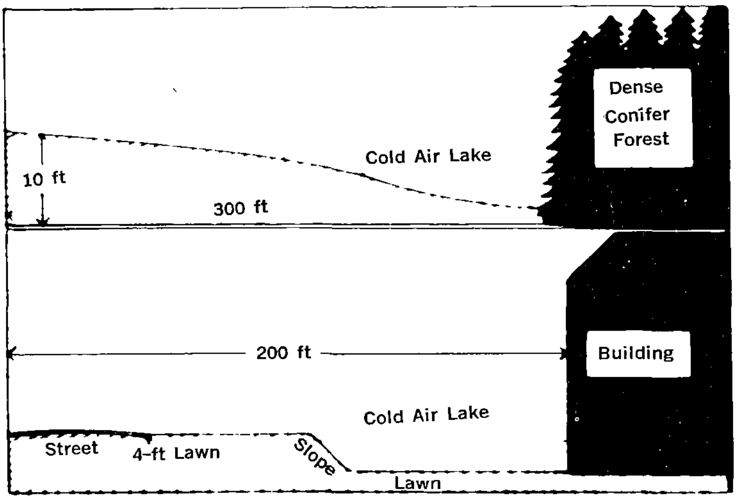


Figure 2 — Frost pockets created by natural and man-made barriers to cold air drainage. (After Geiger)

Figure 3 is another illustration along the same line but includes isolines of minimum temperature showing the increase of temperature with height, the typical nocturnal temperature inversion. In terrain of this kind farmers have long been aware of this effect, and it is a well-established agricultural principle that orchards and other crops that would be sensitive to frost injury or to low temperatures are never planted in the bottom of a valley but on the slopes, so that cold air can drain off. Temperatures usually do not go nearly as low on the slopes as they do in the valley bottom because of this effect.

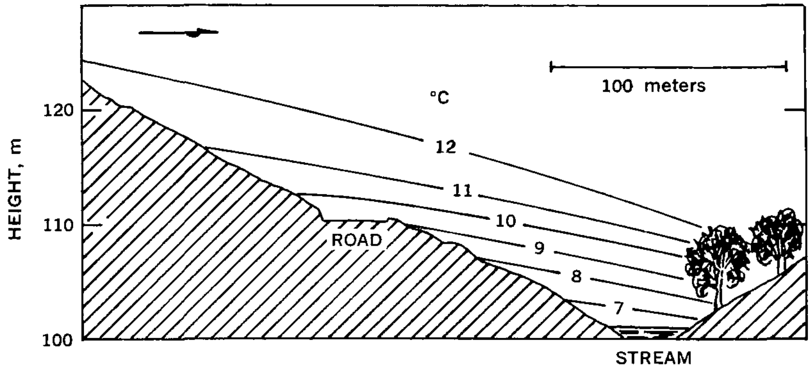


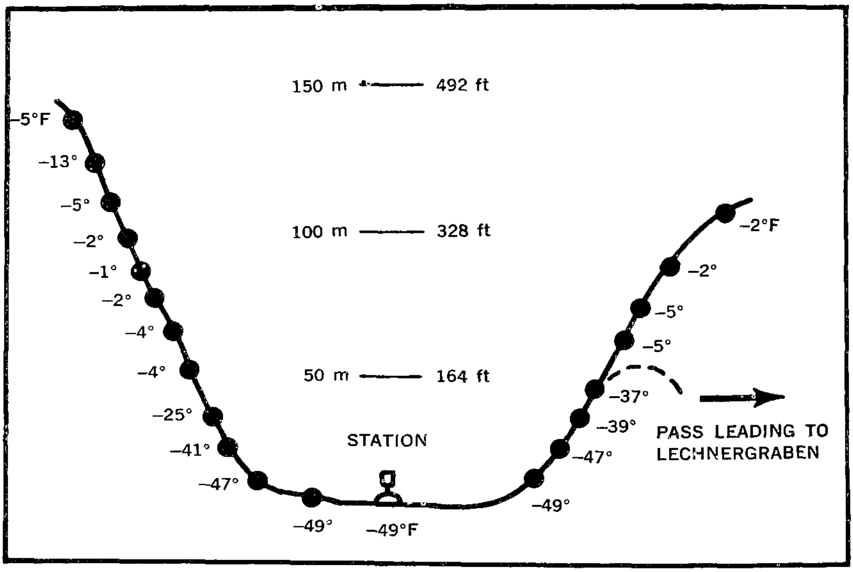
Figure 3 — Isotherms of minimum temperature showing characteristic nocturnal temperature inversion in valley. (After Geiger)

Figure 4 shows the alpine limestone cavity that I mentioned earlier. Here we see —5°F near the ridge and —49°F at the base of the limestone cavity. This is actually a timberline in reverse, where the vegetation at the bottom of the cavity is almost like tundra—herbs and grasses—and only as we go up slope where temperatures are warmer do we find trees.

Figure 5 shows a cross section of the Monongahela River at Donora. As you probably know, an extensive microclimatological survey of the Monongahela Valley at Donora was made after the Donora air pollution disaster. This is the average temperature distribution on calm days having relatively little smoke or pollution. You see a temperature decrease as we go upward in the valley. Under these circumstances convection and vertical mixing of the air would minimize air pollution problems.

Figure 6 shows the temperature distribution in the Monongahela Valley on a calm night with a very pronounced inversion. Temperatures increased about 6 degrees or more from the base of the valley up to the ridges on either side. Under such circumstances stagnation of the air in the valley is to be expected and eventually can lead to very serious difficulties.

Figure 7 illustrates the physical processes that result in drainage of cold air into low places in the terrain. Once a sink of cold air in a valley or in a pocket in the terrain is established, the temperature is eventually reduced to the dew point so that fog forms. Then the solar radiation, which we normally would count on to "burn off" our inversion and create convection and mixing the following day, is simply reflected off the top of the fog layer and so the inversion can remain throughout the day. At night (Figure 8) the fog layer acts as a radiative surface and we have further cooling due to the loss of heat by long-wave infrared radiation from the fog layer. Once this sort of thing is established, whether in the Monongahela Valley or in the vicinity of London, about the only correction for the situation is a major change in the weather, a system moving in with strong winds to clear up the problem.



CROSS-SECTION THROUGH THE GSTETTNERALM DOLINE

THE VERTICAL SCALE IS SOMEWHAT EXAGGERATED IN RELATION TO HORIZONTAL DIMENSIONS.

Figure 4 — Pronounced nocturnal inversion due to cold air drainage into Gstettneralm doline. Vertical distribution of vegetation is also inverted due to frequency, intensity, and duration of temperature inversion. (After Geiger)

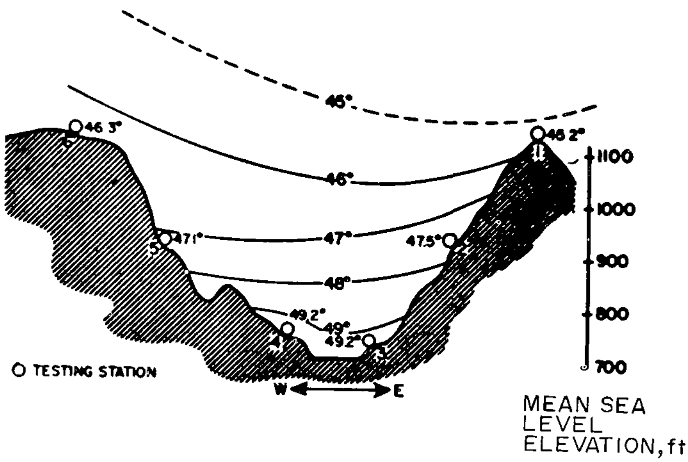


Figure 5 — Average temperature distribution across Monongahela Valley at Donora, Pa., on calm days.

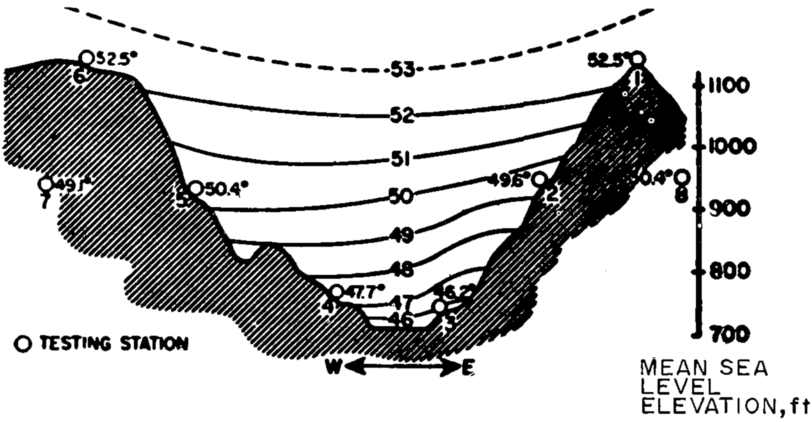


Figure 6 — Average temperature inversion in Monongahela Valley at Donora, Pa., on radiation nights.

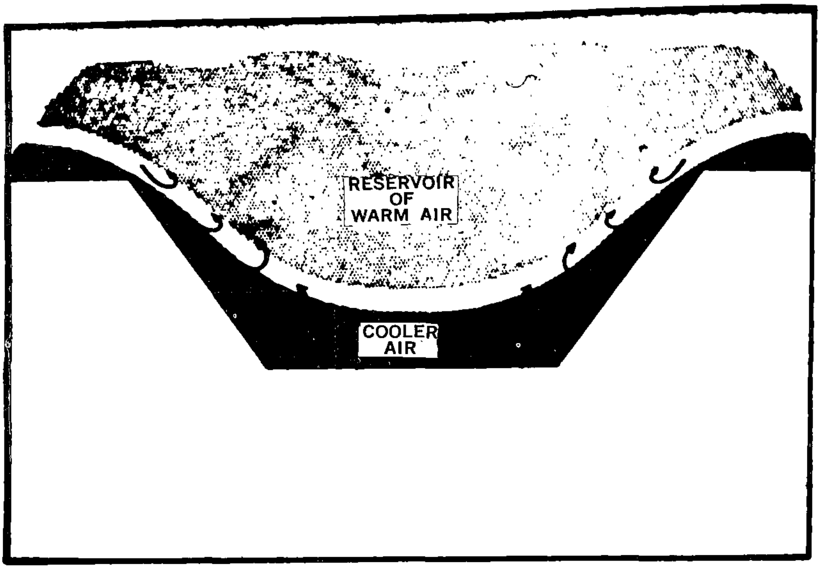


Figure 7 — Diagram of manner in which radiatively cooled air descends into valley.

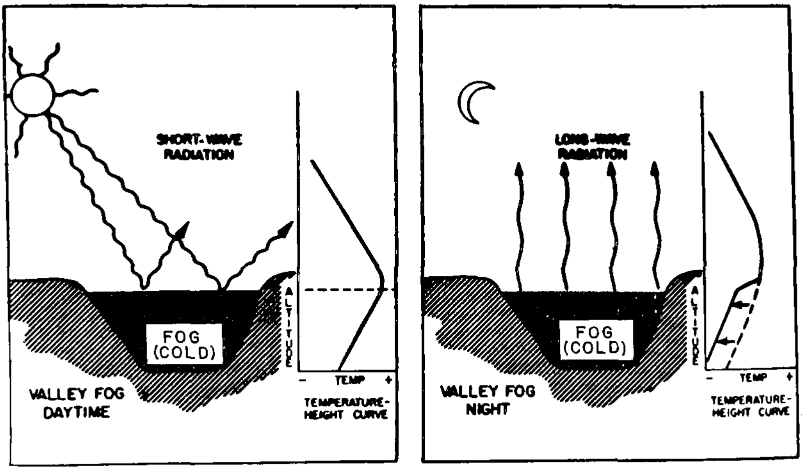


Figure 8 — Role of fog in maintaining atmospheric stability and stagnation in valley.

DISCUSSION

Question: What is the lowest inversion level that you could have under some of these conditions?

Answer: Usually the inversion begins to form right around sundown, or in winter perhaps even a little earlier. It develops upward as the night progresses. I think by sunrise with a clear sky and a light wind the inversion usually will extend upward a minimum of several hundred feet, sometimes as much as a couple of thousand feet.

Question: The reason I asked is that I've seen, particularly at sunset, levels 20 or 30 feet above the ground where the smoke levels off.

Answer: Right. At sunset or shortly after it is common for the inversion to extend upward only a few feet or maybe 50 feet or so. Above this you still have the normal decrease of temperature upward. If you observe smoke plumes and other indications, you can quite often see these effects. Under conditions of strong surface heating by the sun, this decrease in temperature upward sometimes becomes so extreme that peculiar refractions of light take place. The appearance of water on the road in summer is one such effect. And the fabled appearance of a mirage in the desert is another effect of this extremely sharp decrease in temperature upward immediately above the earth's surface, which is being strongly heated by the sun.

Question: You mentioned this meeting of city planners. If you had your micrometeorological druthers, what would you advise the city planners on where to build their cities or their developments within cities?

Answer: This isn't an easy task, but certainly some attention to the microclimate in planning is far better than simply ignoring the problem. We should consider both the microclimate of the immediate vicinity in relationship to terrain and also the large-scale aspects of the microclimate. Certainly to put the stockyards upwind from the residential section, as has happened in certain cities in this country, is not very good planning. We know a lot about the prevailing winds in various parts of the country. The Weather Bureau has enormous amounts of climatological data at the National Weather Records Center at Asheville. Summaries of these data are available, and planners could have ready access to this material. We know less about the microclimate in and around many of our large cities and other urban and suburban areas. But even without measurements, qualified meteorologists should be able to give qualitative estimates of microclimatic effects on the basis of terrain and other features. With a little bit of effort some data could be collected to put some of these estimates on a quantitative, rather than a strictly qualitative basis.

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THE NATIONAL WEATHER RECORDS CENTER

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SUMMARY

The National Weather Records Center (NWRC) provides central storage of weather data in punched card or microfilm form at Asheville, North Carolina, (the equivalent of about 450 million punched cards processed as card decks) and includes data from the Meteorological Rocket Network and from the first atomic-powered automatic weather station at Sherwood Head, Canada. Available to anyone at the cost of reproduction (microfilm, photocopy, Xerox, microprint, etc.) are data in the form of hourly, daily, and monthly summaries giving information on solar radiation, winds aloft, radiosonde significant levels, and absolute humidity.

INTRODUCTION

During World War II years it became apparent to all those who were dealing with climatology or meteorological research that a central locale for the storage of weather data really was needed. In those days if a man wanted some weather data for his research, he wrote to the meteorologist in charge of a weather station; if the records were there, the meteorologist in charge might or might not send them out. As research goes on, records sometimes become misplaced and are not returned. At Washington National Airport, 3 months of records are missing from the permanent files. The data were needed to study a special storm situation. These were never returned and now are forever lost to our nation's records.

During the war years the New Orleans group, which was then called the New Orleans Tabulation Unit, wrote to all the weather stations to get data for wartime studies. They encountered the same problem. As a result of that experience and through the developing meteorological research facilities of the Weather Bureau, the Air Force, the Navy, and universities, it became apparent that a central locale was needed. In 1948 officials started looking for a place, and in 1951 the site in Asheville became available.

ESTABLISHMENT OF CENTER

The General Services Administration delegated to the U. S. Weather Bureau the responsibility to archive the weather reports of the U. S. Weather Bureau, the Air Force, and the Navy, and any other national weather records that could be obtained. With considerable help from the Air Force and the Navy, both financial and physical, the U. S. Weather Bureau established the National Weather Records Center in Asheville in 1951 and 1952.

The National Weather Records Center (NWRC) is housed in a Federal Building formerly known as the Grove Arcade. The NWRC is within 24 hours reach from Washington by most modes of transportation. It is within 24 hours reach from the major cities of the U. S. by plane. Many of our requests are from lawyers who need weather records or certified facsimiles for accident cases. Usually the records are on the way to the requester within an hour or two after he calls. If the airlines are operating he usually has them within 24 hours.

The Federal Building is located in downtown Asheville. It covers half an average city block and averages four stories in height. The space totals about 225,000 square feet, of which about 165,000 is usable. The files contain some 100,000 cubic feet of original records and publications, several thousand reels of magnetic tape, and the equivalent of about 450 million punched cards. The millions of punched cards are handled systematically by assigning deck numbers to cards having like format and content. Some 350 card decks are now available for use in processing of data. Some decks have become obsolete and have been destroyed. We also have foreign data cards.

CAPACITY

The total card volume at Asheville has been greater than it is now. But right now storage of the cards requires a row of filing cabinets one tier high and almost 2 miles long. If all the trays of cards were laid end to end, they would extend 50 miles. Through transfer and microfilm reduction, we have reduced our card holdings in Asheville to 350 million cards. If we had not reduced our storage, we would have almost 600 million cards, all occupying precious space.

We receive copies of punch cards from the Meterological Rocket Network. The handling of the weather satellite photographs and of radiation measurements is under continual development. We also receive magnetic tapes from the satellite observations.

The NWRC has operational responsibility for the Meteorological and Nuclear Radiation data for World Data Center A, initiated under the International Geophysical Year, and has on file records from the first atomic-powered automatic weather station at Sherwood Head, Northwest Territory, in Canada.

New sensors and recording methods will continue to appear. As they appear and give new types of records, we will have to develop new types of storage and servicing. We hope to keep pace with this changing input of data and to provide support to persons interested in meteorological research. Scientific measurements do not lose their value with age, as do cancelled checks, administrative forms, and inter-office correspondence. No one can predict when any of these records will be much in demand. A speech at a convention may spark a lot of ideas. These ideas develop in men's minds and the researchers begin to call for data. We may have to go back 50 years for data from some locale, and face a sudden demand for records that have not been called for or used in decades.

RECORDING TECHNIQUES

The NWRC now uses the FOSDIC machine—the Film Optical Sensing Device for Input to Computers. This is our best hope for keeping ahead of our space problem. Using two filmers, we have placed approximately 130 million punch cards on microfilm. We microfilm these cards with the holes in them on 16-mm microfilm. Each 100 feet of film contains 12,000 card images, 12 to the inch. The microfilm reduction is better than on magnetic tape. It is also much cheaper, because magnetic tape must be updated at least every 3 years because of the magnetic image transfer between layers of tape wound on the reel. So we use the microfilm as a positive type of storage that can be easily duplicated by making copies. Copies of these microfilm records are being stored in salt mines and other places where they will be safe from catastrophe. Use of microfilm is a relatively cheap way of storing data. I say "relatively" cheap because all of these methods are expensive since the magnitude of data storage is so great.

The horizontal reduction of these cards is 24 to 1, and the vertical reduction is 44 to 1. That reduction permits us to place an image of that punch card in 1/12th inch of space. Four card trays—trays about 2 feet long and 8 inches wide, each containing 3,000 cards (a total of 12,000 cards)—can be placed on one reel of 100 feet of microfilm. This film reduces to a box 1 by 4 by 4 inches and weighs only 4 ounces.

You may ask why we microfilm these cards, since it would be difficult to read them through a lens system. But we do not read them through a lens system by eye; we read them by means of a cathode ray follower. We can recover the cards through this optical reader, the FOSDIC reader. The punch card contains 80 columns and 13 horizontal rows. The reader can search 10 columns at a time at a rate of 4,000 cards per minute and select those cards that have the pieces of weather information that you want to use. New cards can be punched at a maximum rate of 100 per minute. Equipment that will provide a faster recovery rate is under development through a coordinated program with the Census Bureau, the Bureau of Standards, and the Weather Bureau. The reader will read 8,000 cards per minute, search 10 columns, identify the columns, and check for accuracy of punches. It will do all of this at 8,000 card images a minute and transfer 2,000 of these to magnetic tape, which then can be transferred as a working medium into computers.

We have many types of cameras at the NWRC to reduce our original documents to microfilm. We save all documents, since every piece of government paper is government property and becomes a part of the archives of the records of the United States. Before we can destroy a weather record we must obtain Congressional approval, and to do this we must show that we have not lost the record. About the only way we can do it is to microfilm the records. One of the cameras under development will photograph a continuous flow of forms once you've set the camera and the stages for the same type of forms—for example, rain gauge charts or wind records. It will handle these forms like a printing press and run them onto a table, place them in position and automatically photograph them. The film used in this camera is 70 mm wide and comes in 100-foot rolls. These can be left in the roll or chopped into 3 by 5 negatives and stored like microcards, which then can be reproduced in negative form or positive form.

COMPUTING FACILITIES

The computing facilities of the NWRC are headed by a Honeywell 800, a parallel processing machine that is module designed. As the requirements increase, the memory and capacity of this machine can be upgraded by adding more memory blocks or by adding peripheral equipment. The system can process eight jobs at a time. The only restriction is that we can't use the central memory on more than one job at the same time. For example, we may have a large scientific job that requires many computations. We can do card editing, tape editing, and punchout, and printing of other jobs on the side while the central memory works on the scientific job. As soon as it's through with one phase of the job, the central memory flips over to another job. At present we only have four of these input devices, but the system can handle eight if we add four more sets of peripheral equipment. Of course. all of these are supported by other types of electrical accounting machines, such as sorters, collators, tabulators, reproducers, and the electronic calculator.

DATA DESCRIPTION

I have tried to give you some ideas of the physical building and the equipment in the building. Now I want to discuss in more detail some of the types of data that are available to those engaged in research.

First of all, the punch card can be considered only as working media. These are not original records, although in some cases these constitute our only holdings of data. For example, we may have received cards from some foreign government on an exchange basis or by trade, in dollars. The German marine deck—about 7 million cards—was purchased in 1952-54, when we initiated the Marine Atlas program for the U. S. Navy. These, of course, constitute our only holdings of data of that type because the original manuscripts are still held in the archives of the German Naval Weather Service.

PHOTOGRAPHIC IMAGES

Original manuscript forms or some reduction of these to photographic images constitutes our main source of data. These are available to anyone at the cost of reproduction, which may be in the form of microfilm, photocopy, Xerox, microprints, microcards, or other type. For forms that use color, such as adiabatic charts for the upper air data, microfilm techniques certainly do not do the job we would like to do. And the adiabatic charts contain so much information that reduction by microfilm loses some of the detail.

PUNCHED CARDS

The punched cards constitute our second largest mode of data storage. About 350 card decks have been documented and a reference manual prepared for each one. The reference manual lists every column in the card and describes the codes used to place data in those columns. Wherever possible we try to give further information about the data. For example, in the coding of inversions we try to draw diagrams for people who will use the data. Since the reference manuals sometimes omit needed information, we must often revise or supplement the reference manual.

Each project requires considerable time and care to develop a reference manual.

Many people want to buy cards for use with a computer in their own organization or one available by contract with a service organization. But about half of the people who purchase cards for their own processing run into difficulties with the coding. These X overpunches can mean many, many things.

Not everyone who prepares cards for weather data will handle certain peculiar problems in the same way—problems such as the indication of minus temperatures or of wind speeds higher than 100 knots. Also, the presence of a space for a weather element on a card does not guarantee that the element will have been observed and recorded at a specific station at a specific time. The reference manual cannot tell you whether the data are there, only that the card has space for such an observation if it was made and recorded. Then too, since changes in operating procedure entail changes in coding procedure, such changes must be carefully watched for in programming for the punched cards.

Let me give you an example of the programming complexities caused by changes in the operation of weather stations. The example concerns the reporting of upper-air data. At different times in recent years wind speeds have been reported in meters per second, in knots, and in miles per hour. Wind directions have been reported at 8, 16, and 32 points of the compass and are now reported in degrees. These changes in reporting procedures were made on different dates. In researching upper-wind data through the years, therefore, you must be aware of the modes of reporting so that you can perform any conversions required to produce data in uniform or comparable units. We know that operating procedures are determined by meteorologists for their professional purposes; considerations of data-keeping are secondary. Our job, then, is to adjust to the changes and to keep the cards and programs current.

CONCLUSION

It would be difficult to describe to you the many and diverse kinds of weather records that are available. We have decks that provide daily summaries, monthly summaries, hourly records of solar radiation, winds aloft data, and, for those who are interested in air pollution, a deck of radiosonde significant levels that gives information on inversions. For biometeorologists the records of absolute humidity (mass per volume) are of interest because the lung is a volumetric machine. Data on absolute humidity have been used in polio investigations. These can be backed up by data on other humidities: relative humidity, specific humidity, and mixing ratio.

All of these and many other potential sources of information are available to you. I hope I have given you some idea of the magnitude of the operation at Asheville and of what the National Weather Records Center offers to aid in your research.

DISCUSSION

Question: How do you indicate the geographical area to which the data apply?

Answer: We use the international block system. It is a grid system on the map that has been arbitrarily fixed by national and international boundaries. For marine data, the 10-degree squares called Marsden squares are broken down further into sub-squares of 5 degrees, and then down to 2 degrees and 1 degree, and further on down to tenths of degrees in some cases for the ocean areas. For continental areas we use an initial block number.

Question: And these are your own maps, not the U.S.G.S. maps for the transverse Mercator projection?

Answer: These maps are developed and agreed upon by the international World Meteorological Organization.

Question: How does one obtain the reference manual that tells of your card formats and the changes?

Answer: Well, first you must know what reference manual you want. We don't send these out to everybody. We use them more as an inshop work manual. Many people and organizations do buy data in cards, and when they buy them we send a reference manual. We have 350 active decks now, and that means 350 reference manuals. If you want to know what's in the cards and you know that a reference manual is available, then we would send that to you for study along with a sample card. We have had people ask us for a copy of every card and reference manual made. We asked them if they would pay the shipping costs; when it turns out to be $100.00, they say, "No, thank you."

Question: We have a little bit of difficulty in finding the Asheville code number for meteorology stations. Is there a list of these code numbers available?

Answer: Yes. There is a code manual for that. This manual is kept current with the assignment of new stations and with the assignment of new code numbers. This code manual is not exactly a publication. It is a work listing which is kept up to date at the National Weather Records Center. Relatively few copies of this listing are available outside of Asheville. The reasons for this are that there are frequent additions of stations to the listing, and that these numbers are peculiar to the processing operations at Asheville—they are not used in any other sense in the meteorological circle. This is not the international index number assigned and coordinated by the World Meteorological Organization. This is purely a work number, and therefore it is a work manual. We discourage requests for copies of this manual. Whenever we send a listing of data run from our card decks, if there is no literal identification of the station by name on each page of the listing, the station is identified by its number. We send a flysheet that translates the number to the name of a station, so that the stations are identified. When you purchase copies of cards, however, we send some descriptive material so that you can identify the particular number of a particular station.

SOME EFFECTS OF WEATHER ON MORTALITY

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SUMMARY

Temperature is the most significant meteorological parameter in the study of mortality and weather. Studies have shown (1) a general inverse seasonal relationship between temperature and death, (2) an identifiable seasonal response in all age groups except age group 1 to 25; (3) significant correlations between total monthly mortality and average temperatures for winter and summer months, but not spring and fall; and (4) significant correlation in data from studies using "heat-death-line" and those using "temperature-humidity-index" criteria. A study of 17 periods from 10 summers of record in New York revealed a significant increase in mortality following a hot spell and/or severe fluctuations in weather.

INTRODUCTION

The material presented here is based on graduate work(4) done at Rutgers University in 1959. The initial study included 9½ years of statistical data on New York City mortality by age groups. These data were recorded on a daily basis by the Department of Health, City of New York, for the date on which the death actually occurred, beginning in June 1949. This symposium has provided the incentive to obtain subsequent data for comparison with the various regression analyses determined from the developmental data.

WEEKDAY VARIATIONS

The data were examined initially to determine whether there were any significant weekday variations that should be taken into account before making correlations with meteorological statistics. Table 1 presents the average weekday mortalities by age groups. These are nearly identical except for the Sunday minimum of 219.1 and the Monday maximum of 227.4. Since meteorological studies have not yielded any statistically significant 7-day periodicities, it was concluded that the Sunday mortality minimum and the Monday mortality maximum were attributable to sociological rather than meteorological factors. Further, neither the maximum nor the minimum was significant at the 5 percent level selected as a measure for statistical significance. For the purposes of this study no weekday corrections were required.

Table 1. AVERAGE DAILY MORTALITY

Age group	Sun.	Mon.	Tues.	Wed.	Thurs.	Fri.	Sat.
1	10.8	11.0	11.1	10.9	11.5	10.9	11.2
1-4	1.6	1.8	1.8	1.6	1.7	1.8	1.8
5-14	1.3	1.4	1.4	1.4	1.5	1.4	1.4
15-24	2.3	2.3	2.1	2.3	2.3	2.3	2.5
25-44	16.2	16.7	16.5	16.2	16.4	16.4	16.8
45-64	72.9	77.6	73.8	74.0	73.8	73.7	74.1
65-over	114.1	116.6	115.1	114.5	114.7	114.7	113.3
Total	219.1	227.4	221.8	220.9	221.8	221.1	221.0

SEASONAL RELATIONSHIPS

Gordon and Ehrhardt(2) indicated the general inverse seasonal relationship of temperature and death, illustrated in Figure 1. For comparative purposes I have also included in Figure 1 the annual total mortality and annual normal temperature curves for Los Angeles and Cincinnati. Tromp(6) has shown the same seasonal relationship in curves for mortality from angina pectoris, coronary thrombosis, and other arteriosclerotic heart diseases and from chronic endocarditis among males in the Netherlands in the years 1953-1958, inclusive.

The annual mortality curves for each of the age groups are given in Figure 2. These curves may be divided into two separate and distinct categories: those that exhibit a pronounced seasonal trend and those that exhibit no readily identifiable seasonal response. This seasonal response is evident in the infant category, disappears entirely in the age groups from 1 to 24 years, reappears in the group from 25 to 44 years, and becomes more pronounced with increasing age.

Since the seasonal mortality trend is evident in the infant group but disappears entirely in the next three age groups, it was at first suspected of being a pseudoclimatic effect, perhaps due to a corresponding seasonal difference in birth rates. This, in turn, would give rise to a corresponding seasonal variation in infant population and hence also in infant mortality expectancy. The birth-rate statistics for this period failed to indicate any significant seasonal trend, however. It, therefore, appears that the seasonal mortality response among the infant population is an indirect effect, due to colds and other infectious diseases passed along to the infant from susceptible adults. This would also account for the disappearance of the seasonal trend after infancy.

The top panel of Figure 2 shows a pronounced change in the mortality curve between the 1900-1911(3) and current data. The very pronounced secondary maximum in July in the earlier data disappeared entirely in the later data. Examination of New York mortality statistics following the turn of the century indicates that this secondary maximum was contributed by the younger age groups, especially those in the 1- to 4-year category. This summertime maximum is an example of "Suedosaisonkrankheiten" (pseudo-seasonal illnesses) mentioned by De Rudder(*1*). It was attributed to stomach and intestinal disorders resulting from food spoilage due to lack of adequate refrigeration during hot weather—an indirect influence of weather on mortality. This secondary maximum was eliminated with the subsequent availability of pasteurized milk and with adequate refrigeration as modern electric refrigerators replaced the less adequate "ice boxes."

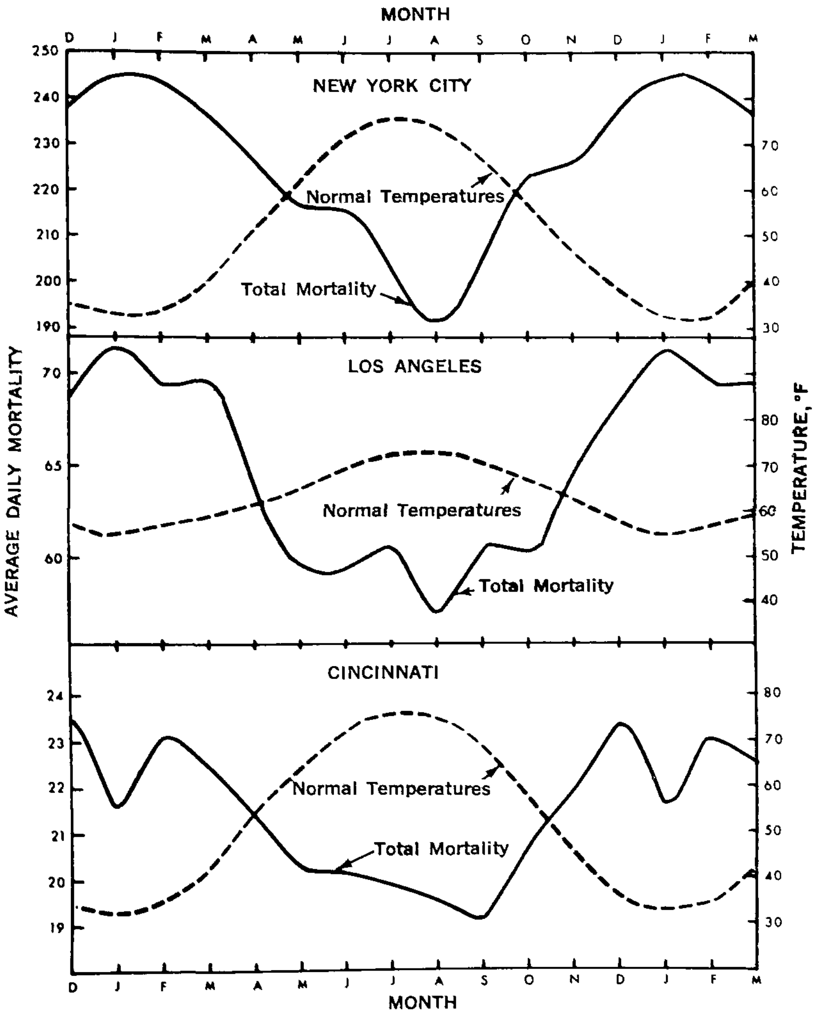

Figure 1 — Annual mortality curves for New York City, Los Angeles, and Cincinnati.

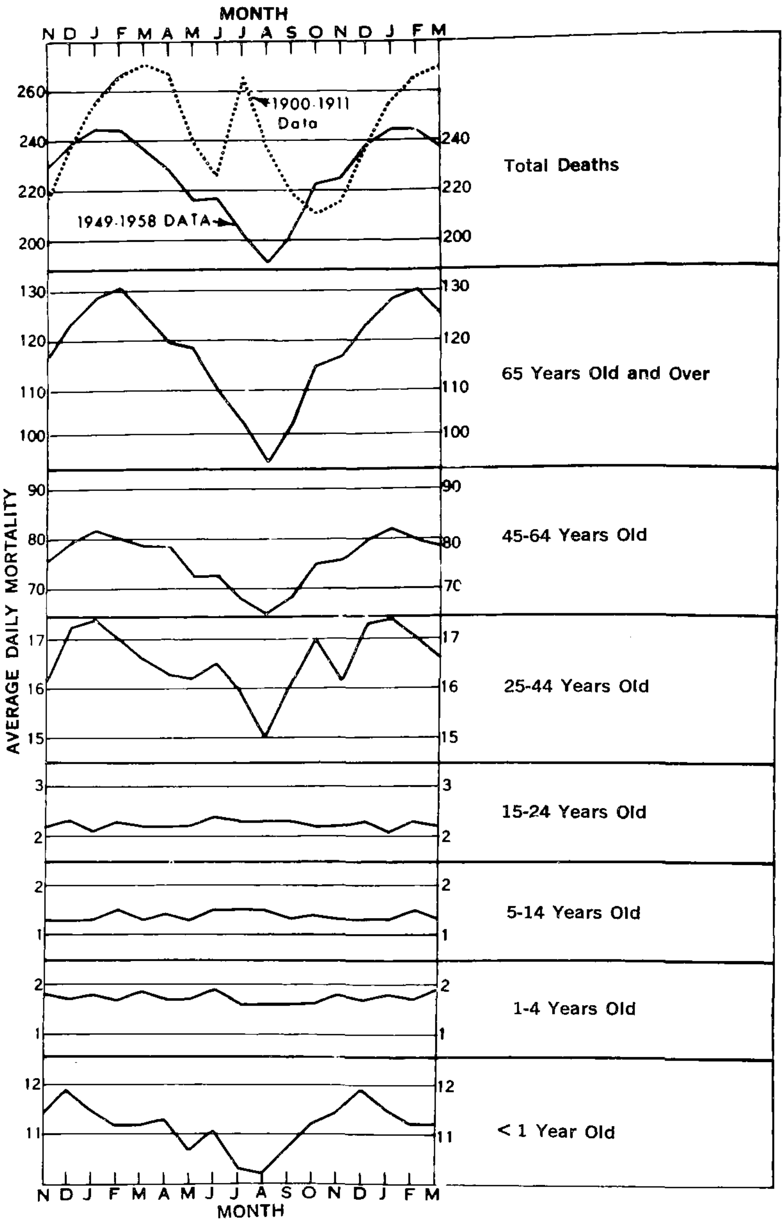

Figure 2 — Annual mortality curves for all age groups.

EFFECT OF ETHNIC BACKGROUND

Since June 1952, the New York City mortality statistics have been further subdivided into white and non-white categories. This gave an opportunity to consider whether the color of one's skin or ethnic background might have any bearing on his reaction to weather and severe changes. The respective curves for the seasonally responsive age groups are shown in Figure 3. There are no significant differences in the characteristics of the two sets of curves. Neither were there any detectable differences in reaction to hot spells, as shown later.

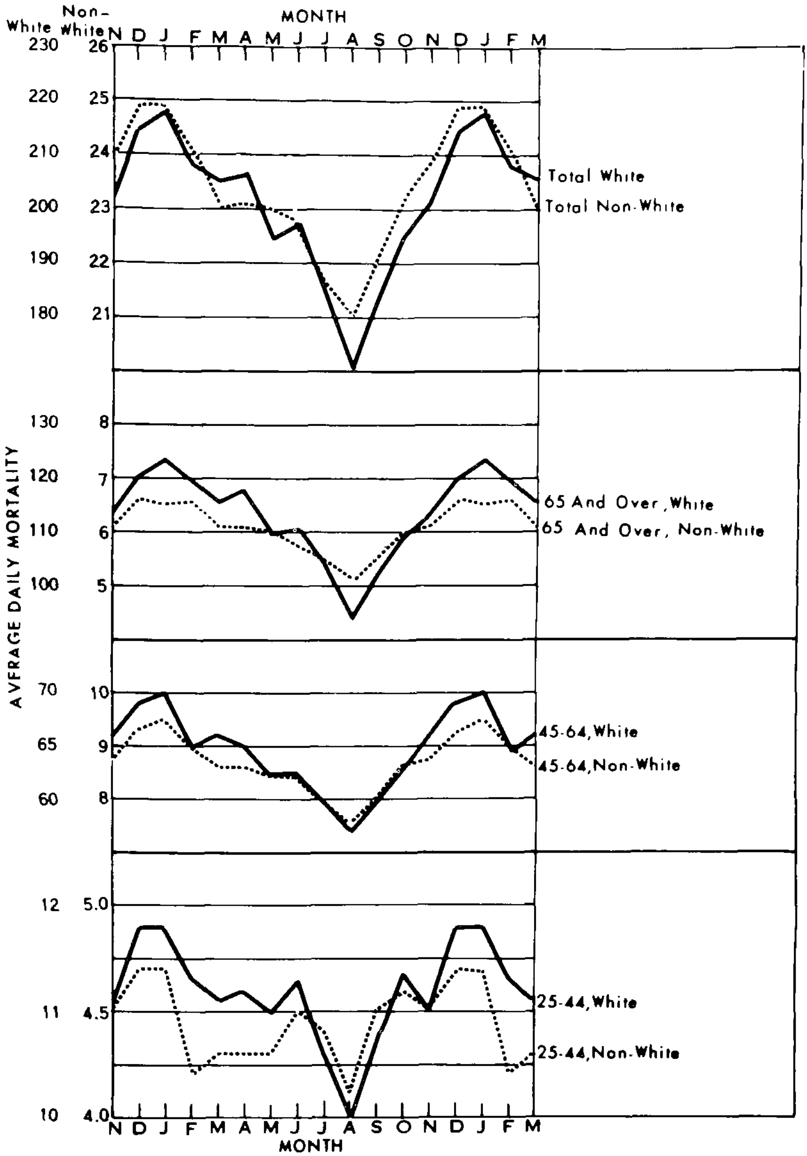

Figure 3 — Annual mortality curves for white and non-white.

Maximum mortality in the white group, however, occurs at age 65 and over, whereas in the non-white group it occurs at ages between 45 and 64. This shorter life expectancy among the non-whites has been attributed to sociological factors and to environmental factors other than meteorological. Accordingly, no detailed effort was made to explain it from a meteorological standpoint.

COMPARISON BY MONTHS

Next, total monthly mortality and average temperatures for the same months were compared. As might be expected from Figure 1, no significant correlations are evident for the spring and fall transition periods but significant correlations are found for the winter and summer months. Computed correlation coefficients for the susceptible age groups and for significant months are given in Table 2. Months with a high incidence of influenza were excluded from these computations on the basis of being outside the "normal" population under study. Note the very high correlation coefficients for December (minus 0.74) and for January (minus 0.96). The latter is significant at the level of 0.1 percent.

Table 2. MONTHLY MORTALITY AND AVERAGE TEMPERATURE, CORRELATION COEFFICIENTS

		Age group							
		25-44		45-64		65-over		Total	
Month	d.f.	r	%	r	%	r	%	r	%
Jan.	8	0.859	1	0.509	—	—0.933	0.1	—0.958	0.1
June	9	0.196	—	0.583	6	0.257	—	0.670	5
July	9	0.317	—	0.581	6	0.384	—	0.673	5
Aug.	9	0.206	—	0.306	—	0.144	—	0.541	—
Dec.	8	0.342	—	0.232	—	—0.568	7	—0.740	2

d.f. = degrees of freedom
r = correlation coefficient
% = level of significance
— = > 10%

Figure 4 shows the computed regression curves. The individual dots represent the 1949-1958 data, which were used in developing the regression equations. How do the mortality figures for 1959 through 1963 fit the regression curves? These independent data points are shown on the graphs as crosses.

The independent data for December and January show approximately the same slope as the regression curves based on the earlier data, but displaced upward by a significant amount. A noteworthy exception is the one January value that appears to be completely out of control. It was at first suspected that this extreme value might be due to a high incidence of Asian influenza. Although this did not qualify as an "influenza month," the incidence of other respiratory ailments was very high. Such ailments are suspected of being weather-related to the extent that the stability of the lower layers of the air governs the concentration or dispersal of airborne irritants and pollutants. The relationship is much more complex than the simple temperature-mortality relationship examined here. The governing meteorological factors are well known, however, and provide the basis for the air pollution potential forecasts performed by the Weather Bureau in cooperation with the Public Health Service.

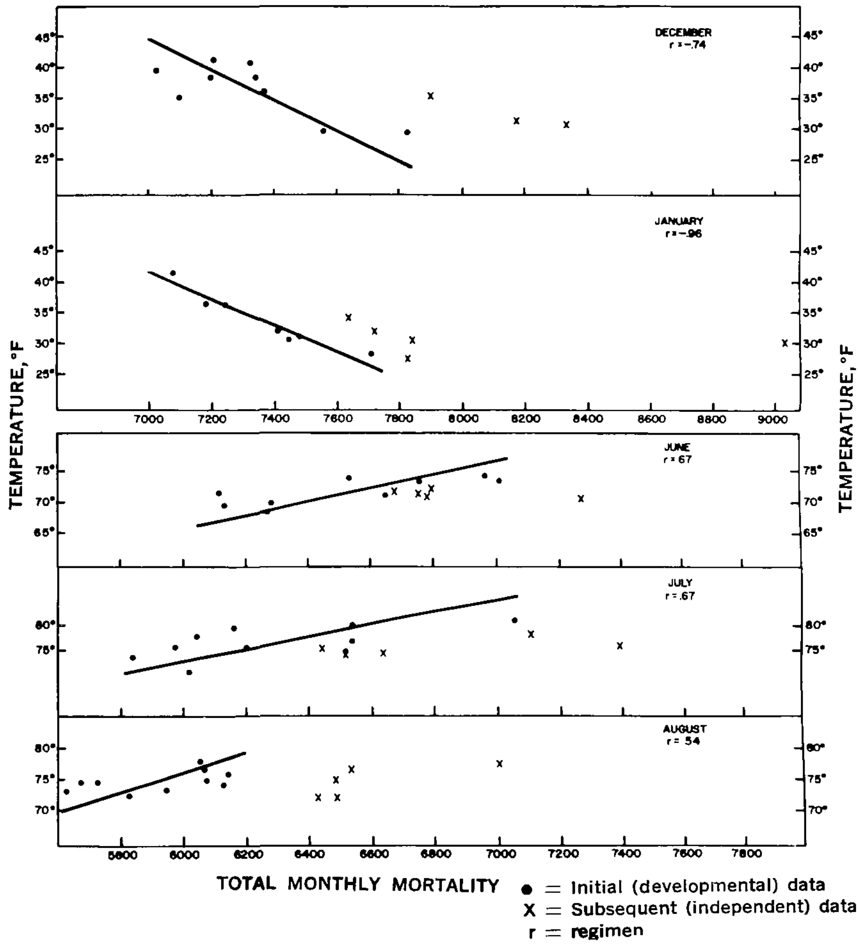

Figure 4 — Regression of total monthly mortality on monthly average temperature.

The apparent upward shift in the January and December regression curves is readily accounted for on the basis of a gradual increase in life expectancy during recent years. This has resulted in a gradual increase in the population of the 65-and-over age group, in which the highest mortality occurs. The downward shift of the independent data for June through August, though not as pronounced (since the correlation coefficients were not as high), is similarly explainable.

DAILY TEMPERATURE VARIATIONS

The temperatures on which these correlations were based were averages for the month. Still another test was a comparison of mortality with daily departure from normal temperature. Comparisons made on this basis indicated that although a large departure from normal temperature (particularly in the summertime) might be a necessary condition for high mortality, it was not a sufficient condition.

DISCOMFORT

A number of authors have reported on studies concerning heat discomfort and heat death. Elizabeth Schickele(5), for example, made a study of heat deaths during World War II and on a scattergram drew what she referred to as a "heat death line." Of 265 heat deaths, all but 7 occurred on the upper side of the heat death line.

During the summer of 1959 the U. S. Weather Bureau began publishing a figure that includes the combined effects of temperature and moisture. This was first called the "Discomfort Index," and later the "Temperature-Humidity Index" (THI), which is still used in many locations. It was determined that whenever the THI is less than 70, practically everyone feels comfortable. At THI 75, at least half the people are uncomfortable. Above 75, discomfort rises very rapidly and acute discomfort is experienced by the time the figure reaches the middle 80's.

A comparison of Schickele's heat-death line and lines of constant THI is shown in Figure 5. Although the approaches used in developing these two concepts differ, the lines become parallel in the critical mid-80 THI region. Further, the heat-death line runs its course within the important THI region of 75 to 85.

EXTREME HEAT

Figure 6 shows the running weekly mortality curve for New York City in 1957. Such curves are maintained on an up-to-date basis by the Department of Health and are based on 5-year, 5-week moving averages. The shaded area is the plus or minus 2 standard deviation "tolerance zone." In addition to the exceedingly high mortality averages attributed to Asian influenza in October and early

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November, there are two noteworthy maxima in the summertime when normally the expected mortality is quite low. One of these has been labelled "3 days severe heat."

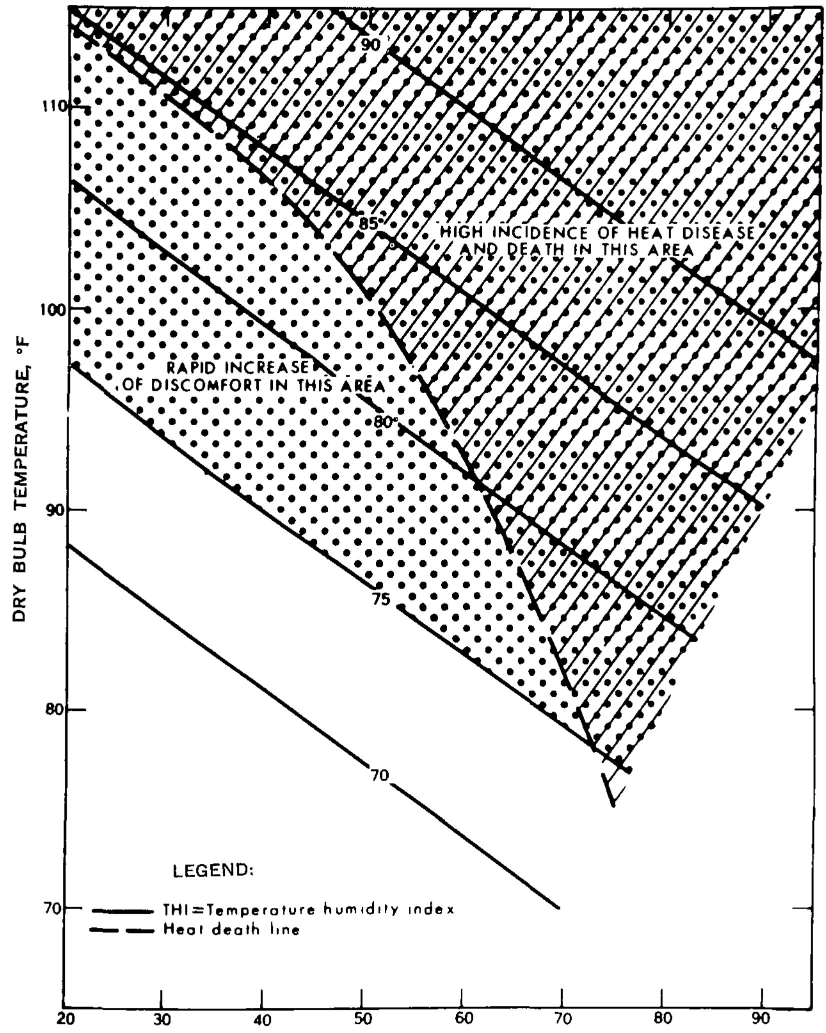


Figure 5 — Temperature humidity index (THI) and heat death line.

Accordingly, I decided to examine the correlation between New York City mortality and weather during "hot spells." For the purpose of this study, a hot spell was defined as:

1. Three or more consecutive days with 3-day mean departure from normal ≧ 5°F.

2. At least one day with a departure from normal (actual departure, not 3-day mean) ≧ 10°F.
3. The 3-day mean departure from normal remains positive throughout the period.
4. The maximum temperature exceeds 90° on at least one day.
5. The hot spell begins on the first day the 3-day mean departure is ≧ 5° and ends on the first day the 3-day mean departure is ≦ 5° and remains ≦ 5°

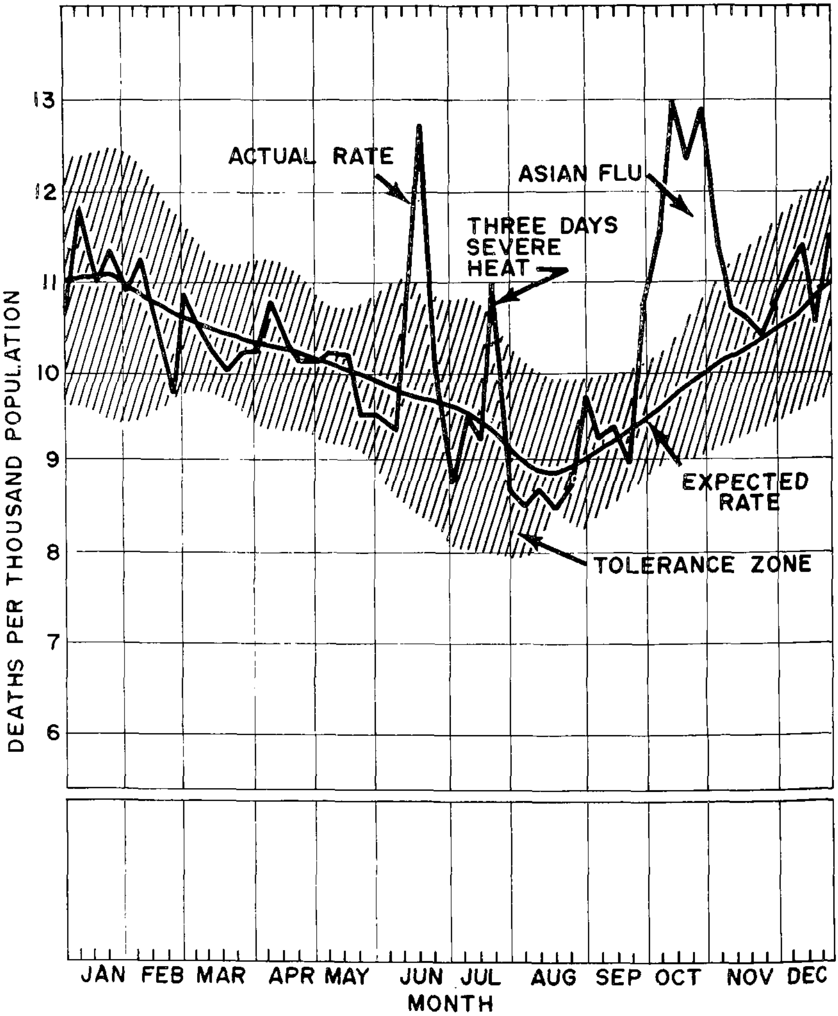


Figure 6 — New York City mortality chart for 1957.

From the 10 summers of record on which this study is based, 17 periods qualified as hot spells in accordance with the criteria.

In examining the mortality figures for the individual hot spells we note immediately that the mortality increased significantly on the day following the first hot day and continued rather high over a 3-day period. Accordingly, 3-day running mean departures from normal temperatures were compared with 3-day running mean values for total mortality, but with mortality figures lagged 1 day behind the normal temperature departures. Graphs for four of the more phenomenal of the 17 hot spells are shown in Figures 7 and 8. For comparison, graphs for five of the less-pronounced hot spells are shown in Figure 9.

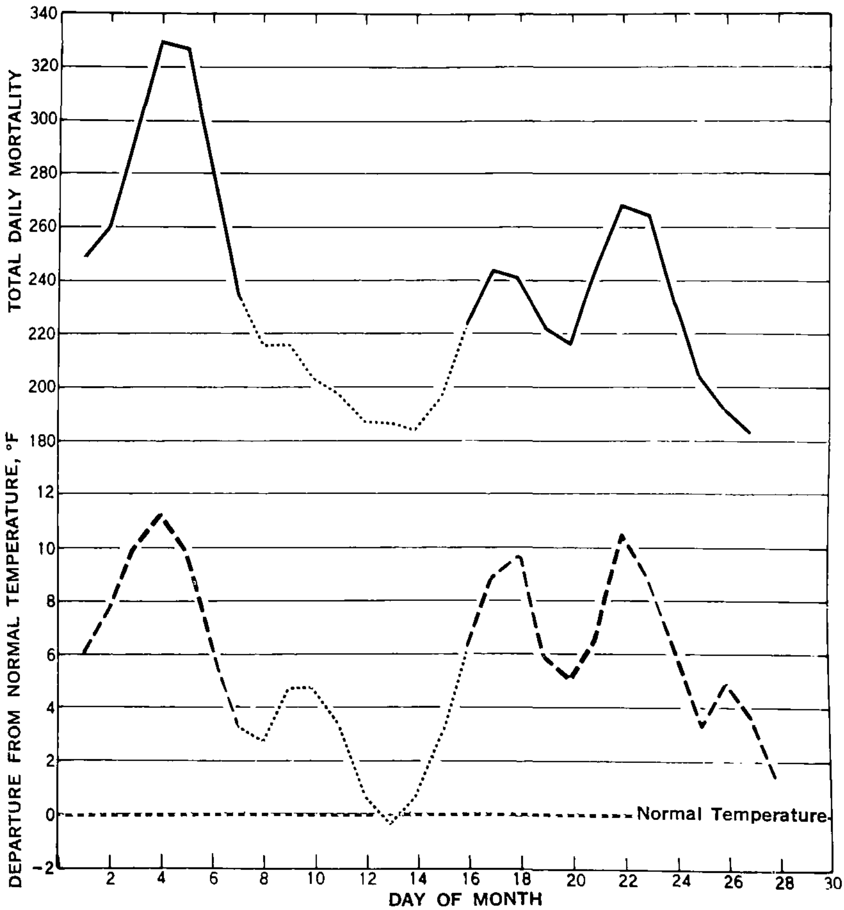
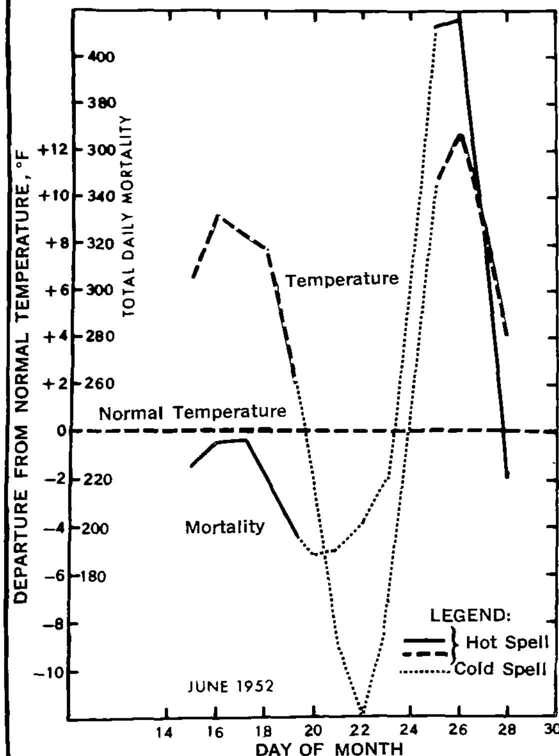


Figure 7 — Time series graphs for two July 1955 hot spells.



JUNE

DATE	Tx	Tn	T	ΔNT	WIND
15	93	68	81	+10	SW 7.8
16	85	69	77	+7	SE 6.0
17	95	70	83	+11	SW 8.4
18	88	70	79	+7	W 10.2
19	87	66	77	+5	SW 10.7
20	78	59	69	−3	NW 8.8
21	64	59	62	−11	NE 8.0
22	62	58	60	−13	NE 9.4
23	64	58	61	−12	E 7.7
24	85	62	74	+1	SW 7.0
25	99	75	87	+14	S 8.6
26	100	81	91	+17	W 7.7
27	90	72	81	+7	N 7.9

Tx	MAXIMUM TEMPERATURE
Tn	MINIMUM TEMPERATURE
T	MEAN TEMPERATURE
Δ NT	DEPARTURE FROM NORMAL TEMPERATURE
WIND	PREVAILING DIRECTION AND AVERAGE HOURLY VELOCITY

Figure 8 — Catastrophic June 1952 hot spells.

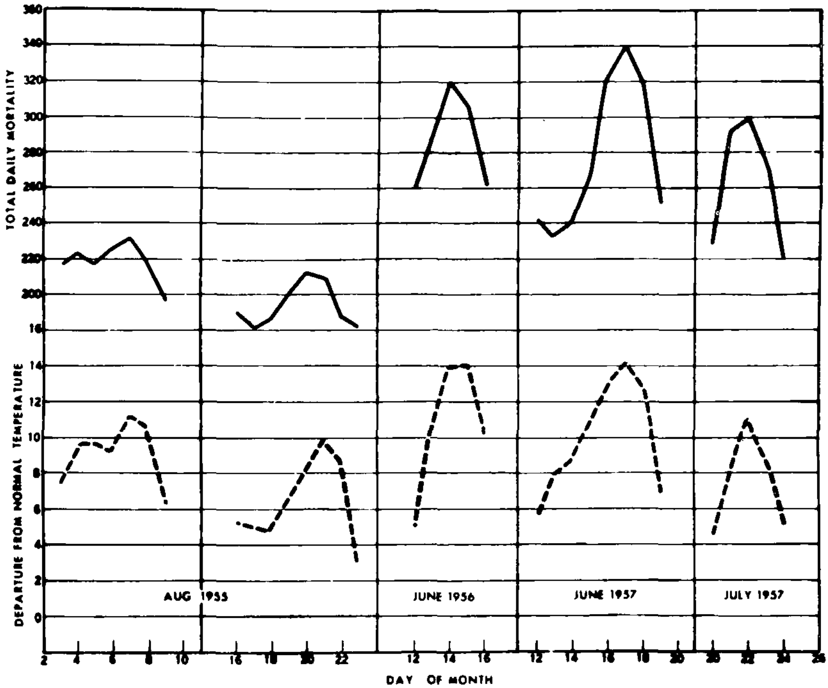


Figure 9 — Time series graphs for several lesser hot spells.

Note particularly Figure 8. The initial hot spell lasted only 4 days. It was immediately followed by temperatures considerably below normal and equally rapidly by an even more intense hot spell. The temperatures and winds for the 13-day period are shown in the tabular insert. These extreme temperature fluctuations exacted a correspondingly heavy death toll.

The body strain resulting from such extreme fluctuations was so severe as to cause a rise in mortality even as the temperature was still falling. The subsequent 100° maximum temperature on June 26 was followed by a record high mortality of 542 on the following day. This is very nearly 3 times the expected mortality. It exceeds the mortality for any other day in the 9½-year period—higher than the mortality even at the height of the Asian influenza epidemic.

Further examination of daily mortality during the summer months yielded still another significant feature: minimum daily mortality for the month occurred very shortly after the end of a hot spell in every instance but one. The minimum occurred 2 days before the beginning of the hot spell in July 1957. Of the remaining 11 months that had hot spells during these 10 summers, the minimum mortality occurred on the day following the end of the hot spell in two cases, on the second day in three cases, the third day in one case, four days and six days later in two cases each, and eight days later in one case.

Two likely contributory factors may explain minimum mortality following the hot-spell maxima. One is the invigorating effect of cooler temperatures following a hot spell. That this effect can be carried to extremes and then actually reversed, however, is evident in the increasing mortality rate during the relatively "cold" period between the two June 1952 hot spells (Figure 8). The other contributory factor is the likelihood that the excess casualties during hot spells consist to a major extent of those who normally would have passed away on succeeding days.

ANALYSES

Linear multiple regression analyses were run for all 17 hot spells. Mortality was the dependent variable. Six meteorological parameters (departure from normal temperature, maximum temperature, wind, THI, relative humidity and barometric reading) were the independent variables. As was expected, temperature was by far the most significant parameter, and barometer reading not significant at all. For the two older age groups (45 to 64 years and 65 and over), temperature alone was significant at about the 0.1 percent level or better, both for white and nonwhite. Correlations for all parameters and all age groups are contained in considerable detail in the original thesis material available at Rutgers University.(4)

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HEAT STRESS

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SUMMARY

Man meets the problems caused by internally generated metabolic heat and externally imposed environmental heat by means of physiological mechanisms such as vasodilation and sweating to increase heat loss not obtained by normal heat exchange by conduction-convection and evaporation-convection. Important factors in the effect of heat on man are humidity, radiant energy exchange, air temperature, and air movement. The four major categories of heat-induced illnesses (heat exhaustion, dehydration, heat cramps, and heat stroke) are discussed.

INTRODUCTION

Problems that confront man when he is exposed to a hot environment and physiological mechanisms he utilizes to cope with the problems are discussed in this section.

Two kinds of heat important to man working or living in a warm or hot environment are: internally generated metabolic heat, and externally imposed environmental heat.

Metabolic heat is a byproduct of the chemical processes occurring within the cells, tissues, and organs. Under resting conditions the metabolic heat production of an adult is about 75 KgCal per hour (300 Btu). Muscular activity is the major source of increased heat production. During very hard physical work heat production may reach 600 to 750 KgCal per hour (2,400 to 3,000 Btu). Thus under conditions of physical work large quantities of heat must be removed from the body if an increase in body temperature is to be prevented.

An internal body temperature of 99°F (98.6°F mouth temperature) is usually considered to be "normal"; however, body temperature varies from time to time during the day and with changes in physical activity. Consequently body temperatures of 97° to 102°F are frequently normal. Body temperature over 102°F in otherwise healthy individuals must be viewed with some concern, and a temperature over 105°F is critically serious. Consequently, the regulation of body temperature is an important physiological function, and

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the ease with which it can be successfully accomplished is determined by the individuals' ambient environment—by the air temperature, the humidity of the air, air movement, long-wave radiation, and solar radiation.

HEAT EXCHANGE

The metabolic heat of the body is exchanged with the ambient environment by the processes of conduction-convection, radiation, and evaporation. If the contact substance, whether it be air, water, clothing, or an external object, is at a lower temperature than the skin, heat will be lost; but if the contacting substance is at a higher temperature, heat will be gained. The rate at which transfer takes place is determined basically by the difference between the two temperatures, but if the contacting substance is fluid, like air or water, movement in the fluid accelerates the transfer. This additional transfer process is termed convection.

HEAT TRANSFER BY CONDUCTION-CONVECTION

Nearly all transfer of "sensible" heat between skin and air is by the combined process of conduction-convection, in which convection plays by far the greater part and may be expressed quantitatively by the equation:

$$H_c = \frac{K_c\,(t_s - t_a)}{I_a + I_c} \qquad (1)$$

where:

H_c = the rate of heat loss per unit area of exposed surface.

K_c = a constant whose value depends upon the units used.

t_s = the temperature of the skin surface.

t_a = the temperature of the ambient air.

I_a = the resistivity of the ambient air to the outward passage of heat.

I_c = the resistivity of the clothing to the outward passage of heat.

To this exchange between the skin and the air must be added heat exchanged between the respiratory tract and the inspired air, since the former behaves simply as an inward extension of the body surface, with a special mechanism—respiration—moving the air away when it is heated.

HEAT LOSS BY EVAPORATION — CONVECTION

Heat may also be lost from the surface of the body to the air by evaporation of water diffusing through the skin from deeper tissues, produced by sweat glands, or applied from without. The rate of evaporative heat loss is determined basically by the difference between the effective vapor pressure of the water on the skin and that of the air, but once again movement of the air greatly accelerates the rate of loss, so that the combined process is properly termed evaporation-convection.

The vapor pressure of water on the skin is determined by the temperature of the skin, but the extent of the water film varies between something less than 10 percent and 95 percent of the maximum. The effective vapor pressure of water on the skin is thus a function of these two factors. The extent of the water film is variously termed "skin wetness" or "skin relative humidity." It represents a balance between evaporation on the one hand and addition of water on the other. It is high only when the sweat glands are active, evaporation is inhibited, or water is applied from without.

HUMIDITY

The vapor pressure of the air is determined by the amount of water vapor present in (unit volume of) the air and corresponds closely to the absolute humidity of the air. Unfortunately, atmospheric humidity is usually expressed in terms of relative humidity, namely, the ratio between the amount of water vapor actually in the air and the amount the air could hold at that temperature. To determine the vapor pressure from the relative humidity, one needs to know the air temperature and to have tables or a graph by which to make the conversion. A great deal of misunderstanding and confusion has arisen from the use of these two measures of atmospheric humidity, between which the relationships are far from obvious. A vapor pressure of 15 mm Hg corresponds to 100% relative humidity at 63°F, 50% at 84°F, and 30% at 100°F, since the holding capacity of the air increases with temperature while the amount of water vapor remains the same. Another measure of humidity sometimes used is the dew point, the temperature at which air, on being cooled, becomes saturated and moisture begins to be deposited from it. Dew point is closely related to vapor pressure and to absolute humidity. The various combinations of dry-bulb temperature and relative humidity just cited as having the same vapor pressure (15 mm Hg) also have the same dew point (63°F).

A generalized equation for heat loss by evaporation from the skin to air is:

$$H_e = \frac{K_e\,(P_s - P_a)}{r_a + r_e}\,w \qquad (2)$$

where:

H_e = the rate of heat loss per unit area of exposed surface.
K_e = a constant whose value depends upon the units used.
P_s = the saturation vapor pressure at skin temperature.
P_a = the vapor pressure of the ambient air.
r_a = the resistivity of the ambient air to the outward passage of water vapor.

r_c = the resistivity of the clothing to the outward passage of water vapor,

w = the proportional wetness of the skin.

To this loss must be added that from the respiratory tract.

HEAT EXCHANGE BY RADIATION

Heat will be exchanged by radiation between the surface of the body and all of the surfaces in its surroundings which are at temperatures different from its own. (The term "surface" is easily understood for solid objects, but for such things as the sky it must be regarded as that hypothetical surface that would exhibit the same radiative behavior as the sky is observed to exhibit). The details of radiative exchange can become very complex, but the following simplified explanation will illustrate the principles involved.

The intensity of the energy emitted from a surface by radiation increases as the fourth power of its absolute temperature. The intensity is usually diminished below the theoretical maximum, however, by the physical nature of the surface, the relative effect being known as its emissivity. The wavelengths of the emitted radiation are usually distributed over a range, with a model length that decreases as temperature increases.

Radiation incident upon a surface is absorbed by it in proportion to its emissivity for the wavelength involved. The absorptivity for a particular wavelength is the same as the emissivity for that wavelength. From an opaque surface, the incident radiation that is not absorbed must be reflected, so that its reflectivity is the converse of its absorptivity and thus of its emissivity—for the particular wavelength involved.

A substance whose surface emits at maximum intensity for its temperature is termed a "black body." (This is an unfortunate term, since it inevitably suggests a visual observation which relates to reflectivity rather than to emissivity, and then only in the portion of the spectrum to which the eye is sensitive). In general, most conventional surfaces other than highly polished metals are classified as "black bodies" in the long infrared, but many of them are obviously far from black bodies in the visible range. Thus, the apparently paradoxical statement can be made that a white shirt may be a black body (in the long infrared).

The surface of the human body and its clothing emit only in the long infrared range, and in this range virtually all such surfaces act as black bodies. Emission from surrounding surfaces, however, is far more complex. Many conventional surfaces at normal temperatures are emitting long infrared radiation as essentially black bodies; but some, at the same temperature, may be emitting less intensely (for example, polished metal surfaces). Some surfaces at higher temperatures may be emitting short infrared radiation, and others at still higher temperatures, visible or even ultraviolet radiation. The exchange between the body and surrounding infrared emitters is fairly simple, being complicated only by the geometrical relationships of the opposing surfaces, which often can be approximated by a single sphere at a uniform temperature. For such a situation the appropriate equation for radiant energy exchange is:

$$H_r = K_r \left(T_w^4 - T_s^4\right) \quad (3)$$

where:

H_r = the rate of exchange per unit area of exposed surface.
K_r = a constant whose value depends upon the units used.
T_w = the absolute temperature of the surrounding sphere.
T_s = the absolute temperature of the skin.

NET HEAT EXCHANGE

The net heat exchange between man and his ambient environment can be expressed by:

$$H = M \pm C \pm R_1 + R_s - E \quad (4)$$

where:

H = net heat gain or loss by the body.
M = metabolic heat production.
C = heat exchange by conduction-convection.
R_1 = heat exchange by long-wave radiation.
R_s = solar heat gain.
E = heat loss by evaporation.

If the body temperature is to be maintained at an acceptable normal level, then H must equal zero. Small fluctuations in total body heat are, of course, permissible. They normally occur as a result of rapid changes in metabolic heat production or in the rate of heat exchange with the ambient environment. Metabolic heat production may increase by a factor of 10 within seconds as one goes from a state of rest to maximum physical effort (from 75 to 750 KgCal per hour, or 300 to 3,000 Btu). Metabolic heat production can be calculated since about 5 KgCal is liberated for each liter of oxygen used by the body cells.

The heat exchanged by convection-conduction can be calculated from equation 1. The insulation value of the air-clothing system will vary with the rate of air movement. These relationships at 95°F are presented in Figure 1.

Evaporative heat loss from the clothed man, as indicated in equation 2 can be a rather complex phenomenon; however, evaporation of sweat from the skin surface is a very effective means of losing body heat. Each liter of sweat requires 580 KgCal to evaporate it. These simplified relationships at 95°F are presented in Figure 2.

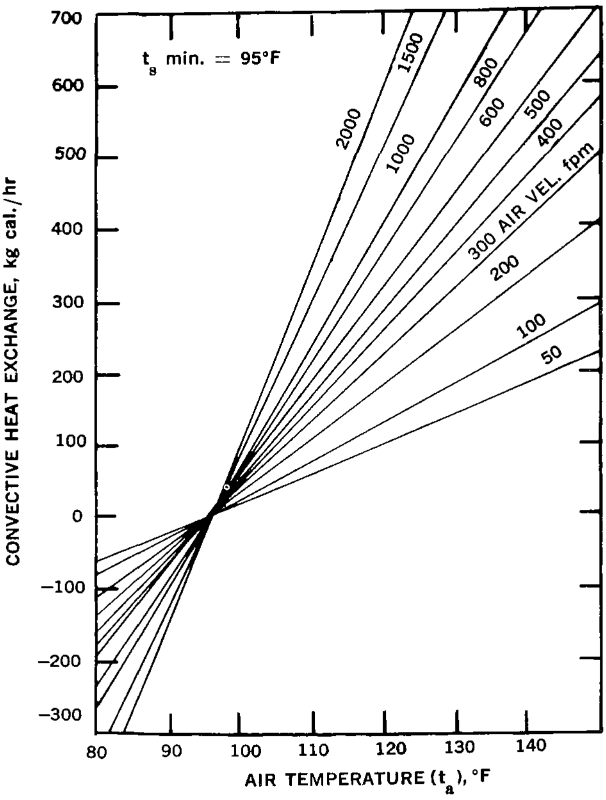

Figure 1 — Heat exchange by convection between man (skin temperature 95°F) and surrounding air.

To calculate radiant exchange from equation 3 requires more complex mathematical manipulation than may appear from the form of the equation. This is due primarily to the complexity of shapes of most surrounding objects. If the surrounding is assumed to be a sphere, the mean temperature of which can be measured, the rate of heat exchange with the nude individual with a skin temperature of 95°F can be obtained readily from a graphic representation of the relationships as shown in Figure 3.

Equation 4 ($H = M \pm C \pm R_1 + R_s - E$) can be solved using Figures 1, 2, and 3 provided the data on metabolic rate, air temperature, radiant temperature, vapor pressure, and air movement are available. These data can be obtained at the worksite in an industrial environment, in a field situation, and in a controlled laboratory setup. In Figures 1, 2, and 3 certain basic assumptions were made in order to simplify the presentation. Interindividual differences in sweating, (vapor pressure, at skin temperature), blood flow to the skin, muscular efficiency, body volume-surface ratio, and other factors make it hazardous to apply data derived from these figures to specific situations.

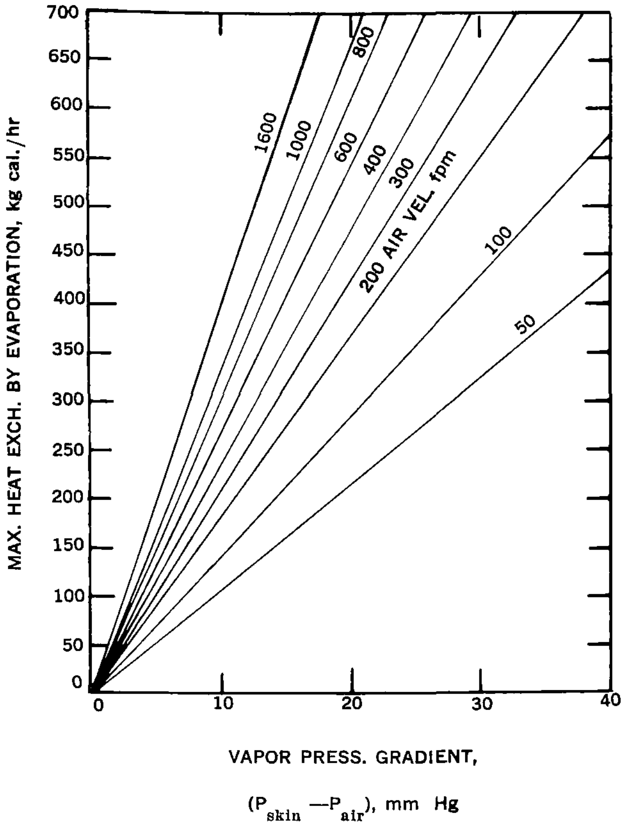

Figure 2 — Maximum evaporative capacity as related to air velocity and vapor pressure gradient.

RESPONSES TO HEAT

Since radiant energy exchange, air temperature, humidity, and air movement all affect, in quantitative fashion, the same physical process, heat balance of the body, their operations are largely interchangeable. An alteration in one can be duplicated or compensated by an appropriate change in another. The effect of a rise in radiant heat gain can be duplicated by that of a rise in air temperature; a rise in humidity may be offset by an increase in air movement; and so on.

At temperatures below 70°F sweating is not called into play, the skin is comparatively dry, and changes in humidity are of little consequence. As long as air temperature is lower than skin temperature, all movement will facilitate heat loss by both conduction and evaporation, but when air temperature exceeds skin temperature a mixed situation is created. Air movement will still increase heat loss by evaporation, but it will now also increase heat gain by conduction-convection. The higher the air temperature, the more important the latter will become, until it may actually override the increase in evaporating cooling. For each set of conditions in which air temperature exceeds skin temperature, there will be an optimal air movement. Lower rates of air movement result in sweat accumulation; higher rates, in additional heating and a bigger burden on compensatory sweating.

The burden placed upon the body to step up heat loss in the face of an environmental heat load is represented primarily by the physiological reactions designed to promote heat loss, but these reactions in turn may provoke other changes that add to the total physiological disturbance. The ultimate consequences of this chain of reactions are illustrated in Figure 4.

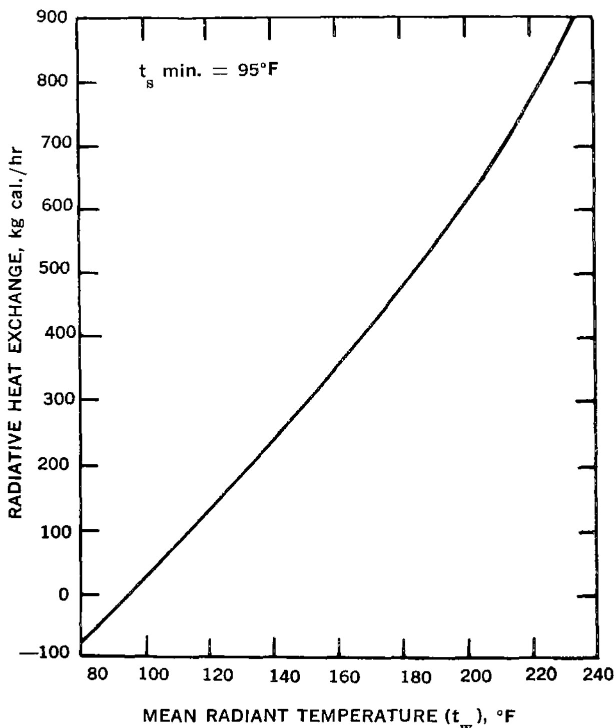

Figure 3 — Heat exchange by long-wave radiation.

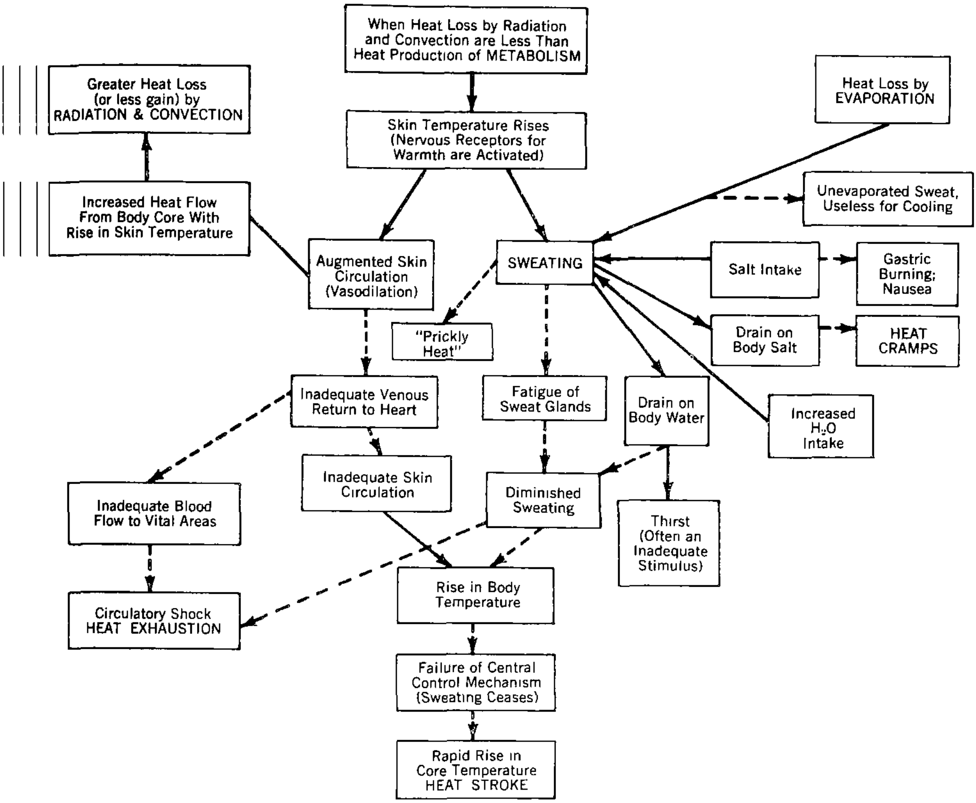

Figure 4 — Physiological reactions related to heat loss.

INCREASED FLOW OF BLOOD

When the heat loss by radiation and convection becomes less than the metabolic heat production, the first corrective action initiated by the body is a vasodilatation of the blood vessels near the surface of the skin, which results in an increased flow of blood to the area and an increase in skin temperature. There is an increase in both convective and radiative heat loss from the body when the ambient air temperature and the average radiant temperature of the surroundings are less than skin temperature; if these are higher than the skin temperature, the heat gain through these channels is decreased.

SWEATING

Sweating, the second defense mechanism, is brought into action when there is an insufficient flow of blood to the skin to meet the requirements for heat loss. This occurs usually when there is anything more than a minor thermal imbalance. The number of sweat glands activated and the rate of secretion of sweat are graded to meet the magnitude of the imbalance. Sweat production of more than 2 liters an hour has been observed, but a continuous sweat rate of about 1 liter an hour over several hours each day is considered to be the maximum production rate. This means that, except for short periods of time, about 600 KgCal per hour is the maximum amount of heat that will be lost from the body surface by sweat evaporation. Sweat that is not evaporated has no value for heat loss.

Sweat production results in a drain on the water and salt in the body. The water is usually replaced by an increase in water intake because the thirst mechanism is sufficient to keep the water intake and water loss in balance. Where heat stress causes large sweat production (6 to 12 liters a day), enough fluids are not voluntarily consumed to replace the water lost. This "voluntary" dehydration may amount to 2 to 3 liters or more during an 8-hour working day. The "voluntary" water deficit is usually replaced during meals and nonworking hours if an adequate supply of drinking water is available. Dehydration in excess of 3 liters may have serious physiological and clinical consequences.

HEAT-INDUCED ILLNESS

If the normal responses of increased skin-blood flow and sweat production are not adequate to meet the needs for body heat loss or if the mechanisms fail to function properly, physiological breakdown may occur. There are four major categories of heat-induced illnesses: heat exhaustion, dehydration, heat cramps, and heat stroke.

HEAT EXHAUSTION

This is a state of collapse caused by an insufficient blood supply to the cerebral cortex as a result of dilatation of blood vessels in response to heat. The failure here is not one of heat regulation, but an inability to meet the price of heat regulation. A critical low arterial blood pressure results partly from inadequate output of blood by the heart and partly from the widespread vasodilation. Inadequate cardiac output results, in turn, from a fall in the volume/capacity ratio below unity. The chief factors that may bring about this state of affairs are:

1. Increasing vascular dilatation and decreasing the capacity of the circulation to meet the demands for heat loss to the environment, exercise, and digestive activities.
2. Decreasing blood volume by dehydration, gravitational edema, adrenal insufficiency, or lack of salt.
3. Reducing cardiac efficiency by emotion, malnutrition, lack of physical training, infection or intoxication, cardiac failure.

DEHYDRATION

In its early stages, dehydration acts mainly by reducing the blood volume and promoting heat exhaustion. But in extreme cases it brings about disturbances of cell function, which increase and reinforce each other with worsening deterioration of the organism. Muscular inefficiency, reduced secretion (especially of the salivary glands), loss of appetite, difficulty in swallowing, acid accumulation in the tissues, and nervous irritability followed by depression intensify; uremia, fever and death terminate the picture. A surprising feature is the persistence of urine excretion in small amounts (5 cc per hour) in the face of dehydration. Clinical experience suggests careful administration of water to drink, the primary treatment. The addition of chloride, glucose, and perhaps alkalies is recommended.

HEAT CRAMPS

A condition of cramp-like spasms in the voluntary muscles is caused by a reduction of the concentration of sodium chloride in the blood below a certain critical level. Just why cramps should follow a fall in blood chloride is not clear, but the association is certain and the relief obtained by the administration of chloride may be spectacular. A high chloride loss is facilitated by high sweating rates, lack of acclimatization, and depletion of chloride reserves by low dietary intakes of salt and adrenal cortical insufficiency. A high water intake makes dilution of the remaining chloride easier. The actual critical level of blood chloride concentration varies and is affected by factors such as general health in a manner not yet understood.

The abdominal as well as the limb musculature may be affected, the site not necessarily being related to the preceding exercise. Whereas abdominal cramps may simulate acute surgical conditions, limb cramps resemble exercise or nocturnal cramps. Their persistence without saline therapy and their abolition by it provide the clue. Heat cramps can be prevented by taking extra salt whenever heavy work is to be carried out in hot dry environments, especially by unacclimatized persons.

HEAT STROKE (HYPERPYREXIA)

Heat stroke occurs when the mean temperature of the body is such that the continued functioning of some vital tissue is endangered thereby. It represents, of course, a marked failure of the heat regulating mechanism to maintain a proper balance between the two sides of the heat balance. The chief factors which may bring this about may be classified as follows:

1. Reduced heat loss—lack of sweat glands, inhibition of sweating, inadequate peripheral circulation, high environmental temperature, high humidity with restricted convection.
2. Increased heat reception—radiant energy absorption, environmental temperatures above skin temperature.

3. Increased heat production—muscular exercise, pyogenic agents, overactivity of the thyro-adrenal apparatus, rising body temperature, agitation.

4. Damaged heat regulating center—brain injuries or infections.

The critical body temperature for man lies between 108 and 112°F, depending upon the length of time that the tissues are so exposed. The cause of tissue damage and finally death is probably a mixture of protein denaturation, enzyme degradation, alteration in the physical structure of the cell membranes, and changes in the viscosity of the cellular protoplasm. It is unlikely that this crisis will be reached in a healthy, acclimatized man carrying out normal activities in a normal climate. But under severe emotional and physical stress and very hot conditions, heat production may reach a level high enough to produce heat stroke without prior onset of the usual escape provided to man, that is, heat exhaustion.

Relief is secured only by an early and effective reduction of body temperature—usually obtainable by wrapping the patient in wet sheets and playing a fan on him. Sometimes it is necessary to resort to packing in ice. A resistance to gentler cooling methods is very likely to occur in cases where the hyperpyrexia is partially caused by infection. In such cases the effect of the infection is to set the heat regulating "thermostat" at an abnormally high level, so that gentle cooling results only in vasoconstriction, with negation of the cooling effects. When drastic cooling is used, however, care has to be taken that the temperature is not lowered too fast or too far.

ACCLIMATIZATION TO HEAT

The fact of acclimatization is well attested by both experience and scientific observations, and some of its features are known; but as yet much of the basic mechanisms are still elusive. With the onset of a heat wave or when one is suddenly transported to a hot environment, it is common experience to observe impairment in performance capacity and strong heat discomfort and distress. Tasks easily performed in a cool environment become difficult, and heat discomfort interferes with rest and eating. If, however, the exposure to the heat is continued for several days, performance gradually returns to normal, heat discomfort subsides, at least to some extent, and acclimatization to heat occurs. The improvement in performance and sense of well-being is more than accustomization; it is the result of certain well defined and other more obscure, physiological adaptations.

Acclimatization to heat results, at least in part, from increased protection against hyperthermia since some of the initial distress of heat exposure results from the hyperthermia. There are other adaptations, e.g., improved cardiovascular function. The acclimatized individual is able to work in the heat with a lower body temperature, a lower heart rate, and a more stable blood pressure than before acclimatization. Some increase in sweat production also may occur. Other alterations implicated, but not fully proved, include changes in adrenocortical activity, blood volume, and venomotor tone. Regardless of which changes are most important, the improvement in performance with heat acclimatization is referable to the increased ability to maintain adequate cardiovascular function despite a high heat load.

The fully heat-acclimatized individual, then, shows no important decrease in ability to do physical work in the heat as compared to the amount he can do in comfortable conditions. This does not mean, however, that he is insensitive to the heat. There may be some psychological effects even in the heat-acclimatized individual:

(1) Some loss of mental initiative.

(2) Decrease in accuracy, particularly in poorly motivated individuals.

(3) Need for greater concentration to do a given task.

(4) Possible personality change.

SUSCEPTIBILITY TO DISEASE

Early studies of mortality during hot weather in a large American city have been supplemented recently by an analysis of records over 9½ years, with the following conclusions:

1. Tolerance to climatic change decreases with increasing age past 25.
2. Mortality increases notably in hot summer months.
3. The mortality is at a minimum in normally hot summer months, but high peaks are superimposed by hot spells.
4. Rapid fluctuations in temperature during summer months are accompanied by a significant increase in mortality.
5. In the total period the highest single daily mortality occurred in an exceptionally hot period.
6. Temperature is the most significant environmental factor in summer mortality.

CONCLUSION

These data and previously familiar evidence place the responsibility for increased mortality firmly on temperature fluctuations and exceptionally hot periods, but absolve continued "normal" heat. It would seem that attempts to control atmospheric conditions should be directed at the rather exceptional peak conditions, and that extension of such controls to lower degrees of heat might not be only unnecessary, but even undesirable, in that it would impose rapid fluctuations upon those who have to alternate between conditioned and natural environments.

EFFECTS OF ULTRAVIOLET LIGHT ON MAN

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SUMMARY

Ultraviolet light produces a variety of changes in the skin, the relationships between which are obscure. These include the erythema and tanning of sunburn, the production of vitamin D, and the induction of skin cancer. More than one photochemical reaction is concerned, but the site of these must be in the epidermis. The injurious effects of ultraviolet light probably outweigh any beneficial ones.

SUNBURN

Everyone is familiar with the phenomenon of sunburn, a complex response to ultraviolet light that may range from a just-perceptible reddening of the skin to the severe blistering and desquamation that may follow very severe exposure. The charts in Figure 1 will orient you to the range of wavelengths that provoke this response and to other spectral relationships. The curve labelled erythema in part B of this figure is based on determinations of the amount of radiation of various wavelengths that will produce a just-perceptible reddening of the skin. The reciprocal of this amount is plotted and the resulting curve is a spectral map, or action spectrum, of sensitivity to ultraviolet light and may be taken as an index of the photochemical changes that underlie sunburn; it is often called the erythemal spectrum. The long-wavelength limit for this sensitivity is about 0.32 micron, whereas the human eye normally perceives no wavelengths shorter than about 0.4 micron. Part A of Figure 1 shows that antirachitic action—the prevention or cure of rickets, which depends upon the formation of vitamin D from its precursor—has about the same long-wavelength limit as sunburn. No relationship, however, between the two photochemical reactions has been shown. In antirachitic action, the light-absorbing molecule, or chromophore, is the provitamin (7-dehydrocholesterol). Part C of Figure 1 shows that the absorption spectra for protein and for nucleic acid (the principal suspects as chromophores for erythema and the sunburn complex) have about the same long-wavelength limit as the action spectrum for erythema. The outer horny layer of the skin, or corneum, which is largely protein, acts as a light filter to alter the shape of the erythemal spectrum, so no close correspondence between absorption by the chromophore and the action can be expected; an idea of the transmission of the corneum is given in Figure 1-B.

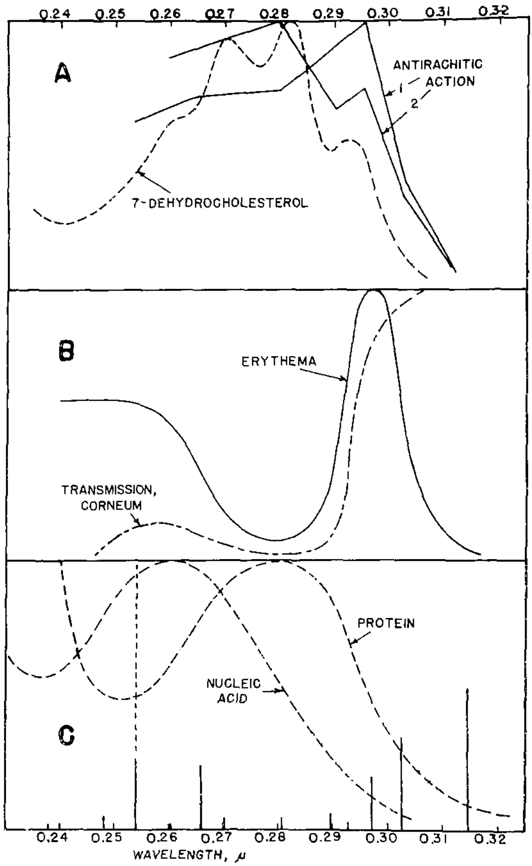


Figure 1 — Wavelengths provoking sunburn; relationships to other actions and responses.

Figure 2-A shows curves for sunlight at the surface of the earth; one representing the maximum condition with the sun at zenith, the other showing the corresponding amount of radiation with the sun at 60°, that is, at 4 hours from the zenith. The spectrum of sunlight ends at about 0.29 micron, and we note that the spectrum that produces erythema—wavelengths shorter than 0.32 micron (indicated by E)—is a very small fraction of the total. Actually there is much more of this radiation outside the earth's atmosphere, but it is largely absorbed by the ozone in the stratosphere, which is responsible for the short wavelength cutoff of sunlight at 0.29 micron.

The human eye is not sensitive to the wavelengths that produce sunburn, but has a range near the maximum of sunlight—about 0.4 to 0.65 micron. The atmosphere absorbs very little in this spectral region so these wavelengths are affected much less by angle of the sun than are those that cause sunburn. At 4 o'clock on a summer

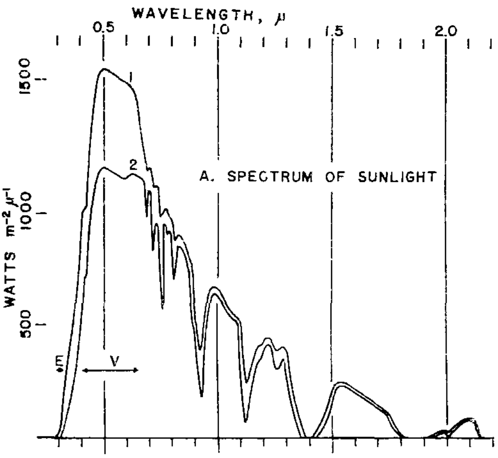
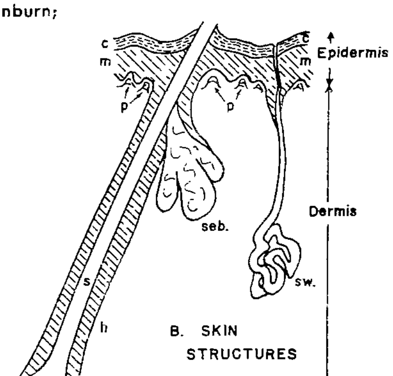


Figure 2A — Spectra of sunlight at surface of the earth: 1, with sun at zenith; 2, with sun at 60° from zenith (4 hr.); E, limits of sunlight causing sunburn; V, limits of vision of the human eye.



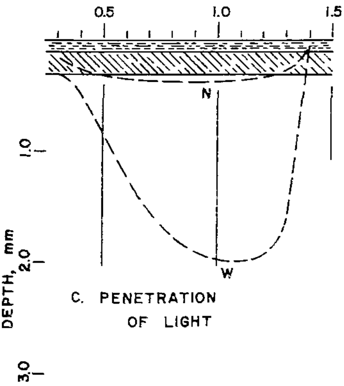


Figure 2B — Diagrammatic cross-section of skin: c, corneum; m, living layer; p, minute blood vessels; h, hair follicles; s, hair shaft; seb., sebacious gland; sw., sweat gland.

Figure 2C — Spectral penetration of light into skin: N, negro skin; W, white skin.

(From The Quarterly Revew of Biology 36:50. 1961. Used with permission.)

afternoon, when the sun is shining very brightly as far as the eye is concerned, there is very little sunburning radiation in the direct rays of the sun, so one must realize that the eye gives no good index of the amount of sunburning radiation. The picture is not quite so simple as the diagram indicates. Not only the direct rays of the sun but also the light that is scattered back from the sky must be taken into account; the sunburning ultraviolet is scattered much more than is the visible part of sunlight. If we measure the amount of solar energy falling upon a flat surface at right angle to the path of the rays, we may find that for the visible spectrum the total light scattered back is about 15 percent of that which comes directly. But for the sunburning ultraviolet the situation is much different, since a greater proportion is scattered back from the sky, coming at you from all parts of the heavens. To our eyes the sun appears a bright flaming spot in a mildly blue sky, but if we saw the ultraviolet that produces sunburn, the sun would appear as a somewhat brighter spot in a flaming sky. These things are to be kept in mind when we consider the risk of sunburn. Because of this scattering back from the sky, we may, on a bright summer day, get a severe sunburn when lying under a beach umbrella that protects us from the direct rays but exposes us to a good portion of the sky. Again, if we had to deal only with direct radiation, we could say with some assurance that one is safe from sunburn before 8 o'clock in the morning or after 4 in the afternoon, even on the brightest summer day, because so little direct radiation reaches us at that time. The presence of sky radiation may modify this to a certain extent, although as a general rule we are relatively safe from sunburn outside the middle of the day.

VARIATION IN SUNLIGHT

The eye is likewise not a good index of the variation of sunburning radiation with latitude and season. We generally think of the tropics as having much more sunlight than higher latitudes but this depends to some extent upon what we are talking about. At the time of the summer solstice on June 21 or 22 there is at the Arctic Circle about 10 percent less radiation than at the equator on the same day; and, of course, we all know of the midnight sun. But the ultraviolet falls off more rapidly with solar angle than does visible or total sunlight because of absorption by ozone, which also varies to some extent with latitude and season. At our summer solstice when the sun is many degrees north of the equator, we should have about as much chance of sunburn, if other things were equal, at the latitude of Geneva as at the equator. There is of course a big "if" here, which includes the amount of scattering from the sky. Clouds also produce an effect (thus far I have spoken as though the skies were always clear). Very little ultraviolet shorter than 0.32 micron gets through heavy clouds, but with a light fog scattering may be so great that one, if careless, is likely to get a bad sunburn. It seems that aerosols—smoke, dust and smog—are less effective in taking out this part of the ultraviolet than is ordinarily thought. Measuring the fraction of sunlight that produces sunburn is difficult; we have less knowledge of its distribution over the surface of the earth than we have for the visible spectrum or for total sunlight. This is something we ought to know more about(*1*, *7*).

I should also mention that sunburning radiation is almost completely cut out by ordinary, old-fashioned window glass, although under some circumstances enough gets through to give a very slight erythema. Window glasses made to let through some of this radiation are on the market today—just why I am not sure. The idea is widespread that sunlight is "good for you" and that one should toast himself in the sun as much as he can. As Figure 1 shows, the same wavelengths that cause sunburn also produce vitamin D in the skin, and this can have an effect in preventing or curing rickets. But as a therapeutic agent sunlight is variable, and vitamin D can easily be obtained in other forms. The treatment of tuberculosis with artificial sources of ultraviolet light or by exposure to sunlight was quite a fad some years ago but now has been virtually abandoned. Some dermatologic conditions seem to be improved with treatment by ultraviolet light; in this matter we could use more statistics to good advantage.

REACTION OF THE EPIDERMIS

Let us now consider the action of ultraviolet light on skin in a little more detail. Figure 2 shows at B a diagrammatic cross section of human skin. Most superficial is the epidermis, which for our purpose may be thought of as consisting of two layers: an outer corneum of dead cells and an under-layer of living cells. Actually there is a gradient of aliveness. The most alive cells are the deepest; most (if not all) of the cell division that renews the epidermis takes place in the basal cell layer. Very little of the radiation of the wavelengths less than 0.32 micron gets through the epidermis, so it is there that the principal photochemical changes take place. The reddening of the skin is the overt expression of dilation and greater blood flow in the small vessels—capillaries, arterioles, and venules—just under the epidermis. Very little of the ultraviolet radiation gets to these vessels; some wavelengths, virtually not at all. So it seems most likely that the ultraviolet produces in the epidermis some substance that diffuses down and causes these vessels to dilate; the nature of this vasodilator substance has never been satisfactorily shown.

The ultraviolet injures a good many of the viable cells of the epidermis. This apparently causes an increase in cell proliferation, so that the epidermis thickens after exposure to sunlight, and along with it the corneum. The latter is a very good absorber of the sunburning radiation and is one of our defenses against its injurious action; its thickening reduces our sensitivity for some time. Along with this proliferation and thickening comes the formation of melanin pigment by some of the epidermal cells that are specialized for its production. This pigment is the basis of suntan. It is popularly supposed that the tan protects us against sunburn, but this picture is not clear. The melanin, being produced at the bottom of the epidermis, does not seem to be in the best place to give protection; but it moves up through the epidermis and is finally lost by desquamation of the corneum. If you rub yourself with a towel after you have been exposed to the summer sun a good deal and are well tanned, you may notice that something black rubs off. You may think you are dirty, but this substance is likely to be small flakes of corneum containing melanin pigment. There is much more pigment in Negro skin, and it is distributed more uniformly through the epidermis. Negroes are much less susceptible to sunburn than are white-skinned people. Corneum and epidermis in Negro skin usually is thicker than in white skin, but it is also somewhat more opaque. The pigment probably plays a role in protection. We do not know much about the absorption by melanin at these wavelengths, however, and the melanin pigment would not be expected to be a much better absorber than the protein of the corneum. The effectiveness of the corneum as an absorber for this radiation is no doubt due largely to its being a good light scatterer on account of its flake-like character; this effectively lengthens the path of the rays through the corneum and permits greater absorption. The pigment may owe its effectiveness to its being finely divided and therefore a good scattering agent.

The tanning reaction is produced by the same wavelengths that cause erythema, but some claim that longer wavelengths are effective. There may be some confusion here. Pigment once produced in skin tends to bleach with time, undergoing a reduction to a leuco-form. After some weeks the pigment may seem to have almost disappeared; but if the skin is then exposed to wavelengths of light from about 0.3 to 0.4 micron, the pigment darkens. The spectral relationship is shown in Figure 3. The pigment-darkening reaction (PD), which is much more prominent in some people than in others, occurs only when there is adequate O_2 in the skin, whereas the initial sunburning reaction, erythema production, and pigment production are virtually independent of O_2. This complex of factors causes some confusion about the sunburn reaction; some of this confusion is reflected in the claims for sunburn-preventing lotions that permit tanning without sunburning. A variety of sun-screening creams and lotions are on the market, and no doubt all of them are effective to a certain extent. The question is how much protection one needs; this is determined by the amount of exposure he is going to undergo and the sensitivity of his particular skin(2).*

SKIN CANCER

The role of sunlight in the production of skin cancer is of special interest. The evidence for this is of several kinds. Negroes, who are relatively insensitive to sunburn, are also relatively immune to cancer of the skin. Among the white population, cancers of the skin occur most frequently on the parts that are not habitually covered with

* Certain rare diseases are caused by light of wavelengths longer than 0.32 micron, to which the above rules for protection obviously do not apply(5).

clothing, a very large proportion on the face. Some evidence indicates a north-south distribution of skin cancer; it has been claimed that outdoor workers are more likely to get skin cancer than indoor workers, but this claim is not yet on a sound epidemiological and statistical basis. Perhaps the most convincing evidence is that one can induce cancers of the skin of mice or rats by repeated exposure to ultraviolet light of the same wavelengths that cause sunburn; under appropriate conditions 100 percent are affected. In experiments of this kind in our laboratory at the National Cancer Institute albino mice were subjected to carefully measured doses of radiation at regular intervals: once a day, once a day for 5 days a week, and once a week. After about 3 or 4 months the animals began to develop tumors of the skin. Figure 4 shows time to appearance of tumor plotted against percentage of mice with tumor. The higher the dose or the shorter the interval between doses, the shorter was the time to appearance of tumor; the four curves from four experiments represent the three different dose-conditions. In Figure 5 the same data are plotted on the basis of the logarithms of the time to appearance of tumor; the data for the four experiments are fitted by similar S-shaped curves representing the integrals of a normal distribution. In Figure 6 the points from these same experiments and quite a number more, involving a total of over 600 mice, are pushed together to a common mean value on the abscissa; the same curve describes the data quite accurately. In all these experiments the dosage of ultraviolet light was continued until the tumors appeared. The dosage was stopped early in some experiments with the result that the tumors were delayed in appearing, as is shown in Figure 7. I present these data to indicate that we have something here that is quantitatively satisfying and should be susceptible to analysis.

Such analysis permits a few definite conclusions *(3)*. Whatever the action of ultraviolet light that underlies the production of the cancers, it is cumulative; and the effect is irreversible. A number of other things might be said about mechanism; but these two points bear particularly on the problem of skin cancer in man. Carrying this reasoning over from the mouse to man, one may conclude that all of us have some beginnings of cancer in skin that has been exposed to ultraviolet light. But statistics indicate that only a very few of us will develop observable skin cancers in our lifetimes—depending, we may suppose, on exposure, individual susceptibility, and luck. I don't think most of us should worry about this very much, although anyone who has already had a cancer of the skin ought to be careful to avoid sunlight; this does not mean shunning the light of day but only staying out of it or behind window glass during the hours of severest exposure. Those who are habitually exposed to the sun, such as farmers in some of our Southwestern states or Australia or other areas of high insolation, may find it an important problem.

Although the evidence converges to indicate that sunlight is probably an important etiologic factor in cancer of the skin, particularly in white-skinned people, this is difficult to prove statistically. We lack good epidemiological studies made in coordination with

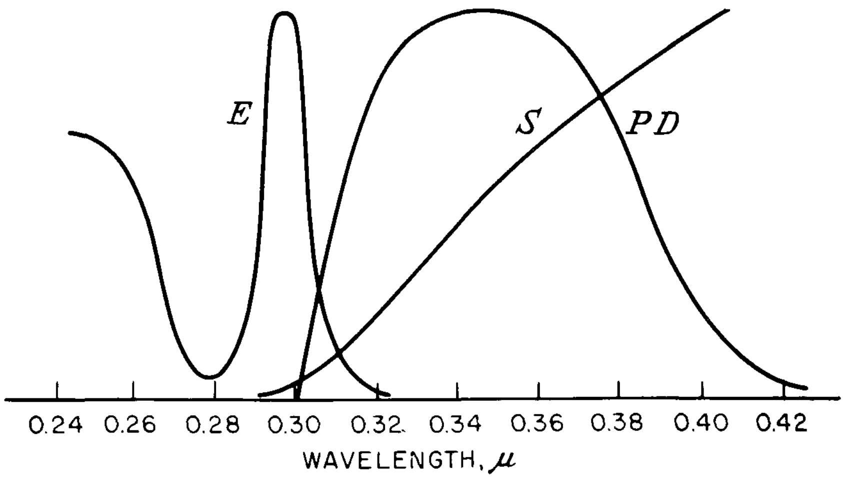


Figure 3 — Relationships of spectra. PD, pigment darkness spectrum; E, erythemal spectrum; S, spectrum of sunlight. Ordinates are not quantitatively comparable. (From H. F. Blum, *Carcinogenesis by Ultraviolet Light.* 1959. Princeton Univ. Press. Used with permission.)

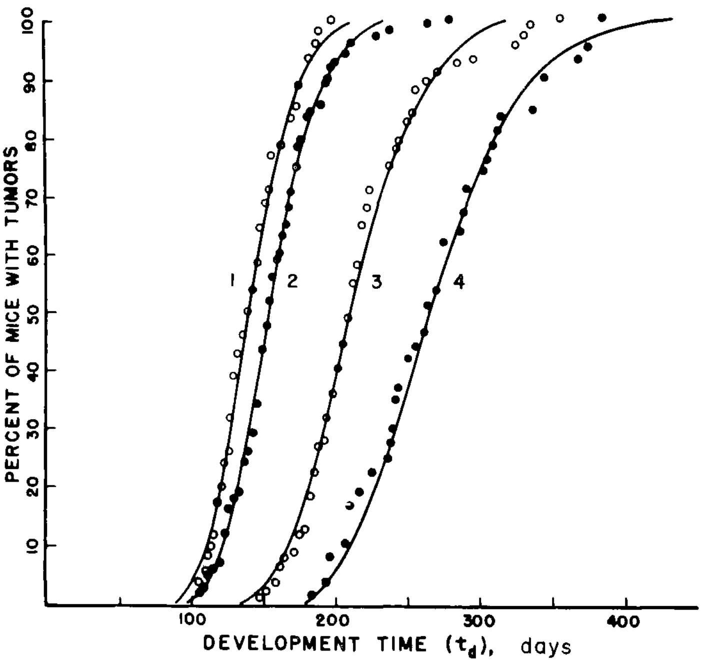


Figure 4 — Induction of skin cancers in albino mice with repeated doses of utraviolet light. Data from four experments; development time is time from first dose to appearance of tumor. (From H. F. Blum, *Carcinogenesis by Ultraviolet Light.* Princeton Univ. Press. 1959. Used with permission.)

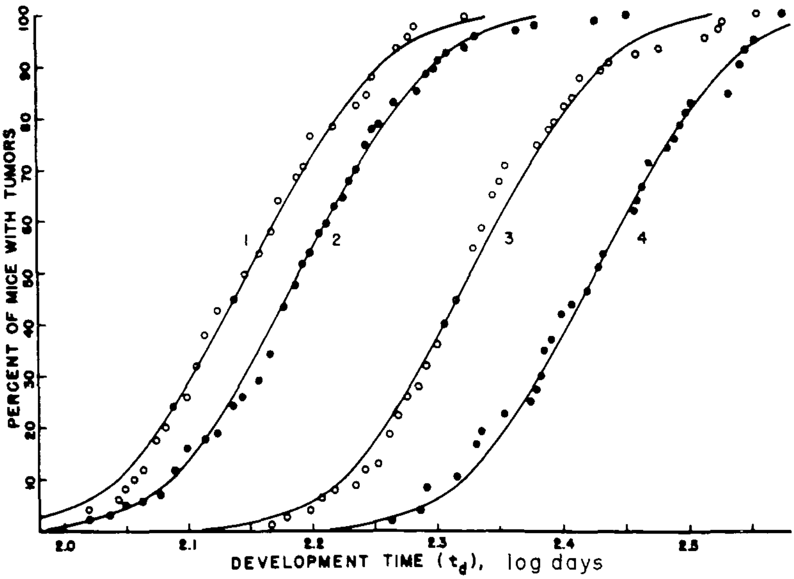


Figure 5 — Same data as Figure 4, plotted on semi-logarithmic coordinates. Curves are integral of normal distribution. (From H. F. Blum, *Carcinogenesis by Ultraviolet Light*. Princeton Univ. Press. 1959. Used with permission.)

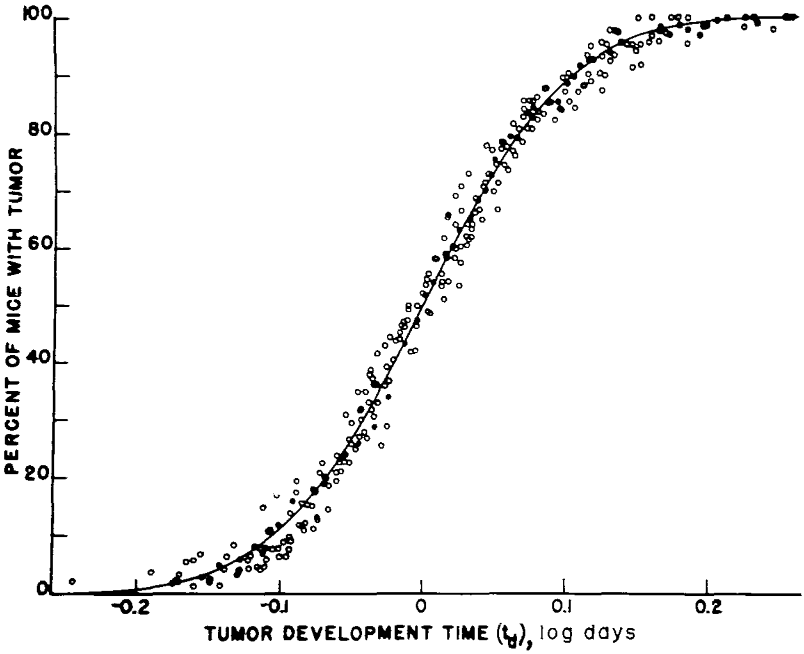


Figure 6 — Data from eight experiments including those described in Figures 4 and 5 (676 mice total), brought to common mean (zero log days). (From J. Nat. Cancer Inst., 11:463-495. 1950. Used with permission.)

measurements of sunlight; both involve considerable difficulty. To make the epidemiological studies we need to know more about types of skin cancer. Some types, for example, probably have little relationship to sunlight; for example, the melanomas, which often appear on parts of the body that are not exposed to sunlight.*

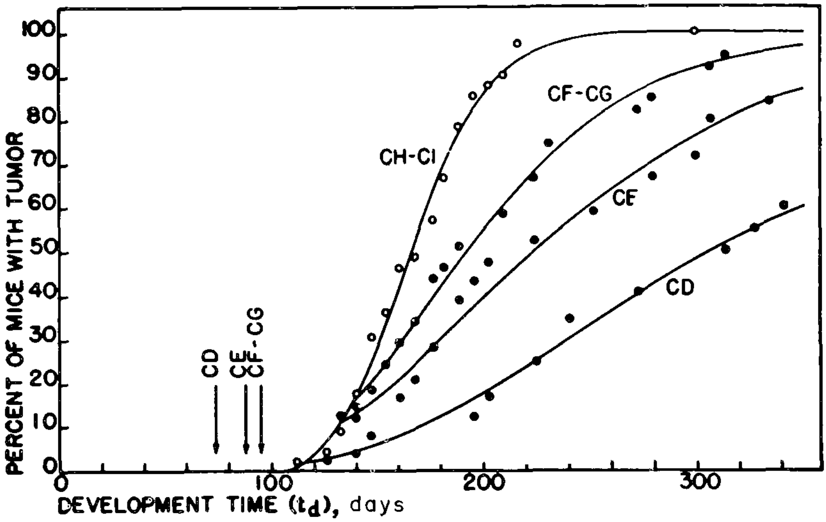


Figure 7 — Delay in appearance of skin cancers in albino mice as result of discontinued dosage. Curve CH-CI describes results of continuing doses until cancers appeared. For other curves, dosage was stopped at times indicated on abscissa by respectively labelled arrows. (From J. Nat. Cancer Inst., 11:463-495. 1950. Used with permission.)

At present the field is open, as is any field where data are not adequate, and one can hear many conflicting statements. For example, one idea goes back to Charles Darwin in the middle of the last century, that the Negroes inhabit the tropics because their pigmentation protects them against sunlight, and that this is a matter of natural selection. Darwin was very cautious about this suggestion; but others have taken it up, and it has come to be widely accepted. In Darwin's time, and even up to 50 or 60 years ago, little was known about the action of sunlight on skin. Today when we analyze this particular concept we find very little to support it(4).

Until we have better statistical data, it is hard to assess the importance of the ultraviolet of sunlight as a cause of cancer in man. When we bring together all the converging evidence, we can hardly doubt that it is a factor. We know that a very severe sunburn can

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* Since this paper was presented, a small conference was held under the auspices of the National Cancer Institute; people particularly interested in this question, coming from different disciplines, discussed various aspects of the problem and how better data could be obtained. Requests for a conference report should be addressed to the author.

be a debilitating experience—even a dangerous one—and we might, without unduly frightening the public, try to wean them a little from the idea that lots of sunlight on the skin is good. In the meantime the action of ultraviolet light offers many problems for study.

DISCUSSION

Question: Could you tell me a little about the effect of ultraviolet light on eyesight, such as in chambers having considerable numbers of sun lamps? Is a little looking at them all right and prolonged looking not all right?

Answer: The cornea of the eye can be sunburned. The ultraviolet wavelengths shorter than about 0.32 micron do not penetrate very deeply, and probably do not cause cataract as was once thought. But sunburn of the cornea can be very annoying and temporarily incapacitating, and I suppose repeated dosage could be dangerous. Cancers of eye tissue have been produced in mice by repeated dosage with ultraviolet light(6); but here the amount of radiation reaching deeper tissue is much greater than in man because the mouse's eye is much smaller, so it is difficult to draw any parallel. Exposure of the eye to ultraviolet is surely something to avoid as much as possible.

Ordinary glasses will cut out the ultraviolet that causes sunburn, but some may get in around the margins, particularly with reflection from the walls of a room. Most plastics now in use also cut out the sunburning wavelengths very effectively.

Question: But ordinary eyeglasses should protect you?

Answer: Yes, except for the ultraviolet light that may get in around the margins.

Question: We are interested in evaluating the effects of air pollution. I wonder if you could say anything about the bactericidal action of ultraviolet or its ability to destroy odors in the city?

Answer: I can't say anything definite except that the long-wavelength limits for the killing of bacteria and other microorganisms is about the same as the long wavelength for sunburn (about 0.32 micron). The killing of microorganisms seems to be tied closely to the absorption spectrum of nucleic acids, which have their long-wavelength limits at about this wavelength.

As for odors I have no information.

Question: Is skin cancer thought to be related to some alteration in the DNA in the cells?

Answer: In the present state of our knowledge nucleic acids seem the most probable chromophore, but the intimate mechanism of cancer induction is not understood. One thing that comes out of our analysis is that there is not a sudden mutation at the cellular level, but a gradual change, which is presumably intracellular. It seems most unlikely that we deal with a mutation in the usual genetic sense, but rather with what might be thought of as accumulation of intracellular mutations at the molecular level.

Question: Has anyone ever attempted to study the effect of ultraviolet radiation on bacteria that have not died but whose metabolism may have been profoundly altered?

Answer: Ultraviolet light has been a powerful tool in genetic studies in producing mutations among microorganisms surviving after treatment; usually a large fraction of the microorganism population is killed off.

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HYPOXIA: HIGH ALTITUDES REVISITED *

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SUMMARY

Data on oxygen gradient, basal metabolism, pH of arterial blood, and hemoglobin concentration obtained during the 1962 followup studies to the 1935 International High Altitude Expedition are presented.

INTRODUCTION

In the summer of 1962 six of the eight surviving members of the International High Altitude Expedition of 1935 revisited high altitudes in a study of adaptation as related to age. The six are listed in Table 1. Bryan H. C. Matthews of Cambridge and E. H. Christiansen of Stockholm could not participate. H. T. Edwards died in 1937 and E. S. G. Barron, in 1957. Details about the locale, the White Mountain Research Station, and the scope of the observations have been published(4). In this paper we shall refer to each station in terms of its mean barometric pressure (P_B):

Station	Altitude, m	P_B, mm Hg
Crooked Creek	3093	535
Barcroft	3800	485
Summit	4343	455

METHODS

First to arrive to set up equipment were J. L. Newton and J. W. Terman, graduate students, Indiana University. The six subjects then arrived in pairs at about 10-day intervals. During their first week these daily observations were made in the basal state and supine position:

1. respiratory minute volume, average for 10 minutes (Tissot gasometer),

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2. percentages of CO_2 and O_2 in the collected expired air (Haldane apparatus),
3. blood pressure, heart rate, respiratory rate, rectal temperature, and body weight,
4. 8-minutes spirogram with the subject breathing oxygen from the Sanborn-Benedict apparatus. (These measurements included two or three records of expiratory reserve, tidal, inspiratory reserve and vital capacity volumes. The maximum excursion was the basis for comparison.)

After these observations had been made at least once in each station, arterial blood was obtained from the brachial artery. Before the puncture an end-inspiratory Haldane-Priestley sample of alveolar air was obtained; a second sample was collected during the puncture. Less frequent observations were later made on Forbes, Hall, and Dill, who remained 17, 23, and 35 days, respectively. The other three subjects departed after 1 week. Finally some exploratory observations were made of exercise tolerance by use of the bicycle ergometer.

Table 1. BASAL OXYGEN CONSUMPTION.

Subject	At sea level, ml 0_2/min	First week at altitude, % of sea-level value		
		$P_B = 535$	$P_B = 485$	$P_B = 455$
Dill	213	108	121	121
Hall	255	108	109	111
Forbes	227	111	112	107
McFarland	242	119	119	100
Keys	236	105	106	122
Talbott	231	111	110	113
Average	234	110	113	112

	Subsequent weeks at $P_B = 485$, % of sea-level value			
	2nd week	3rd week	4th week	5th week
Dill	109	108	105	112
Hall	102	105		
Forbes	100	101		

RESULTS

RESPIRATORY MINUTE VOLUME, V_E

Respiratory adaptations have been described(6). The average percentage increases expressed at BTPS (body temperature and pressure, saturated) are given for each station:

P_B, mm Hg	Average ventilation increase, %
535	20
485	34
455	44

Comparable observations were not made on these men in 1935, but Chiodi(*3*) has made similar observations on young men: their responses were on a par with ours.

The average observed V values, BTPS, were inversely proportional to the partial pressure of oxygen in the atmosphere. Observations of Dill were continued for 5 weeks. A steady state was reached in the second week, as shown in the following comparison, taking the sea level value as 100:

	V_E		
P_B, mm Hg	535	485	455
1st week	114	141	143
2nd week		119	133
4th week		120	131
5th week		117	

Cheyne-Stokes breathing(*7*), was not obvious while subjects were awake but frequently occurred during sleep. One awakens with an acute air hunger and breathes rapidly and deeply for a minute or less.

BASAL OXYGEN CONSUMPTION

The many records in the literature of basal oxygen consumption at altitude leave one undecided as to whether it differs from that at sea level. One such study(*11*) reported increases from 6 to 11 percent indoors at 3,470 m and much greater increases outdoors in the sun, with subjects clothed and unclothed. A review of 14 studies of basal oxygen consumption at altitude(*1*) revealed changes ranging from 0 to 49 percent with median values of 7.5 percent at 3,470 meters and 8 percent at 2,900 meters. Balke reported an average increase of only 1.4 percent; he believed that the wide range of values reported in the literature can be explained by fluctuation in factors other than altitude, including radiation, temperature, and the degree and intensity of prior exercise. The last factor may play a major role: the residual effects of long-lasting strenuous exercise on resting oxygen consumption may last many hours or even days(*9*). In a recent study(*8*), three measurements were made of V_{O_2} on successive days first at Denver, 1,600 meters, and then on Mt. Evans, 4,320 meters.

In one male and one female Vo_2 decreased 5 percent. In another female and in three males the increases ranged from 4 to 8 percent. The ages ranged from 24 to 37 years.

Our observations appear to be the first on record on men of ages 58 to 71 at altitude. The summary of basal Vo_2 values in Table 1 clearly demonstrates that an increase occurred in all subjects, averaging from 10 to 13 percent in the six subjects during the first week at altitude. Values for Dill, Hall, and Forbes remained elevated during subsequent weeks, although less so than during the first week. Heart rate tended to increase with the metabolic rate, but the correlation was low; evidently in the basal state independent influences affect heart rate and metabolic rate.

Interpretation of our findings is difficult because of the lack of prior comparable measurements on four of us previously at high altitudes. We do have single observations on Talbott and Dill before, during, and after our 1929 Leadville study at 3,100 meters:

	Vo_2, ml/min		
	Before	During	After
Dill	246	230	220
Talbott	242	240	265

These values are all within the normal day-to-day range; at altitude the Vo_2 was the same or slightly below the average at sea level. We were moderately active in climbing at Leadville. In 1962 none of us exercised much and during the first week very little. Hence the long-lasting increase in basal Vo_2 that follows strenuous exercise could not have explained the increase in metabolic rate seen in all of us in 1962. For the moment we shall describe this increase as being associated with age for reasons unknown.

GAS EQUILIBRIA IN THE LUNGS

Observations on the composition of alveolar air and arterial blood have been reported(*14*). Compared with responses of the subjects in 1935, alveolar pCO_2 values were somewhat lower for a given altitude. This seems somewhat incongruous since their respiratory minute volumes averaged the same as those reported for young men(*3*). Except for Hall the difference is small; it may be accounted for by individual differences unrelated to age. There was no significant gradient of pCO_2 from blood to alveoli. On the other hand, the gradient for oxygen averaged $+3.0$ mm Hg in 1935 as compared to 12.4 in 1962. In two young men, Terman and Newton, the $p0_2$ gradient was low as in ourselves in 1935.

By virtue of the increased alveolar ventilation and the maintenance of an alkaline pH (about 7.5), we were able to maintain about the same percentage saturation of arterial blood with oxygen as seen in young men at comparable altitudes, a topic we will now consider.

ACID-BASE BALANCE AND PERCENT OXYHEMOGLOBIN

Studies of arterial blood included determination of pH_s, CO_2, and O_2 contents, of hemoglobin by the cyanmethemoglobin method, and of CO_2 and O_2 contents of blood equilibrated at known pCO_2 and pO_2 values and at body temperature. The pO_2 in the tonometer, 172 mm Hg, was adequate to saturate the hemoglobin and thus to give the oxygen combining capacity. The pCO_2 in the tonometer was 34.7. From this baseline and the known properties of blood we calculated the T_{40}, i.e., the CO_2 content of oxygenated blood at pCO_2 = 40 mm Hg. The interrelations between these measurements enabled us to check the reliability of our results. In addition, as reported elsewhere(4), some of our measurements were compared with those made by Severinghaus with a gratifying outcome.

The summary of our findings in Table 2 shows a moderately uniform pattern of response. The average CO_2 combining capacity of oxygenated blood, T_{40}, declined almost 2.4 mM in the six subjects during the first week. It did not change significantly thereafter in the two subjects studied. In round numbers the decrease was from 21 to 19 mM. Among the six individuals only Hall departed from the pattern. His T_{40} was low at the beginning; it ranged from 19.1 at the beginning to a minimum of 17.6 at the summit a week later and then increased to a final value of 19.0 in the third week at P_B 485.

The pH of arterial serum showed an immediate response; it was 7.40 at sea level and averaged 7.49 on the first day at P_B 535. It increased to 7.53 at P_B 485 and to 7.54 at the summit P_B 455. In Hall and Dill it remained stabilized at about this level during the remainder of their stays. Dill was the only one to depart much from the general response: his pH_s was 7.41 the first day, whereas the others ranged from 7.48 to 7.52.

Values for percentage saturation of hemoglobin were more scattered than those for other properties of the blood. At P_B 535 the range was from 76 in Dill to 88 in Keys. At P_B 435, Talbott was lowest, 69, and McFarland highest, 82. In subsequent weeks at P_B 485 Dill's values were 83 and 86 and Hall's 84 and 84. Finally, during a visit to the summit in the fourth week Dill's value was 81 percent, compared with 73 percent 3 weeks earlier.

The barometric pressure at the summit, 455, was appreciably greater than at the Montt station in our 1935 study(5), 429 mm. This difference must be taken into account in considering the following averages for 10 men at Montt and for 6 of them at the summit in 1962.

	1935, $P_B = 429$	1962, $P_B = 455$
Arterial HbO_2, %	78.0	79.0
Arterial pH_s	7.45	7.49

Table 2. ACID-BASE BALANCE AND PERCENT OXYHEMOGLOBIN IN ARTERIAL BLOOD IN BASAL STATE

Subject	at sea level			First week at altitude								
				$P_B = 535$			$P_B = 485$			$P_B = 455$		
	T_{40}[a]	pH_s	$\%HbO_2$	T_{40}	pH_s	$\%HbO_2$	T_{40}	pH_s	$\%HbO_2$	T_{40}	pH_s	$\%HbO_2$
Dill	21.7	7.42	93	20.6	7.41	76	20.4	7.52	76	20.9	7.53	73
Hall	19.1	7.38	97	18.0	7.50	94	18.6	7.56	80	17.6	7.53	87
Forbes	21.6	7.38	92	19.1	7.50	87	19.1	7.52	82	18.2	7.57	83
McF.	22.5	7.40	95	20.4	7.48	84	19.5	7.52	80	18.7	7.53	82
Keys	20.9	7.40	99	21.1	7.51	91	20.2	7.56	88	18.2	7.54	80
Talbott	21.5	7.43	94	21.9	7.52	82	20.6	7.53	78	19.1	7.52	69
Avgs.	21.2	7.40	95	20.2	7.49	86	19.7	7.53	81	18.8	7.54	79

	Subsequent weeks at altitude											
	$P_B = 485$			$P_B = 485$			$P_B = 455$			$P_B = 485$		
	2nd week			3rd week			4th week			5th week		
Dill				19.4	7.49	83	19.8	7.53	81	19.2	7.50	86
Hall	18.0	7.52	84	19.0	7.50	84						

[a] Total CO_2 of oxygenated blood at $pCO_2 = 40$ mmHg.

HEMOGLOBIN CONCENTRATION

It is well known that one of the early responses to the stimulus of oxygen deficiency is increase in hemoglobin concentration in the blood. No exception has been found to this from the days of Paul Bert to recent observations in Peru(*10*). Re-examination of data from the Anglo-American expedition to Pike's Peak in 1911(7) yielded interesting information. Haldane, aged 51, showed the slowest rate of increase in hemoglobin concentration, and at the end of the 35 days on Pike's Peak the lowest value. Douglas, aged 29, showed the most rapid and the greatest response. Responses of Henderson and Schneider, aged 38 and 37, respectively, were intermediate. Our findings, reported by Dill, Terman, and Hall, Clinical Chemistry 9:710-716(1963) in a number honoring D. D. Van Slyke, surprised us. Five members of our party showed a decrease and the sixth, only a small increase. In the three subjects who spent 2 weeks or more at altitude, hemoglobin concentrations rose above the sea level values eventually: in Dill at 23 days, in Hall at 8 days, and in Forbes at 11 days.

We have no observations on blood volume and hence can only speculate on the nature of related responses to high altitude. One possible interpretation of our findings is that in the early stages of adaptation in our age range, plasma volume increases faster than red cell volume. It does not seem likely that a high rate of red cell destruction was involved, since we did not engage in much exercise during the first week. Neither is it likely that water balance was upset, since body weight changed little from day to day. The changes ranged from a gain of 2.5 kg by Talbott to a loss of 2.2 kg by Forbes. The novelty of our findings points to the need for further study. Frequent measurement of red cell and plasma volumes should be coupled with daily observations of hemoglobin concentrations. Cardiac output might be useful in interpreting observations on work capacity and other criteria of acclimatization. The daily urinary content of erythropoietin might prove significant.

BASAL HEART RATE

Comprehensive reviews (*12, 2*) indicate that up to a critical altitude the basal heart rate eventually returns to its sea-level value. In mountaineers this critical altitude may be as high as 6500 m (*13*). The rate is higher during adaptation and the time required for attaining the sea-level rate is greater as altitude increases. Results are summarized in Table 3. Dill, McFarland, and Keys showed small increases during the first 2 days at P_B 535. All but Keys showed increases during the next 3 days at P_B 485; during the next 2 days at the summit increases above sea level were less and were seen only in four of us. In subsequent weeks values at P_B 485 and 455 were within the day-to-day range of sea-level values. Our group tended to show small increases during the first week, but in the three who stayed longer the sea-level value was attained.

Table 3. BASAL HEART RATES

Subject	At sea level	First week at altitude, % of sea-level value		
		$P_B = 535$	$P_B = 485$	$P_B = 455$
Dill	65	106	114	112
Hall	70	100	103	89
Forbes	61	98	107	108
McFarland	60	109	113	107
Keys	58	104	96	100
Talbott	66	99	122	106
Average	63	103	119	104

	Subsequent weeks; % of sea-level value				
	$P_B = 485$				$P_B = 455$
	2nd week	3rd week	4th week	5th week	3rd week
Dill	101		102	96	106
Hall	107	106			
Forbes	104	89			
Average	104	95	102	96	106

BASAL BLOOD PRESSURE

The record of basal blood pressures is presented in Table 4. Although some values exceeded the expected day-to-day range, no consistent pattern of response was apparent.

Table 4. BASAL BLOOD PRESSURES BY AUSCULTATION

Subject	At sea level	First week at altitude, % of sea-level value		
		$P_B = 535$	$P_B = 485$	$P_B = 455$
Dill	121/78	135/78	136/80	126/74
Hall	140/76	143/109	136/90	140/96
Forbes	129/88	125/75	128/80	127/71
McFarland	125/88	126/84	130/79	134/82
Keys	123/74	142/86	146/87	136/65
Talbott	158/114	144/88	163/98	152/93
Average	135/86	137/87	140/86	136/80

	Subsequent weeks				
	$P_B = 485$				$P_B = 455$
	2nd week	3rd week	4th week	5th week	3rd week
Dill	126/78	132/80	140/78	126/80	130/84
Hall	124/84	140/85			
Forbes	130/85	132/80			

PARTITION OF LUNG VOLUMES

Observations of the breathing pattern and partition of lung volumes were made with the Sanborn-Benedict apparatus two or more times at each station and once or more at sea level. The pattern at altitude may have been altered as part of the response to the increased oxygen pressure. We have no evidence as to the nature or magnitude of such possible effects. Hence for the moment we shall devote our attention to lung volumes. The procedure was to obtain a 2- or 3-minute record after the subject had been in the supine position for ½ hour or longer. He was then instructed to expire slowly and completely and then to inspire slowly and to his limit. He resumed natural breathing for 2 or 3 minutes, then the maneuver was repeated in reverse order. The maximum excursion was taken as the record of vital capacity. The best-fitting parallel lines were drawn to represent the end-tidal and beginning-tidal excursions. The vertical distance from the point of maximum expiration to the line of end-tidal excursions is taken as a measure of expiratory reserve volume. Similarly the vertical distance from the line of beginning-tidal excursions to the point of maximum inspiration measures the inspiratory reserve volume. These distances measured in mm are converted to ml; on our apparatus 1 mm = 20.9 ml. Volumes were then calculated to conditions in the lung, BTPS.

The results, summarized in Table 5, showed large differences between individuals. Dill's vital capacity was down 1/6 at P_B 485 but thereafter was as high or higher than at sea level. Hall's vital capacity was down 1/6 during the first 2 days at P_B 535. It was higher at P_B 485 than at P_B 535. Thereafter it was near the sea-level value. Forbes' vital capacity was down by 3 to 10 percent at each station. McFarland's vital capacity, if it changed at all, was higher at altitude than at sea level. We have no sea-level measurements on Keys, but his vital capacity was higher at the low and the upper stations than at the intermediate station. Talbott showed the greatest changes. His vital capacity was down 10 percent at P_B 535, 20 percent at P_B 485, and 27 percent at P_B 455.

EXERCISE

In cooperation with Bruno Balke our group measured exercise tolerance on a few occasions. Since the full details have been published (*J. Appl. Physiol.* 19:483-488(1964) only a summary is given here. The test involved adding equal increments to the work load on the bicycle ergometer minute-by-minute and measuring the ventilation and oxygen consumption during each of the last few minutes as the subject was approaching his limit. After about two days at P_B 485 the maximal Vo_2 was 55 percent of the sea-level value in McFarland, 80 percent in Keys, and 56 percent in Talbott. After a week it was 72 percent in Dill. These studies were continued on Dill. After 20 days at altitude his performance at P_B 485 was up to 78 percent, and after 35 days, 88 percent of his Indiana maximum. A week earlier at P_B 455 he reached 83 percent of his Indiana maximum. This marked improvement was not wholly due to acclimatization to low oxygen: an ergometer test made a few days later at Santa Barbara, thanks to the hospitality of S. M. Horvath and staff at the University of California, revealed an oxygen intake 5 percent larger than during the previous year in Indiana.

DISCUSSION

A few generalizations may be made. One of the most surprising is that none of us showed a rapid increase in hemoglobin concentration. On the contrary five of us showed a decrease; the oldest, Dill, showed the greatest decrease—about 5 percent—and he did not exceed his sea-level value for 3 weeks. Having made this finding we discovered that there was an inkling of this phenomenon in the report of the Anglo-American expedition of 1911(7). Further studies are required for an understanding of this phenomenon.

For reasons unknown, the basal oxygen consumption tended to increase. This happens sometimes but not always in young men. In

Table 5. PARTITION OF LUNG VOLUMES AT ALTITUDE

(Subject supine; volume in liters, BTPS)

Subject	Sea level				$P_B = 535$				$P_B = 485$				$P_B = 455$			
	Exp. res.	Tidal	Insp. res.	V.C.	Exp. res.	Tidal	Insp. res.	V.C.	Exp. res.	Tidal	Insp. res.	V.C.	Exp. res.	Tidal	Insp. res.	V.C.
Dill	0.57	0.79	1.67	3.03	0.69	0.85	1.66	3.20	0.37	0.74	1.43	2.54	0.72	0.68	1.74	3.14
Hall	0.56	0.76	3.22	4.54	0.14	0.70	2.93	3.81	0.40	0.81	2.85	4.06	0.40	0.93	3.09	4.42
Forbes	0.64	0.90	3.46	5.00	0.47	0.95	2.99	4.41	0.73	0.85	3.27	4.87	0.69	0.81	3.26	4.76
McFarland	0.05	0.58	4.45	5.08	0.37	0.69	4.29	5.33	0.27	0.74	3.99	5.00				
Keys					0.48	0.78	3.14	4.40	0.57	0.98	2.55	4.10	0.53	0.85	2.97	4.35
Talbott	0.29	0.54	3.28	4.11	0.17	0.76	2.76	3.69	0.17	0.78	2.27	3.22	0.20	0.81	1.97	2.98
	2nd week, $P_B = 485$				3rd week, $P_B = 485$				4th week, $P_B = 455$				5th week, $P_B = 485$			
Dill	0.63	0.85	1.97	3.45	0.36	0.66	1.99	3.01	0.65	0.82	1.66	3.13	0.52	0.77	1.87	3.16
Hall	0.68	0.79	3.05	4.52	0.47	1.00	2.99	4.46								
Forbes	0.63	0.81	3.08	4.52												

young men it may be explained in various ways, including the long-continued after-effects of strenuous exercise. Nothing unusual was noted in the responses of the heart rate or blood pressure.

The gradient of pCO_2 from arterial blood to alveolar air was normal, but the gradient of pO_2 from alveolar air to arterial blood was greatly increased, about 12 mm as compared with about 3 mm in the same subjects 27 years earlier and in the two young men in our party. This increase indicates a reduced diffusing capacity or an increase in the pulmonary ventilation-perfusion imbalance. Despite a greater pO_2 gradient, the percentage saturation was attained, in part at least, by maintaining a more alkaline reaction in arterial blood; the pH_s was at least 0.05 greater than in 1935 for roughly equivalent conditions.

More marked individual differences were observed than were seen in 1935. Dill, who has periodic difficulties with bronchial asthma, soon became free of symptoms. His immediate respiratory response was poorest: at the first station his pulmonary ventilation and pH_s had not responded adequately and his saturation was only 76 percent. A week later at the summit it was 71 percent, and 3 weeks later at the summit it was 81 percent. Response of vital capacity covered a wide range: in five of us it was up or down without a regular pattern. The exception was Talbott, whose vital capacity declined with each station: 10 percent at the first, 20 percent at the second, and 27 percent at the third.

SUMMARY

Six of the eight survivors of the International High Altitude Expedition of 1935 returned to high altitudes in 1962 for followup studies. While their responses were youthful in some respects, they differed quantitatively or even qualitatively in some respects. The oxygen gradient from alveoli to pulmonary capillaries was greatly increased, basal metabolism was elevated, and the arterial blood was more alkaline. The major difference was in hemoglobin concentration: instead of rising rapidly, it declined in five subjects and rose quite slowly in the sixth. Eventually it began to increase. Further studies are required for better understanding of these responses.

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were both subjects and investigators; they lengthened their stay on this account. Ancel Keys, R. A. McFarland, and J. H. Talbott each took a week out of busy lives to participate. All tolerated the discomfort and even the ordeal of arterial punctures with scarcely a murmur. Our exercise studies were carried out with Bruno Balke and will be reported jointly with him. Finally, the summer's work was brought to a successful conclusion by Sid Robinson, then head of the Department of Anatomy and Physiology, Indiana University.

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INDOOR CLIMATE

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SUMMARY

Indoor climate is discussed in terms of associated factors: atmospheric dry bulb temperature, relative humidity, air velocity, mean radiant temperature, and air contaminants, particularly carbon dioxide, control (heating, air conditioning, and ventilation), optimum climate (activity to be conducted), and effectiveness of control (optimum from 97 to 70 percent). Variables affecting control include sex, age, weight, degree of acclimatization, type of activity, and clothing. Man's interaction with his atmospheric surroundings is defined as a zone or band, rather than a straight-line relationship.

INTRODUCTION

The purpose of this presentation is a general discussion of the factors that we normally associate with indoor climate and of their effects on the people who are confined within indoor spaces. My contacts with certain researchers indicate that we are just beginning in this area and that we may find some radically different approaches to housing, house construction, construction materials, and the whole matter of the structures in which people live and work and move around. Some of the very fundamental concepts of housing are strictly traditional—things are done because they have always been done that way. I think that we are going to have some real breakthroughs in housing.

When we discuss indoor climate, we usually consider such things as atmospheric dry bulb temperature, relative humidity, air velocity, and a long-neglected element, the temperature of surrounding surfaces—sometimes given as the mean radiant temperature. Then there are what we might call normal air contaminants, if we think in terms of lecture halls, classrooms, theatres, homes, offices, and other structures that do not have industrial contaminations. Industrial structures and buildings can present a whole new field of contaminants.

I have been doing some work with the Office of Civil Defense recently; when we talk about the civil defense shelters, we must take into account factors that we do not normally consider—such things as the carbon dioxide content of the air and oxygen depletion.

CONTROL

We can approach this matter of indoor climate from the standpoint of its control by heating, air conditioning, ventilation, or some combination of these. Or we may consider a climate that we are simply checking to determine its acceptability and whether it will adversely affect some operation. This approach, of course, requires a somewhat different type of analysis. Even when an indoor climate is controlled, certain activities or operations are involved. Specification of the most desirable climate cannot be separated from the nature of the activities to be conducted in the enclosed space.

INDICES OF COMFORT

Let us discuss specific indoor spaces with controlled climates. We most frequently control the climate from the standpoint of comfort. The factors that affect the comfort of an individual are such that regardless of what you do to the climate, not everybody will be comfortable. The Heating and Ventilating Society at one time produced a comfort chart showing "percentage of people feeling comfortable." The maximum shown was 97 percent; this was with very carefully controlled conditions that were varied until the maximum number of people said they were comfortable. In a less idealized situation about the best one can do is to get about 70 percent of any statistically average group comfortable. Among the variables are sex, age, weight, degree of acclimatization, type of activity, and clothing. Since these factors vary among individuals, it is impossible to devise any set of conditions that will make everybody comfortable. Since all of these factors do affect comfort, it is little wonder that researchers have failed to develop one single index number to specify degree of comfort, although they have tried very hard to do so.

The list of the indices of comfort that have been proposed and evaluated is very long. Gagge has proposed "operative temperature"; Missenard has proposed a "resultant temperature"; Vernon and Warner have proposed a "corrected effective temperature." There is the concept of "effective warmth." There is an "effective temperature," originated by Houghten with the Heating and Ventilating Society laboratory in about 1923. The Heating and Ventilating Society has since proposed a "revised effective temperature." An "equivalent temperature" is more commonly used on the continent and especially in England. This terminology was developed by Duffton, who proposed it in 1932. He worked with a device that he called a eupatheoscope, and in 1936 he developed a Mark II eupatheoscope. When you check the literature on this "equivalent temperature," you must find out whether the reference concerns Duffton's 1932 or Duffton's 1936 instrument. Then, in a conference sponsored by the Office of Civil Defense a physician from the Navy presented a paper indicating that the Navy didn't approve of any of these indices; the Navy uses a term called "effective temperature"—the same name as that used by the Heating and Ventilating Society, but calculated in a totally different way.

BODY ADAPTATION

My reaction to this confused situation is that each of these concepts has substantial merit. But we must consider that man's inter-reaction with his atmospheric surroundings is not a straight-line proposition. That is, human physiology does not have a single variable by which it controls temperature, the control varying in some sort of a straight-line relationship with any one parameter. The human body adapts itself to its surroundings by different mechanisms when subjected to different thermal surroundings.

Instead of trying to find a straight-line relationship, we can say that physiological reaction to thermal surroundings goes by zones or bands, depending upon the type of physiological adaptation that the human body is making. I classify this adaptation into seven zones, or types, of reaction. I do this because the physiological reaction is different in each of these zones. When a person is normally relaxed and the body is making no particular attempt to adapt itself to its thermally related surroundings, there is no particular dilation or contraction of the blood vessels and no abnormal pulse rate or anything of this sort. I call this the Neutral Zone of Adaptation, which, in general corresponds to the Comfort Zone. What happens if the atmospheric conditions become warmer? (Not necessarily a matter of dry-bulb temperature or wet-bulb temperature or radiation, but perhaps a combination of several or all of these things.) If the body senses a warmer situation, the first thing that happens is a dilation of the peripheral blood vessels. This dilation transfers the blood circulation closer to the skin; it changes the thermal conductivity of the flesh, and it changes some of the modes of heat exchange within the body. I find the human body to be a fascinating subject for engineering analysis. It has some very good built-in heat exchangers. When blood flows down to the extremities, the extremities tend to assume a temperature close to that of the deep-tissue temperature. The blood coming back dissipates heat through the flesh to the skin, whence it leaves by the standard heat transfer methods of conduction, convection, and radiation. This is in a condition that is just slightly warmer than normal or neutral. In the next higher zone of regulation we have a completely different mechanism for cooling. If this peripheral vessel dilation cannot regulate the amount of heat dissipation from the body, then we get into a sweating regime. The temperature at which sweating starts is different for different people, and it is also different with different levels of activity. But when sweating starts, heat is dissipated by evaporation. Thus we cannot assume a straight-line relationship based on temperature to indicate heat dissipation when one form of heat dissipation is by radiation and convection and another is by evaporation. The next zone might not be classed as a separate zone of regulation because it is the zone beyond regulation. If the thermally related conditions are such that the body cannot dissipate heat at the correct rate, then you go into a storage regime. Heat remains in the body, body temperature begins to increase, and if this continues for an extended time you just have to write off the individual as a dead loss. This is actually a failure of heat regulation.

Now let us come back down to the Normal or Neutral Zone and see what happens in the cooler situations. If the sensation devices within the body indicate that the heat dissipation is too great and that it should be reduced (and this is what happens when we feel cold), the peripheral blood vessels begin to contract; the blood circulation is still down the deep-seated arteries, but the return circulation is back up through veins that are deeper in the flesh and therefore further from the skin. This action changes the thermal conductivity of the flesh. It also puts the two streams of blood closer together dimensionally and creates a fairly effective heat exchanger, so that the warm blood going down the arms and legs is cooled by the blood coming back. You have a distinct drop in temperature of the extremities—the fingers and toes—and the blood coming back from these extremities is warmed by the blood going down. Nature is very effectively trying to maintain the temperatures in the vital organs of the body—the brain, the heart, the lungs, etc. This is, again, a method of heat regulation entirely different from the others. Now suppose that this still can't do the job. The body temperature continues to drop, and nature wants to take corrective action. The next step is for the body to start an involuntary action that increases the amount of heat generation; this is the shivering regime. The body actually does internal frictional work, which generates more heat energy and tries to compensate for this heat loss. Finally, if all of these regimes cannot control the situation, you again go into a negative storage situation. Body temperature starts dropping, and if it drops too much, you again have a failure of the heat-regulation mechanism.

The reason, then, that we have such a confused situation on comfort indexes is that the heat-regulation mechanisms operate in bands or zones, and no one index will give you a continuous line through all of these zones. These zones are not rigidly fixed; the boundaries between them vary among individuals. For example, the point of initial sweating may vary, even with people at rest, between 86 and 91.4 degrees. It varies even more with people under various levels of physical activity. In addition to these variations, research in the United States indicates that the conditions under which people are comfortable today are somewhat different from those shown by experimental results obtained back in the 1920's; these, in turn, differ very substantially from those that have been arrived at in England.

TEMPERATURE-HUMIDITY

In the zone of neutral adaptation, the comfort zone, apparently the principal parameter affecting comfort is the dry bulb temperature. Second to this is the temperature of surrounding surfaces; that is, the mean radiant temperature. Relative humidity seems to be much less important than was thought at one time. This was a defect in the original "effective temperature" of the Society of Heating and Ventilating engineers and the comfort zone that they established originally. Their latest revision shows that the majority of people are comfortable at a dry-bulb temperature of about 77.5°F.

The line is essentially a straight line and is virtually independent of relative humidity between values of about 20 percent on the low end and nearly 80 percent on the high end. The maximum number of comfort votes came at about 77.5 degrees. Now this value disagrees with results of studies in the 1920's, in which the maximum comfort temperature was somewhat lower—about 72°F. A very extensive study, also in the 1920's, by the New York State Commission on Ventilation for Schools placed the temperature for maximum comfort even lower, at around 67°F.

One of the experimenters in England has interviewed over 3,000 subjects in factories. The figures aren't meaningful until you know the conditions under which the studies were taken. This was a group of between 3,000 and 3,200 people, probably acceptable as statistically large enough. These were female factory workers doing light factory work, essentially sitting at tables. The maximum-comfort response for the group was listed at temperatures between 62 and 64°F, dry bulb.

I started working in the heating area nearly 30 years ago, and in the earlier days I did quite a bit of service work on heating plants. From time immemorial the standard heating specification in the United States has been 70°F, but in the whole time that I have been associated with the heating business I don't think I have seen a half dozen thermostats set at 70. I've seen them all the way from 72, which is a fairly common setting, to 74 which is also fairly common, and on up to 78.

The matter of humidity, as far as comfort is concerned, is even more controversial than temperature. In one reference I can cite, the author makes the flat statement that there is absolutely not one iota of experimental evidence to indicate that humidity has anything whatsoever to do with comfort. I suspect that this is a somewhat biased position, because this gentleman is arguing for low humidities in residences. He contends that high humidities are doing some structural damage to residences. Now maybe the effect of humidity has been overestimated, but I could not go along with the statement that there is not one single item of evidence to indicate its effect on comfort. I think that the old comfort chart of the Society of Heating and Ventilating did overemphasize the effect of humidity. Regardless of the effect of humidity on the sensation of warmth (you see I'm not saying "comfort" now, I'm saying "warmth"), I think that in a range of possibly 20 to 80 percent relative humidity there is not much effect. An indoor climate that is too dry produces side effects that are highly undesirable and tend to make the individual highly uncomfortable. For example, when the relative humidity drops too low, I immediately begin to get a dryness of nose and throat that is extremely irritating.

MEAN RADIANT TEMPERATURE

In the United States the matter of mean radiant temperatures was long overlooked. In the original research of the Heating and

Ventilating Society on comfort, the subjects were tested in a test chamber in which the walls were at the same temperature as that of the air; the effects of mean radiant temperature were completely masked in this study. Although this study was a monumental breakthrough in the study of comfort, we must recognize that it was done before all the factors were tied down. Baker, in England, started working on radiant heating concepts, and one of his disciples, Adlam, came over to the United States and carried the gospel over here. While I am not a strong exponent of radiant heating, I think that one thing that this movement did was to emphasize that there is such a thing as a radiant effect that must be taken into account. The general rule of thumb is that you can drop the air temperature in a room 1°F for each 1°F increase in mean radiant temperature, starting at about 70°F.

There may even be some directional effects in radiation. The mere fact that you have a high mean radiant temperature does not assure comfort if you have a situation like that in many school buildings, where windows contain a single glass and the student's bodies radiate to this glass. Even a corresponding high-temperature-radiating surface in some other direction may not produce comfort. Nevertheless, all kinds of ridiculous commercial claims are made in respect to this situation. One company manufactures a school heating unit that throws a curtain of warm air up over the glass; some of their salesmen claim that this blocks the radiation to the glass. If you can block radiation with an air current, you are doing something that I never had explained by basic physics. You can force enough hot air up over the glass that the rate of heat transfer through the glass climbs to such a high level that the surface temperature of the glass increases and thereby reduces the amount of radiation. But this seems to be to be doing it the hard way.

MODEL SETTINGS

To summarize this part of the discussion, we can say that most commercial specifications accept 70°F dry bulb as the correct winter temperature. Humidity is usually specified somewhere between 30 and 40 percent for winter comfort conditions. But most thermostats are adjusted somewhat higher. Summer conditions almost universally are specified at 80°F dry bulb and 50 percent relative humidity. Summer conditions are a little more complex. In the summertime there is a question of just how much comfort you can afford in a given air-conditioning situation. Certainly it is beneficial in certain industrial and commercial applications to maintain a temperature below the sweat point, even if it does not produce complete comfort. For example, if you maintain a drafting room below the sweat temperature, you will improve the quality of the tracings tremendously.

The ideal condition also seems to depend on the period of occupancy. At one time we felt that severe physical hazards are involved in going into a hot atmosphere from a cooled space and also in coming to a cooled space from a hot atmosphere. Recent information indicates that this does not produce much chance of physical damage, but certainly it does produce a psychological shock. To condition a store or commercial building for people who are coming in, staying in a short period of time, and going out, you raise the dry-bulb temperature somewhat and also produce a compensating effect by reducing the relative humidity. If you work with nature and set up a situation in which the perspiration can evaporate quite readily and let this do a part of the cooling job, then you can produce some fairly comfortable conditions even at high temperatures. We are now talking about the regime in which there is enough sweating to make this effective. If temperatures are below the sweat point, relative humidity will have virtually no effect. When you complete the design, set up the specifications, and get the equipment installed, you'll probably find that the owner has arbitrarily set the thermostats for the comfort of his employees because he says clerks are harder to get than customers.

SPECIAL APPLICATIONS

I want to add a few footnotes here about some special applications. The Federal government, through the Department of Defense, Office of Civil Defense, is dispensing information on engineering requirements for fallout shelters. A fallout shelter is a space that provides a reduced incidence of radiation; if you stay in this shelter for approximately two weeks, the radiation level outside should have fallen enough that you have a fair chance of survival. Here you are not designing for a plush situation in which people can relax and enjoy themselves in complete comfort for 2 weeks. You want the people to survive, and also to be able to do certain tasks when they leave the shelter. We are trying to find some happy medium between plush comfort conditions and the minimum conditions required for survival. One of the first problems you encounter in the design of mechanical equipment for fallout shelters is oxygen concentration. Air normally contains about 21 percent oxygen; if the percentage goes below about 14 percent, then you begin to encounter difficulties with the respiration processes. Fortunately, this is one of the easier problems in fallout shelter design. With blast shelters or with biological and chemical warfare shelters, which must sometimes be buttoned up absolutely tight, you may run into difficulty. Also in a submarine or any other completely closed container for human beings, oxygen concentration may become a matter of grave concern. In the design of fallout shelters, however, some other parameter usually is more important than the oxygen concentration. One of these is the carbon dioxide concentration. At present it is considered that a 3 percent concentration will impair functioning—people can't perform minimum routine tasks properly. The thinking recently was that with 1½ or 2 percent concentration, people would not be physically impaired. Later research has indicated that such concentrations do produce very definite physiological changes, some of which will continue to affect a person for a week or so after he leaves the environment if he has been exposed to it continuously. Here again, you must try to devise experiments that are directly related to actual situations. In the initial studies on carbon dioxide concentration the subjects were exposed to the test concentration for 8 hours. Then they left the test facilities, went home to go about their business—eating, sleeping, and other activities—for 16 hours in a normal atmosphere. Then they returned for another 8 hours under test conditions. Later, in studies in which subjects remained in the test atmosphere for 24 hours a day continuously, the experimentors obtained different results. The general thinking now is that carbon dioxide concentrations should be maintained not higher than 1 percent if the exposure is continuous and prolonged. Normally, if ventilation is sufficient to maintain a concentration of carbon dioxide below this level, then the oxygen concentration is also controlled to a sufficient extent.

Recently it has become apparent that substantially more ventilation may be required for heat removal from a fallout shelter than is required either to maintain oxygen supply or to diminish the carbon dioxide concentration. The body is undergoing metabolic processes at all times, and this energy must be dissipated. If a large number of people are concentrated in a small fallout shelter, fairly substantial amounts of sensible heat must be dissipated. If conditions put people in the sweating regime, or if such activities as cooking or washing throw moisture into the air, you must also remove substantial amounts of moisture. If you do it with ventilation, the amount of air required to reduce the moisture content of the air is often greater than the amount necessary to reduce the dry bulb temperature, and the amount required to reduce the dry bulb temperature may be substantially greater than that required to control the concentration of carbon dioxide.

CONTROL AND EFFICIENCY

To return to special applications, suppose you wish to specify an indoor climate for a factory. Is there any real reason why we should specify the climate that gives comfort conditions? This area has not been explored adequately by research. Ideally, since one operates a factory for a profit, one should try to establish a condition that yields the greatest rate of productivity from the workers. Very little work has been done on the correlation between indoor climates and the maximum efficiency of workers. A tremendous amount of work has been done on the limits within which the climatic conditions must be held for health reasons, and on how adverse the heat conditions can be before efficiency decreases markedly. Above certain temperatures, work effectiveness can drop off very fast and very substantially. When temperatures go over 100°F, specifically, effectiveness drops very, very rapidly. But in the range of normally acceptable factory conditions, I know of no research that indicates whether the temperature ought to be 60, 62, 65, 68, or 70°F for the greatest work efficiency.

Now we consider the indoor climate of schools. It is amazing how little statistically sound work has been done on schools. One study was made in New York back in the 1920's, and incidentally, some people questioned some of the statistical and test procedures used in that study. Aside from this study no well-documented research tells us whether students work more effectively and more efficiently at a comfort condition or at some other condition. Many spot checks are made, and all kinds of people are trying to promote ideas. At a recent meeting, one of the presentations was based on results obtained by a questionnaire. Teachers were asked whether they thought the students did better in air-conditioned classrooms or in non-air-conditioned classrooms. About 90 percent of the teachers replied that they thought that the students did better in an air-conditioned atmosphere. One of the representatives of an air conditioning company jumped up and said, "Gentlemen, we've got it now. Here's the message. Students learn 90 percent better in air-conditioned classrooms." We do have a tremendous amount of misinformation like this, but nothing that documents data on whether students derive more educational value in an atmosphere keyed to the maximum of comfort or whether control of the indoor climate should be based on something else. One piece of research indicates that sometimes subjects do better under a programmed fluctuation of indoor climatic conditions.

DISCUSSION

Question: Do you know of any studies of concentrations of carbon dioxide or any other chemical species in office buildings or similar areas?

Answer: No. I think 1 percent carbon dioxide is considered to be completely safe. Here again we may need longer-range studies, such as those that changed the concept from 2 percent to 1 percent. According to current thinking, 1 percent is satisfactory and it's almost impossible to button up an office building tight enough to attain this. Natural infiltration will hold the CO_2 concentration below that level.

Comment: We are very much concerned about the outside atmosphere and about the industrial hygiene atmosphere; but huge numbers of our population live indoors most of the time—certainly in the winter, and for at least 8 hours a day in the summer in metropolitan areas—yet we apparently have no concern, not from the heating and ventilation standpoint but from the general atmospheric standpoint, with the atmosphere we live in. Now if this atmosphere is identical with the outside atmosphere you can say, "Well, it doesn't make any difference." But is it identical? And if not, how does it vary from the outdoor atmosphere?

I could also have discussed the matter of odor control. One of the things that concerns me is that some of the odor control devices simply depress the nerve sensations of odor, and all the chemicals involved in the odor are still in the atmosphere. Is this a satisfactory situation? The individual just doesn't know whether odors are present. But they're still there. This area of research has been somewhat neglected.

Question: Would you say something about the geographical regional differences of comfort in buildings? Do you have the same comfort conditions in an arctic climate and a southern climate?

Answer: Two of the relevant factors here, even for one given individual, are the type of clothing customarily worn and the state of acclimatization. Dress habits vary from one section of the country to another. Since comfort is essentially based on a regular heat dissipation from the body, the matter of neutral zone and the matter of comfort can really be brought down to the concept of the body generating a certain amount of energy, part of which goes into work and part of which goes into heat. The heat must be dissipated. Now, very obviously, various weights of clothing, as an insulating effect on the skin, will vary the rate of heat transfer from the skin. Regarding acclimatization, it is definitely known that when you are thoroughly acclimated to one set of situations and move to another, if the changes are extreme, then the physiological changes are pronounced. The quantity of blood that is in circulation varies. The body thins out the blood and produces more blood for circulation under certain conditions. These two factors, clothing and acclimatization, vary considerably from one point to another, and the atmospheric conditions for optimum comfort also vary. One rather extensive study was made in four or five key locations in the United States on optimum conditions for summer comfort. Results did not show much variation. But as I have mentioned, the variation between comfort standards in the United States and England is wide.

Question: What would be the role of the psychological effects here—the perturbation of the normally expected heating or cooling situation? In England, where central heating is much more rare than here, don't the people normally anticipate that the best you can have could be less than you have here? You'd expect the temperature at which they'd be satisfied to be lower, just as if you went back in time in the United States, into the 19th century. You would find increasingly lower temperatures that were satisfactory in terms of comfort. And conversely, as you press more and more air conditioning on the population, aren't their demands in turn going to vary in terms of wanting cooler and cooler summer temperatures or else being less and less satisfied? In a southern state in the summertime, 85°F was considered really nice 30 years ago. Now, with air conditioning, 85° is no longer satisfactory in terms of humidity.

Answer: Psychology is a very, very real consideration. An early investigator once undertook to referee a dispute about comfort in an opera house. The conductor wanted one particular set of conditions, and one of the singers wanted some different conditions. In the language of today, the investigator concluded that people are so darn ornery that there is no way to reconcile these differences. And since there is no scientific way to establish who is right, you just ignore the people. You set the conditions according to the standards and let the people conform.

Question: You used the term "conditioning" as a factor in comfort. Is there any evidence to suggest that you can condition people to a lower temperature with comfort through exposure?

Answer: I can't cite specific research, but I am firmly convinced that this is so. The matter of physical condition does have some effect. When you install an air conditioning system, the most difficult space to condition is the one that houses the high-level executives. At a tire plant one time, the works engineer had been out with the flu. He came back to his office much sooner than he should have. He reported that the office was drafty and uncomfortable and totally unacceptable. We moved in a portable temperature recorder, a portable humidity recorder, and I think even an anemometer. We let them sit there for about 4 days and did absolutely nothing else. By the end of the week he was perfectly comfortable. We had done nothing but let the recorders record; but in the meantime he had finished getting over the flu, which he should have done at home, and was perfectly comfortable. So I'm quite sure that physical condition has a marked bearing on some of these things.

Comment: Regarding this situation in England, I think dress habits have a great deal to do with it. A friend of mine just returned from 6 months at the Rothamstead Experiment Station in England. The laboratory there was kept at 59 degrees. They really piled on the sweaters and jackets.

Question: I want to ask a question in regard to adaptability, whether it is a matter of physiology. In the case of sex—women versus men—is it a matter mainly of adaptability in that women apparently are able to adapt themselves to cold weather with lighter clothing than men? Or is it the question of fat tissue that insulates a little better?

Answer: I'm not enough of a specialist on the subject of females to answer this completely, but as I have mentioned, the conduction of heat is a primary consideration. You see the body has a forced-circulation heat dissipation mechanism—you couldn't call it a hot water system, it's a hot blood system—for conveying heat out of the deep tissue and getting it to the peripheral members. From there it must be conducted out to the skin and dissipated. As you point out, women do have a layer of fat under the skin that definitely affects the thermal-conduction characteristics of the flesh.

Comment: I'm a good observer of women. In Brazil while I was there the temperature got down to 77 and this was considered cold weather. The girls started putting on sweaters; they thought this was actually cold.

Question: Would you comment on air movement or ventilation rate in relation to discomfort?

Answer: Two elements are important with respect to the air movement rate. One, that in the standard formula for calculation of convective heat transfer the heat-conduction coefficient varies with velocity. Further, in the evaporation of perspiration, if the air velocity is high enough to remove the film of high-moisture-content air that surrounds the body, then the moisture evaporates more rapidly. Air motion very definitely changes the heat-transfer characteristics. A further consideration, which has not been investigated enough, is that certain parts of the human body are more sensitive to air movement than others. You can tolerate an air movement from the front over your face to the back at a much higher velocity than you can tolerate a movement from the back of the head toward the front. Some studies have been made, too, on the effects of drafts on bald heads.

Comment: Perhaps we should make a distinction between being accustomed to conditions and being adapted to them. One tribe of Indians in South America lived down toward the southern extremity of the continent and were pretty primitive. They had never developed clothing. They used only capes made of animal fur, a cape that went around the shoulders and came down approximately to the waist. These people would go out in fishing boats in 30 to 32 degree weather. To protect their capes from damage, they hung them on the shore when they went fishing. So here were people with absolutely no clothing on in a climate of around 30°F. The human body is wonderfully adaptive if you omit the consideration of comfort. I can't conceive of those conditions being comfortable even to one who is thoroughly accustomed to them.

Question: Did this tribe die out after a while?

Answer: The last time I heard there were still a few of them left, but they were dying off at a very rapid rate.

Question: Did they die down after they introduced clothing?

Answer: As I recall, they proved to be very susceptible to white men's respiratory diseases, and this led to a very high death rate.

AIR IONS AND HUMAN HEALTH

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SUMMARY

Results from 50 years of research on the effects of aeroionization are not uniform, but norms pertaining to polarity, size, and motility of ions have been established. For treatment purposes the natural distribution and balance of ions, including numbers, proportions, and polarity, are changed radically. Patients respond to both negative and positive polarity. Although ionization is not a cure, it is effective in treating hay fever, asthma, and burns and in general post-operative care.

INTRODUCTION

I have to apologize for presenting a topic, the significance of which is still a matter of controversy. Scores of reputable investigators on both sides of the Atlantic have demonstrated convincingly the broad spectrum of the biological, physiological, and clinical effects of air ions. The very vocal opposition is by far less numerous, but more insistent, basing its objections on flimsy tests, poor equipment, inadequate technique, or the occasionally too-exuberant statements found in foreign literature.

We can look back to over half a century of research on the effects of aeroionization but must concede that the results are still not uniform. I come from a school carrying the proud name of a famous Philadelphian, Benjamin Franklin, the genius who demonstrated the existence of atmospheric electricity. This demonstration, however, has not stimulated the curiosity of environmental scientists. In fact, work in our field has been discouraged in various ways. Lack of support is certainly most embarrassing, since the development of suitable ion generators and ion counters must precede the experimental and clinical phases of research. Both require part-time cooperation of a mixed team of electrical engineers, biologists, physicians, laboratory experts, and medical technicians. In this stage of development, investigating the effects of air ions is not a one-man affair, and we miss very much the advice and help of a heterogeneous group.

HISTORY

The discovery of the principle of conductivity of the air by Elster and Geitel some 66 years ago, and the work successively by Wilson, Langevin, and Pollock, gradually led to the establishment of certain norms pertaining to polarity, size, and motility of ions. By 1903, the Russian Sokolov had formed definite ideas about the health-promoting or health-restoring value of the negative ions; shortly afterwards, in Western Europe, Ashkinass and Caspari came independently to similar conclusions. Credit for introducing artificially generated unipolar ions in experimental work goes to Tchijevsky, who, in his institute in Voronez shortly after the first World War, gave us the proofs of their biotropic potential. Dessauer and his co-workers in Germany, Edström in Sweden, Yaglou and his collaborators, and Bierman in this country added much to our knowledge and understanding of the physiological and clinical aspects of artificial aeroionization.

In the early 1930's work on ionization was completely abandoned in this country until, nearly two decades later, the late W. Wesley Hicks of San Francisco, manufacturer of electric heaters, with the brand name of Wesix, revived the interest in this modality. Complaints about discomfort in rooms heated electrically aroused the curiosity of Hicks and Beckett and led to construction of polonium ion generators. In 1953 we acquired one of these units and tested it on ourselves by sleeping under the generator for about 2 months. No after-effects were observed. Only then did we try this method on others. In the first year we treated 11 patients suffering from hay fever. The results were a complete failure. The twelfth patient, an 8-year-old boy with bronchial asthma, responded to inhalation of negatively ionized air. For the first time in years he could sleep through the night without wheezing and without shortness of breath. The following year, employing an improved Wesix generator, we were able to show positive results in cases of hay fever and selected forms of asthma. At that time we did not know much about the physical properties of ionized air and could not explain some common phenomena. Only during the last decade was a little knowledge accumulated.

IONS

As a physician I don't dare to present our version of the physics of ionization before this forum, since you know much more about it than we do. Some pertinent information has been gathered in years of practical work, however. Uppermost on this list is the fact that for our purposes we change radically the natural distribution and balance of ions. We modify their numbers, their proportion, and their polarities. Outdoors one always finds both polarities. Under no conditions does only one polarity, the positive or the negative, exist alone. With rare exceptions the positive polarity is always slightly preponderant over the negative. The negative ions discharge much faster, recombine, and therefore disappear much faster than the positive ions. Since ionization does not follow any political boundaries, we are living around the globe in an ionized atmosphere. How vital this is biologically is still unknown. Outdoor counts were made in Philadelphia by Davis and Speicher and in Richland, Washington, by Corrado. A limited number of indoor studies were conducted by Beckett, Hansell, Norinder, Siksna, and others. The most revealing findings came from Case Institute. Steigerwald, in cooperation with Weinberger and Lynn, reported that the polluted air in cities shows excessive amounts of large ions, both positive and negative, at the expense of the small ones, which are common in the fresh, clean air in the country.

RADIATION

Because of increased ultraviolet and cosmic radiations, higher levels of radioactivity, and lower relative humidity, we have even greater concentrations of small ions of both polarities in the mountains and substantially lower levels of the large Langevin variety than in the densely populated, industrialized areas with heavy motor traffic. We have learned that the outdoor conditions with respect to the polluted air are similar to those indoors. As long as the windows are open, concentrations of ions of both polarities are about the same indoors as outdoors. As soon as the windows and doors are closed, the number of the light, small ions of both polarities decreases, while the level of the intermediate and Langevin types goes up. Closing doors and windows brings the concentration of small ions in a room to a fraction of the ion levels outdoors provided, of course, that the soil or the building materials do not contain any radioactive substances. In some brick and stone houses the outside walls contain enough radioactivity to account for unusually high ion levels, sometimes much higher than outdoors. But that is only an exception.

POLARITIES

Common household activities, such as smoking and cooking, lower appreciably both polarities of light ions. After smoking, frying seems to be the greatest offender. At the same time, while the small ions decrease, the large, slow-moving ions of both polarites increase rapidly, creating an environment similar to one in the heavily contaminated city atmosphere. This is important since, according to Chalmers, there is an inverse relation between large-ion content and conductivity of the air.

Reinet took daily and hourly measurements of ions over a period of 2 years in Tartu. His metering device permitted simultaneous determination of both polarities of the small and the large ions. Aside from diurnal and seasonal differences he was able to show that the large ions predominate even in Tartu, which cannot match the traffic of an American city of its size.

I would like to stress that there are no such things as good negative ions or bad positive ones. Many patients respond to the negative ionization, but in some instances the positive polarity is more effective. The reasons are still obscure.

AIRBORNE ALLERGIES

After this long introduction I shall limit myself to the original theme, the influence of air ions on human health. As mentioned before, our first attempts were directed toward control of airborne allergies, in particular hay fever. We noticed that a large proportion of people in acute distress showed a substantial improvement up to complete cessation of all subjective symptoms; the improvement, however, was not lasting. Ionization does not cure hay fever. After the patient leaves the ionized room, up to 2 hours later all symptoms reappear. Patients with bronchial asthma due to airborne allergens respond differently. Once the bronchial spasm is relieved, the patients are comfortable for a few hours. While the wheezing frequently persists, the patients breathe freely and without effort. In the beginning of our work we were very careful. We exposed the patients for 30 to 45 minutes to relatively low ion concentrations. This procedure was dictated not so much by the fear of possible complications but by lack of better and more powerful equipment. With this initial experience on hand, we went a step further and tried to determine whether ionized air has any influence on the electroencephalographic activity of the brain. These experiments were done at the Graduate Hospital of the University of Pennsylvania. Silverman found that negative ionization gave a sedating effect similar to that of some tranquilizing drugs. We observed that persons exposed to positively ionized air had an increased respiration rate and complained of dryness of the throat, nasal obstruction, and occasional headaches. We were always alert to the possible effects of ozone. Ozone was regularly determined for a number of years but has not shown any appreciable increase in the treatment rooms above the background level. Dryness of the throat and nasal obstruction were the most common complaints of the people exposed to the positive polarity. Winsor and Beckett, working with a different type of equipment, noted similar after-effects.

BURNS

Besides the sedating and desiccating properties, ionized air has also a marked deodorizing effect. This suggested the use of ionotherapy in conditions where pain, discharge of serous fluid, and malodor exist, as in burns. The cooperation, openmindedness, and vision of Minehart and his associate, David, gave us the welcome opportunity to test the value of negatively ionized air on burns. The results were most rewarding. A very high proportion of patients claimed cessation of pain after the first 10 to 15 minutes of exposure. Secretion from the denuded surfaces of severely burned areas was greatly diminished, facilitating the formation of dry scabs. Dryness and the early formation of scabs greatly reduced the number of infections. To this date a few hundred burns of all degrees have been treated successfully with this modality.

POSTOPERATIVE CARE

The sedating and pain-relieving quality of negatively ionized air prompted us to broaden the scope of our investigations by extending it to postoperative cases. On Minehart's service, unselected patients were divided into two groups. One group received negative ionization; the other group was exposed to the same generator with the pilot light flashing and the fan running but without the ion-producing component. The results were quite amazing. About 50 percent of the patients who were treated postoperatively with negative ions for 2 days, six times for 30 minutes, were comfortable without additional narcotics, otherwise indispensable during this period. Peculiarly, certain postoperative patients do not react as well as others. For instance, patients having been subjected to herniorrhaphies or appendectomies responded rather well to negative aeroionization, while those having had oophorectomies and hysterectomies were not relieved of pain. Our experience with postoperative cases is limited to less than 200 patients including 50 controls. We understand that an osteopathic hospital in Stella, Missouri, successfully treated a few hundred postoperative patients, who required no narcotics, or only minimal amounts, during the early period of convalescence. The generators used in Stella were much more efficient than our own; the patients were exposed more frequently and for longer periods of time. In all probability, the higher dosage accounts for the better results.

In animals there seems to be quite a difference among the various species in response to artificially ionized air. Deleanu from the Department of Hygiene of the University of Kluj in Roumania, observed in animals many positive results with predominantly negative but also frequently with bipolar ionization. Since clean outdoor air features a preponderance of small ions of both polarities, we may be tempted to employ bipolar ionization indoors not for therapeutic purposes but only as a replacement of the lost light ions for restoration of natural conditions.

OBSERVATIONS

The reasons for the systematic debasement of and aloofness from aeroiono- and electro-aerosol-therapy are manifold, some quite obvious. For instance, placing the patients below an ion generator suspended overhead instead of facing it is perhaps only a technical mistake. Exposing asthmatics in attack-free intervals to ionized air is a regrettable misconception of basic facts. But misinterpretation of the results of one's own study belongs into a different category. After nearly three decades, the late C. P. Yaglou was allegedly unable to confirm some of his previous observations. A close look at his tables shows definitely positive results. Exposure of five infants being treated for malnutrition to very low concentrations of light negative ions twice daily for 2 hours for a period of 2 weeks, revealed that "the infants seemed to be more quiet and cried less during ionization periods than at other times of the day." All five had higher body temperatures and three out of the five gained weight during the 2 weeks of exposure. During the preceding and the following weeks no elevation of temperature was observed. Of six adult arthritic patients tested all felt relaxed after negative ionization. Only four of these patients were exposed to the positive polarity; all reported unpleasant or painful sensations after the seances. It is difficult to understand why the registered feeling of air freshness noted by some of the normal subjects under both polarities and the respiratory irritation after inhalation of positive ions, as compared with the controls, were entirely ignored by the same author.

Aeroiono-therapy is not a universal panacea, but it is certainly a valuable addition to our therapeutic armamentarium and is worthy of further exploration.

DISCUSSION

Question: I would like to ask the speaker what the mechanism of the effect of air ions could be. If we assume it is a chemical mechanism we could take a relatively high level of ions, such as 1000 ions per cc, convert it to its chemical equivalent, and derive something like 10^{-9} ppm. We know that even the most powerful or reactive chemicals would show hardly any effect at 10^{-3} ppm, so it is hard to visualize how there could be any appreciable effect from 10^{-9} This brings up one other point: every time you ionize air you form a certain amount of ozone. You could easily have 10^{-3} ppm and not be able to detect it without some very sensitive method, which, I think, is probably far beyond the capacity of the equipment today. Many of the symptoms that are attributed to ions are also symptoms of very low concentrations of ozone. For example, increased respiration rate occurs at very low ozone levels. To me the only possible reasonable explanation would be very low ozone levels, below the detection threshold of the equipment that has been used. I wonder if you could shed some light on these problems.

Answer: For a number of years we have carefully watched ozone concentrations, but could not find any appreciable increase over the background level. Someone even took the pains to report us to the state authorities, but the investigating engineers were completely satisfied and permitted us to continue our work with high-voltage ion generators. For 3 or 4 years we employed exclusively polonium and tritium generators, which have practically no ozonizing effect. Still, our clinical results were, except for the very first year, identical with our later findings. Krueger, Winsor, and Worden use or used in their experiments only radioactive isotopes for ion generation. Many of those present are acquainted with Krueger's ingenious experiments, which open entirely new vistas in the field of aeroionization. We are greatly indebted to him for laying the foundations indispensable in clinical investigations. By the way, contrary to reactions to ozone, the respiration rate declines under the influence of negative ions.

At present we are unable to answer the question about the modus agendi of artificially ionized air or electro-aerosols. There are a number of theories, but none appears convincing. This observation could be extended also to a substantial number of popular pharmaceutical products, whose effects are known but not the ways of action. We realize that only a relatively small number of charged gaseous or particulate molecules enters the respiratory tract through the nose and the oral cavity and that some of them reach the bronchi and the alveoli. We can practically exclude any other port of entry, since we cover the patient with nonconductive material. One school of thought, however, suggests that exposure of the unprotected body to high levels of ionization produces secondary induction currents. Tchijevsky and others exposed animals to a de-ionized atmosphere of unusually low ion concentration and reported peculiar results. It would be most interesting to conduct similar experiments on man and register his physiological and psychological reactions in such an unusual environment.

I presume that you are aware of the effects of certain synthetic fibers that produce relatively large amounts of static electricity. The French literature is replete with statements on the pain-relieving properties of fabrics made from polyvinyl chloride. These fibers produce negative static electricity. A substantial proportion of rheumatics and arthritic claim freedom from pain as long as they wear undergarments made from these fibers. This material is known also in the Soviet Union and recommended for similar conditions.

Question: Is the French polyvinyl material available here?

Answer: I think that a New York textile firm carries the French PVC fabrics. For some time we have been using special gloves made from this material for massage to learn if the negative friction electricity offers some additional benefits. At present, we cannot make any definite statements. It is interesting that while the thermal properties of worn underwear remain essentially the same, the static properties are greatly inhibited or entirely annulled if the garment is not properly washed every 48 hours.

Question: Awhile back the Meteorological Department at the Penn State University was interested in conducting some studies on the effect of ionization on the learning rate and perhaps the retention rate. Do you have any information on this?

Answer: To the best of my knowledge these studies were either never done or are still in a very early stage. The primary difficulty, as I see it, is the lack of powerful and reliable equipment.

Question: You mentioned that you have no information on measurements of natural ionization in South America. A study has been going on for a number of years in which the radioactivity from thorium-bearing sands is being measured. In Brazil, the World Health Organization, I believe, is supporting this study. The question came about because a number of areas have a large amount of thorium-bearing sands. In fact, whole cities are built upon this substance, and people have been living on top of this natural radiation for generations. This study is being done by the Catholic University in Rio de Janeiro, I suppose by the Department of Nuclear Physics. It has been going on for at least 5 years.

Answer: I have not been aware of this work in South America. However, South American medical literature sporadically brings papers related to the field of artificial aeroionization.

Question: In your experiments how do you measure the presence or absence of ozone?

Answer: We have been using the method of Crabtree and Kemp for determination of ozone. As mentioned before, our experience points to the need for a research team and constant supervision of patients during the treatment period.

Question: Have you published lately in this field?

Answer: Papers on the effects and the technique of aeroionotherapy were presented in May 1963 upon invitation of the X Health Conference in Ferrara and in September of the same year at the summer session of the Balneo-climatological Research Institute of the University of Rome in Montecatini.

Question: Was the professor Yaglou that you mentioned C. P. Yaglou?

Answer: Yes, the same man who in the early 1930's attributed to ionization a "normalizing effect" and three decades later denied everything, in spite of the obvious facts evident in his own data. These data show physiological or pathological effects, depending on the kind of polarity he used. It should be mentioned that with our present methods of assay we find that younger persons in good health are not responsive to ionized air. Children, older people, or persons under stress are susceptible, however.

Question: About a year ago the Farm Journal published an article on raising chickens in Wisconsin. I am curious about what they hoped to accomplish by using ionized air.

Answer: A paper on this topic was presented at an agricultural conference in Chicago in December 1962. As I understand, the investigator, an agricultural engineer, had later some difficulties with duplication of his original findings. The first impression was that the chickens exposed to negatively ionized air had, in comparison with the control group, fewer respiratory infections, an allegedly common condition in chicken coops, and that their weight was slightly higher. Somewhat similar observations on animals and chickens were reported by Tchijevsky, who claimed that the animals grew faster and reached their sexual maturity earlier under negative ionization. In this country, Worden of the Bonaventure University, has shown on golden hamsters that healing of surgical incisions and regeneration

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of severed femoral nerve were enhanced by a negative ion environment and unaltered by the positive. Worden noted in mammalian cell cultures a diminshed cell proliferation under the positive polarity but practically no change under the negative. We are unable to explain why a cell culture behaves differently from cells in situ in a living animal.

Question: You mentioned previously the difference in response to both polarities. In some cases there was a positive response to negative ionization and in some cases there was a positive response to positive ionization. Has anyone attempted to correlate these responses with different blood types or some other physiological phenomena?

Answer: As far as I know no attempts were ever made in this country to correlate the effects of unipolar ionization with racial, constitutional, or physiological characteristics of man. Healthy young persons are, in the opinion of many investigators, not suitable subjects for research in this field. In cooperation with Griffin we have exposed students for 30 to 60 minutes to negative ionization. No changes of blood pressure or pulse rate were noted. With few exceptions, the subjective reactions of these students were negligible. The response of a high percentage of patients in acute distress is quite different. The effect of the negative polarity on persons of different races or national origin was essentially alike. Our subjects were American whites and colored, European whites, and North-African Arabs and Berbers. The experience of foreign investigators seems to be similar. Our somewhat nebulous knowledge of the optimal dosage and polarity induced Malysheva-Kraskevich to make the following statements: "It is conceivable that identically charged ions may produce a different effect on the organism if administered in different concentrations and under different experimental conditions. It is possible too that the effect of identical doses will vary in relation to the length of exposure, and that heavy doses administered in a few sessions may act differently from small doses extended over a longer period. On the other hand, it may be assumed that in certain combinations of the fundamental factor (ionization) with definite experimental conditions (constitutional characteristics of the patient, his behavior, etc.) oppositely charged ions will not necessarily produce a reverse biological effect."

Judging from the number of participants in three congresses on aeroionization in the Soviet Union, we can rightfully assume that the interest in this field is especially keen there.

Question: Do I understand that the treatment of burns is effected by means of inhalation of ionized air?

Answer: In treatment of hospitalized burns, Minehart uses the open air method. The burned areas are not bandaged. The patient rests between two sterile sheets and remains covered except for the face during the periods of treatment. On very warm days some patients pull the covers partly off, but that is an exception and not the usual routine. In our series of treatments no attempt was made to eliminate other therapeutic modalities as intravenous fluids, antibiotics, or vitamins. Ion-therapy is used in burns only as an adjuvant to other established methods. Without any doubt, the results are greatly superior.

Question: Very often you hear the comment that people feel good under certain meteorological conditions, like before a storm or some weather fronts. I wonder if any measurements have been made under these conditions.

Answer: Continuous metering of natural outdoor ionization levels was undertaken in Boston by Yaglou; in Haifa, Israel, by Robinson and Dirnfeld; in Philadelphia by Davis and Speicher; and in Richland, Washington, by Corrado. The last two studies were published in the Proceedings of the International Conference on Ionization of the Air. Too many other meteorological factors are involved to permit evaluation of the biotropic effect of a single natural element. Only under laboratory conditions are such experiments possible.

Question: Are you familiar with the ultraviolet treatment of blood as a means of curing hepatitis? Is there any correlation between this and the negative ions?

Answers: I am only vaguely familiar with this method, but I don't believe that there is any correlation with aeroionization.

Question: Do artificially generated ions sterilize the air or precipitate the aerosols? Could this possibly explain the beneficial effects on humans?

Answer: Ions don't have a significant bactericidal or bacteriostatic effect but do precipitate the aerosols and have a marked deodorizing force. The walls and the ceilings in the sick rooms are getting very dirty already after a few months of intermittent employment of ion generators.

Question: In the recent Russian literature a paper describes the ionization of air in a chamber that destroyed microbiological aerosols. Ions were generated by a water jet; papers in the American literature discuss alterations in humidity having a bactericidal effect on suspended organisms. I think possibly some confusion has arisen. The Russian investigator is perhaps getting a humidity effect and not an ion effect.

Answer: We have great difficulties with the Russian literature, since we cannot afford complete translations. I am not acquainted with their method of sterilization of pathogenic aerosols. In this country, Krueger did some related work.

Therapeutic employment of charged water aerosols, known in Western Europe under the name of electro-aerosols, was introduced in Wiesbaden, Germany, a known spa, where a hypotonic natural mineral water, was used for inhalation therapy in respiratory ailments. In later years, a negative electric charge was added. Such inhalation units are being commercially manufactured in Cologne and more recently also in Dallas, Texas. Wehner has introduced electro-aerosol therapy (or as the Russians call it hydro-aeroiono-therapy) in this country. He has published detailed reviews of the available literature and his own most remarkable clinical results in respiratory conditions. The steadily increasing numbers of upper respiratory allergies, chronic bronchitis, asthma, and pulmonary emphysema as sequelae of atmospheric pollution emphasize the need for this form of adjunctive therapy proven most successful on thousands of victims here and abroad.

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ECOLOGICAL PERSPECTIVE IN BIOMETEOROLOGY

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SUMMARY

The meteorologist's atmosphere-oriented data when used by the biologist in solving biological problems must be reinterpreted in terms of "life." Essentially the parameters established have meaning in terms of flow of energy, and this flow as temperature affects the internal physiology of the body and, in fact, determines its survival.

INTRODUCTION

I want to give you an approach to bioclimatology and biometeorology that I have taken in connection with the studies of vegetation. What I have to say about plants is equally appropriate for animals. The techniques are the same.

The very first concern is the matter of definitions. If we say we're going to study climate, we must also say for what purpose. Lack of definition has persisted in ecological work for the last half century. There are two definitions of climate, one pertaining to the atmosphere and the other, to life. In studies of biological organisms it is rather astonishing that the first definition has been used so consistently, and the second has been almost totally ignored. The meteorologist, in studying the atmosphere, has defined certain parameters that must be registered and studied to evaluate the properties of the atmosphere. He has measured these parameters—he has set up networks. The biologist, far too often, has taken over the meteorological data for various correlations in biology, without critically questioning the application of the meteorological data to the biological problem at hand. It is not difficult to delineate this very clearly in the literature —to show where some property, such as growth of an organism or plant, has been correlated with mean temperature, or maximum temperature, or the rainfall pattern.

But we must be more specific. We must ask "What do these parameters mean?" Well, they have meaning in terms of the flow of energy. It is actually energy that is transferred and consumed. It is not sufficient to talk about temperatures per se, or moisture per se, or any other parameter.

TEMPERATURE

Figure 1 shows the normal temperatures for certain animals and groups of plants. These are normal body temperatures, with the maximum and minimum temperatures known for survival. This information comes from the handbook of biological data. Although not highly accurate, the data do indicate the temperature situation in plants and animals. For many organisms the survival regime is in the vicinity of 40°C. This is very striking. Some plants tolerate only up to about 40°C, and others up to 50°C. Particularly interesting are the thermal blue-green algae, which exist at temperatures as high as 85°C. (If you put your hand in water like that you will burn it, of course.) Lichens have been observed to survive up to 100°C.

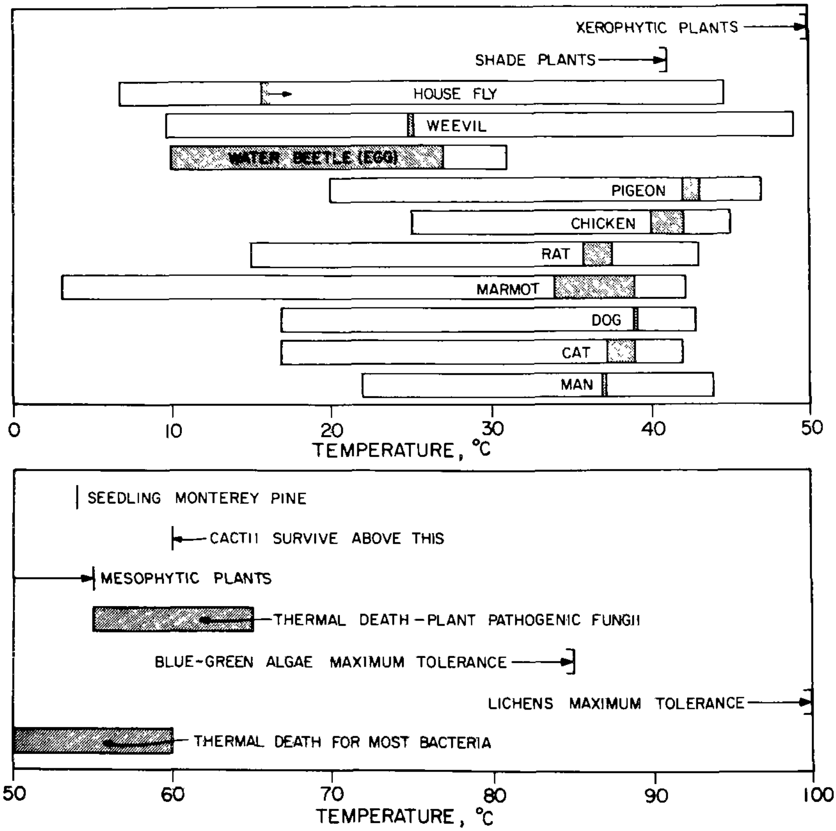

Figure 1 — Normal body temperatures of animals and plants and maximum and minimum extreme temperatures for survival.

Now the question of temperature has enormous meaning. It is a matter of an organism in an environment, the environmental characteristics affecting the temperature of the organism, and then the temperature of the organism affecting its internal physiology. The rate chemistry is very dependent upon temperature. Many proteins are destroyed by moderately low temperatures. Certainly many proteins are destroyed in the range of 50 to 60°C; and since some plants tolerate much higher temperatures, we must ask the question "Are the proteins of some plants, such as the thermophyllic algae, such that they are not being denatured in the same way as the proteins of other plants and animals that survive only at considerably lower temperatures?"

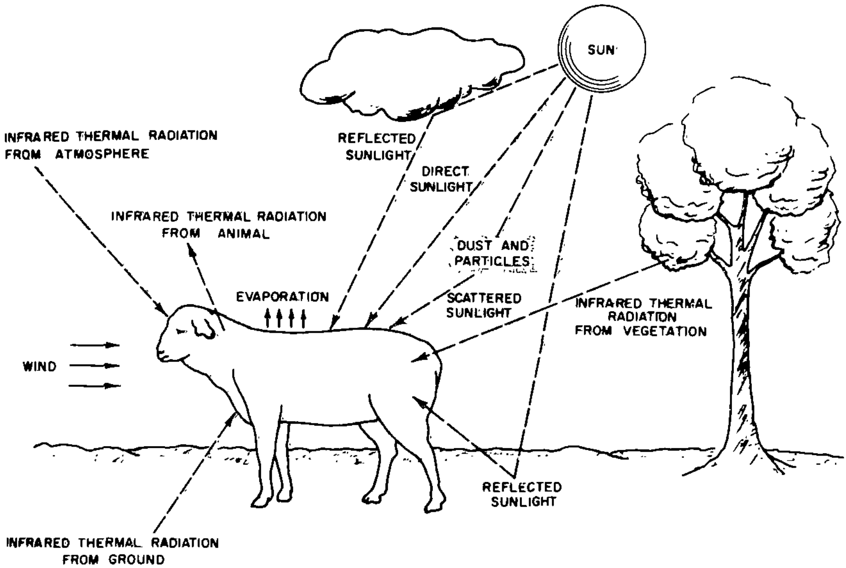

Figure 2 — Streams of energy to and from an organism in its natural environment.

RADIATION

Figure 2 is a schematic view of an organism in a normal external environment, consisting of radiation, wind, and water. All objects at a temperature above absolute zero radiate heat according to the fourth power of their temperature. You get radiant heat from the trees, rocks, and clouds. When clouds are absent, the surface of the earth becomes much colder at night than when they are present. The ground radiates heat thermally, and the atmosphere radiates heat. This is particularly important, because without radiant heat from the sky, our environment would be very much colder. Each of us radiates heat individually, at a rate approximately equivalent to a 100-watt bulb. This heat loss must be compensated by the flow of energy in the environment. Here in this room you are in a pure infrared radiation environment; you're in a black-body cavity. It's very easy to define the energetics of this environment: there is a small amount of convective heat transfer due to the flow of air, but since there is not much wind in the room, it is essentially a radiant-heat thermal environment, pure and simple. If the wind blows and it is warmer than the air, it delivers heat to the organism. If it is cooler, it abstracts heat from the organism.

SWEATING

Many organisms have the ability to sweat—to evaporate moisture to reduce the heat stress—and save their lives through the exchange of water. Certain animals, like the salamander, can sweat profusely. It sweats like a wet-bulb thermometer and cannot survive a dry atmosphere. In a dry atmosphere a salamander would lose 9 times its body weight in 24 hours. It must live in a humid microclimate, near streams, under rotting decayed logs, in order to survive. On the other hand, most insects cannot lose much moisture and have essentially no control over their body temperature and their survival through moisture. By virtue of size, they cannot lose much moisture, and also most insects have a very impervious, chitinous shell, which reduces the loss of moisture to a very small value. You and I have the ability to sweat when we need to reduce the heat load and keep our temperatures down.

FLOW OF ENERGY

Figure 2 depicts environment as a flow of energy, and this is the manner in which we must evaluate our environment. If we consider meteorological parameters, such as air temperature, relative humidity, and wind speed, we must use these properly to evaluate the flow of energy. It is often fortuitous when you correlate the biological behavior of some organism's growth, or distribution, or some similar factor, with temperature and you get a good correlation. It is fortuitous unless you really can show why a correlation should exist. Is there a causal relationship? That is the question to be answered.

PLOTTING

Figure 3 shows the spectral distribution of direct sunlight and some of the molecular reactions that occur in response to various frequencies of radiation. The scale is frequency or wave-number scale, which is the reciprocal of the wavelength. A wavelength scale is shown at the top. The distribution of sunlight outside the atmosphere is the solid line. Notice that the spectral distribution now peaks in the near-infrared when plotting against wave number, rather than in the green as on all wavelength plots. The peak of solar energy distribution is not in the green of the visible. A lot of fiction has grown up around this idea that the sunlight peaks in the green. We are told that this is one reason why plants are green, that the human eye has its peak response in the green for this reason, and other similar phenomena. This is not true. If you plot the distribution of sunlight on a wavelength scale, you do get the peak in the green. But if you plot it on any other scale, you get the peak elsewhere. When you plot it on a wavelength scale, you are plotting the amount of energy per unit area per minute per wavelength increment. When you plot it on a frequency scale, you plot the same energy per unit area per minute per frequency or wave-number increment and that changes the shape of the curve. There is nothing sacred about per wavelength increment, anymore than there is anything sacred about the wave-number increment. The important thing is not where the peak is, but rather how much energy occurs within certain frequency or wavelength intervals. The same frequency interval or wavelength interval would give the same amount of energy on any plot, but the curve has a different shape. I just wanted to point out this feature so that you don't think always in the old patterns. For the extraterrestrial distribution of sunlight, 50 percent is in the infrared, about 30 percent in the ultraviolet, and only about 20 percent in the visible.

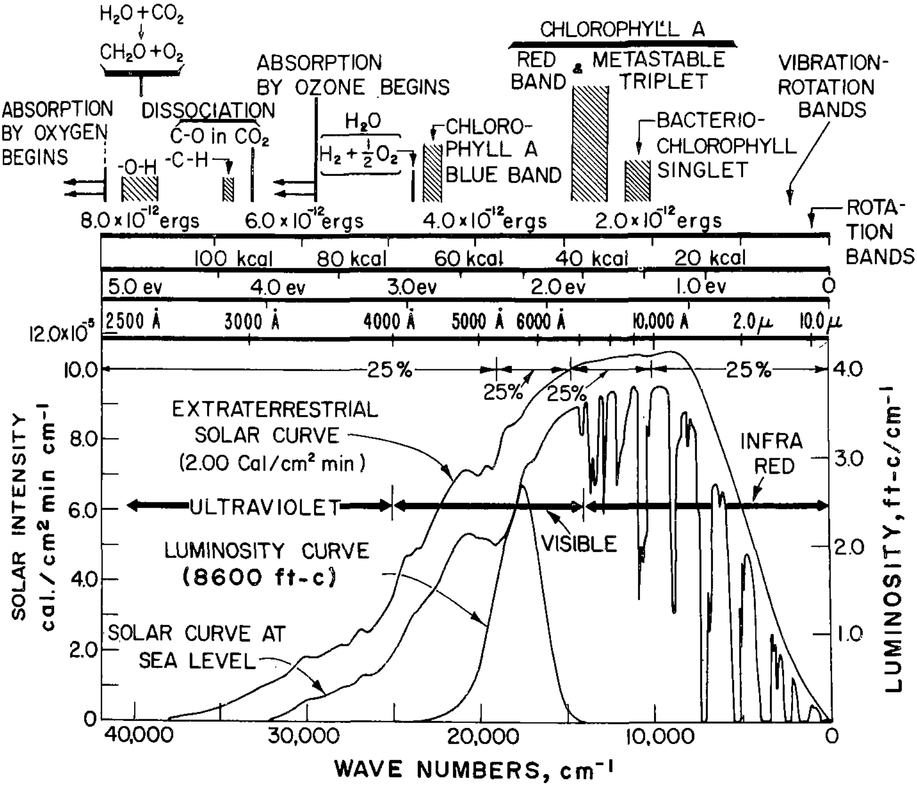

Figure 3 — Spectral distribution of solar radiation as function of wave number. Wavelength scale is given above curves. Energy content of each quantum of radiation is shown in ergs, kcal, and electron volts. Reaction that may occur in plants or animals when irradiated with each quantum of radiation is shown at top.

SOLAR RADIATION

The solar radiation reaching the earth's surface is also shown in Figure 3. The incident radiation is strongly absorbed by water vapor and carbon dioxide in the infrared, strongly cut off by ozone and Rayleigh scattering in the incident sunlight at the earth's surface as ultraviolet. The human eye will see the incident sunlight at the earth's surface as approximately 8,600 foot-candles, and the response is shown in Figure 3. A great deal of observations in the natural environment have been made in foot-candles. The foot-candle is useful if you're interested in the spectral distribution within the sensitivity limits of the human eye, but it does not give a measure of the ultraviolet or infrared intensity. The foot-candle measurement has hurt us very seriously in terms of making use of a vast amount of old data for biological studies. Above the spectral curves the energy content of each quantum of radiation is given as a function of the frequency. Three different scales are shown, depending on whether you think like a physicist or like a chemist. To define it in terms of the strength of bonds, we give it here in kilocalories, as well as in ergs. In the visible, there is useful, bond-building, molecule-building, photochemistry generated by radiation and plants or animals. The chlorophyll bands are located here. In the infrared, the energy absorbed by any organism simply goes into kinetic energy of vibration, translation, and rotation. In other words, the infrared energy absorbed largely goes into heating an organism, and the heat helps to maintain body temperature at a point where active physiological and biochemical processes can be carried on. In the ultraviolet, the quanta absorbed largely go into breaking bonds or breaking molecules down. Too much ultraviolet radiation, of course, causes a destruction of organic complexes rather than a building up. There are, therefore, the useful photochemical region of the visible spectrum, the heat region in the infrared, and the destructive ultraviolet.

CARBON DIOXIDE

Figure 4 shows the bands of infrared radiant heat that come from the atmosphere toward the ground. If our atmosphere were comprised of only oxygen and nitrogen, as it is primarily, and had no water vapor or carbon dioxide, the earth would be very much hotter on the sunlit side and much colder on the dark side. Life on this planet would not have evolved to its present form, because of extremes of heat and cold. Although these are minor constituents (CO_2 is 0.03 percent by volume, and water vapor is highly variable, but seldom as much as 2 percent), they do a great deal toward conditioning and controlling the climate of the earth.

The idea that an increase in the CO_2 concentration of the earth's atmosphere has produced a warming of the earth by about 1.5°C during the last half century does not seem to be correct. It appears that such an effect would have required a far greater change in the CO_2 concentration than actually has occurred. A law in physics says a good absorber is a good emitter at the same wave length. Now if the atmosphere were black and absorbed throughout at all these wave lengths, then it would reradiate according to the solid line shown in Figure 4. But the atmosphere is not black; it is only semitransparent, and it absorbs in specific bands. The atmosphere then reradiates energy in these same bands: the radiant energy at 6 microns is due to water vapor, at 9.6 microns to ozone, and at 14 microns to carbon dioxide; practically a continuum beyond 22 microns is due to water vapor. The reason the CO_2 theory of climatic change does not work well is that the CO_2 emission at 14 microns is strongly overlapped by absorption and emission by water vapor. The overlap by water vapor washes out any effect of radiation exchange on the planetary temperature caused by CO_2.

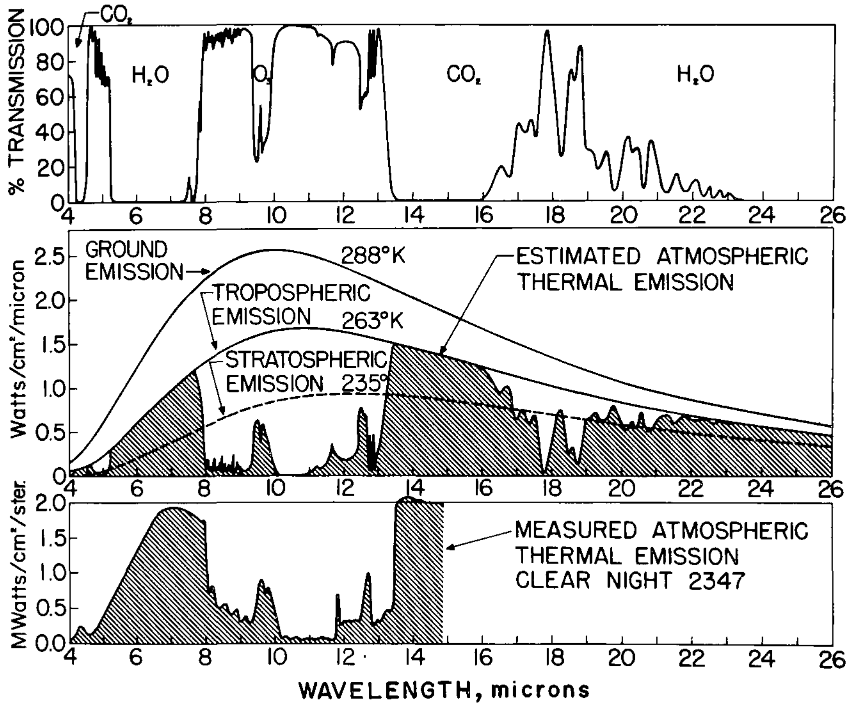

Figure 4 — Thermal, infrared radiation emitted by atmosphere and blackbody radiation from ground surface and from surfaces at 263° and 235°K.

INFRARED RADIANT HEAT

Everything on the earth's surface receives from the atmosphere these streams of infrared radiation. If we had infrared eyes, we would see bands of radiation of different frequencies streaming downward from the sky at night as well as during the daytime. Without this radiation our climate at night would be very substantially colder. This is what gives the citrus farmer so much worry when the air temperature cools to say 35°F and the sky is clear and dry. Then the surface can lose much radiant heat to outer space with little replacement, and crops may freeze severely. The infrared radiation from the atmosphere is an important energy component for life on the surface. When the sky clouds over and becomes completely overcast, the clouds will radiate like the solid line shown in Figure 4. The energy radiated by the clouds is the full area under the curve shown. This represents considerably more energy than that from a clear sky, which radiates only in bands.

PLANT ABSORPTION

Plants are fabulously adapted to the radiant energy environment here on earth. Figure 5 shows how plants absorb, reflect, and transmit radiation. Plants absorb the ultraviolet and the visible with great efficiency. The plant pigments such as chlorophyll produce strong absorption throughout the visible. They absorb this energy where they need it for photochemistry. Immediately beyond the position of the red chlorophyll band a plant becomes a brilliant reflector. It becomes very white in the infrared. Infrared photographs of forests and trees show up white—the trees look as though they are covered with snow. This is shown in Figure 5 by the reflectance and the low absorptance in the near-infrared. But this, strikingly enough, occurs where the sunlight has a great bulk of energy located in the near-infrared. If the plant absorbed this energy in the near-infrared with the same efficiency with which it absorbs the visible, it would become very substantially warmer than it does. Plants often reach temperatures that take them right up to the threshold of thermal death. If they were absorbing with very good efficiency throughout the near infrared, they would not survive as constituted with the types of proteins they have. Farther out in the infrared, at the longer wavelengths, the plant absorbs very well again. High absorptance at long wavelengths does not matter from the standpoint of sunlight absorbed, since sunlight has very little energy at long infrared wavelengths. But by absorbing very well at these long wavelengths, a plant functions as a good emitter, or an efficient radiator, of thermal energy. A plant absorbs effectively where it needs the energy for photosynthesis; absorbs poorly the near infrared, which it does not need; and absorbs well at long wavelengths to function as an efficient radiator. Reradiation accounts for about 75 percent of the energy balance on a plant.

RADIATION MEASUREMENTS

Figure 6 shows the radiation regime in which we live. These are actual values, measured at Hamburg, Germany, in June 1954. As the sun comes up in the morning, the direct sunlight and the scattered skylight produce this well-known diurnal pulse. Then the ground may reflect sunlight, depending upon the nature of the surface. The two together give the total solar energy received on the upper and lower surfaces of a horizontal leaf. A plant or animal here on the surface receives these streams of radiation. The sum of the individual streams of radiation determines our energy budget, not the difference or net streams. Both the downward and the upward streams that are incident on our bodies are effective. The meteorologist considers the difference in radiation streams because he is interested in net fluxes, and he has a valid reason for doing this. But the biologist often gets himself in trouble by using net fluxes, because the organisms are receiving the sum, the downward plus the upward. Figure 6 shows the sums of the individual streams of radiation. A large percentage of biological observations in external environments have dealt with the solar radiation components and not with thermal radiation components. Yet thermal radiation contributes a very important amount of energy to the heat budget of a plant or animal.

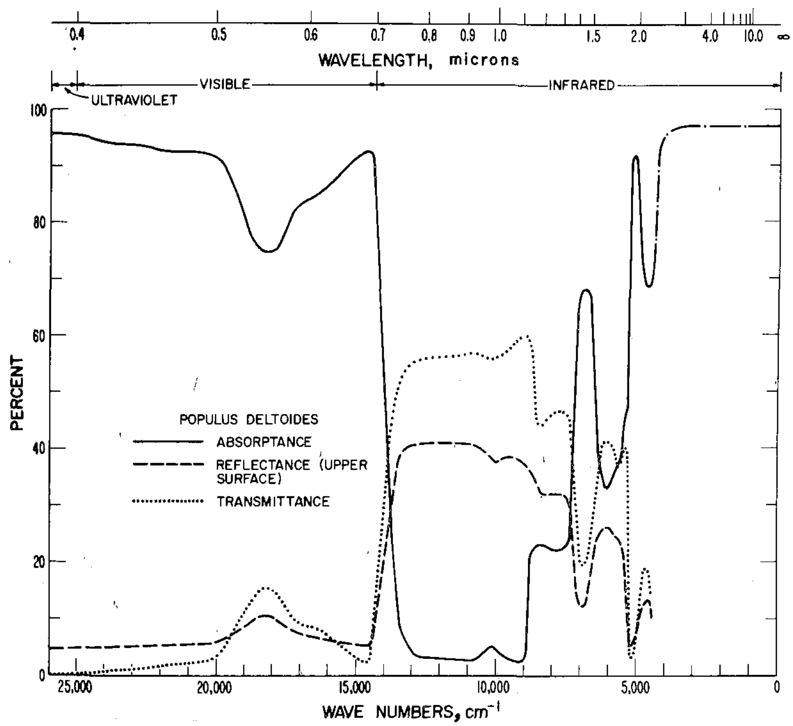

Figure 5 — Spectral absorptance, reflectance, and transmittance of *Populus deltoides* leaf.

RADIATION CLIMATE

Figure 7 shows a few radiation climates of the world as they affect a horizontal leaf. One of the most intense radiation climates is at the top of the Rockies and the top of the Sierras in midsummer. The soil becomes very hot in sheltered areas out of the wind. When the sun comes up in the early morning and strikes the high mountain slopes, things happen fast. It is a very dramatic experience. The desert has a strong component of this infrared radiation level. The solar term itself may not be particularly strong, because of dust attenuation and so forth, but the infrared component is certainly elevated and very strong. Figure 7 gives us some idea of our radiation climates, the bioclimates that we must evaluate to deal with man in the open, man on the desert, man in the arctic.

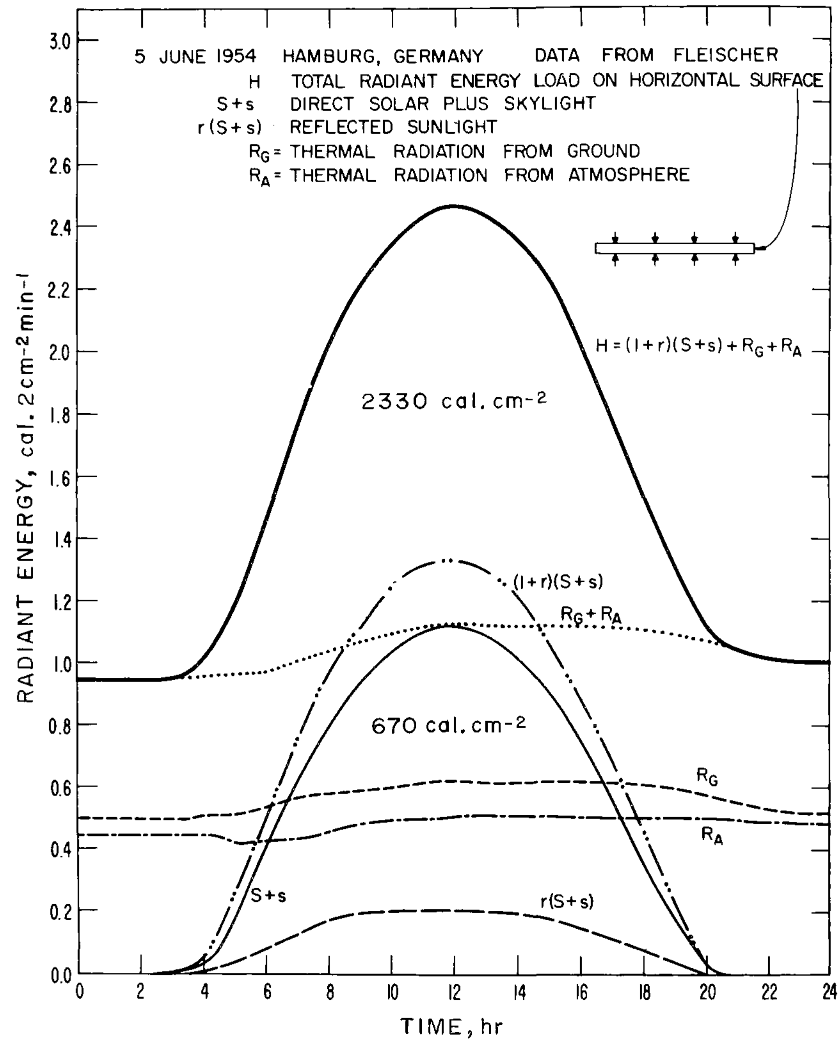

Figure 6 — Diurnal variation of radiation components incident on upper and lower surfaces of horizontal leaf. Total radiation incident on two surfaces is shown.

BOUNDARY LAYER PHENOMENON

Figure 8 shows the boundary layer of air near the faces of my two young girls. This picture is a composite of two that were taken by schlieren photography. The photographic technique shows up with enormous sensitivity any changes in air density throughout the field of view. Near our surfaces is a boundary layer of stationary air. This boundary layer represents the transition from the warm skin to the

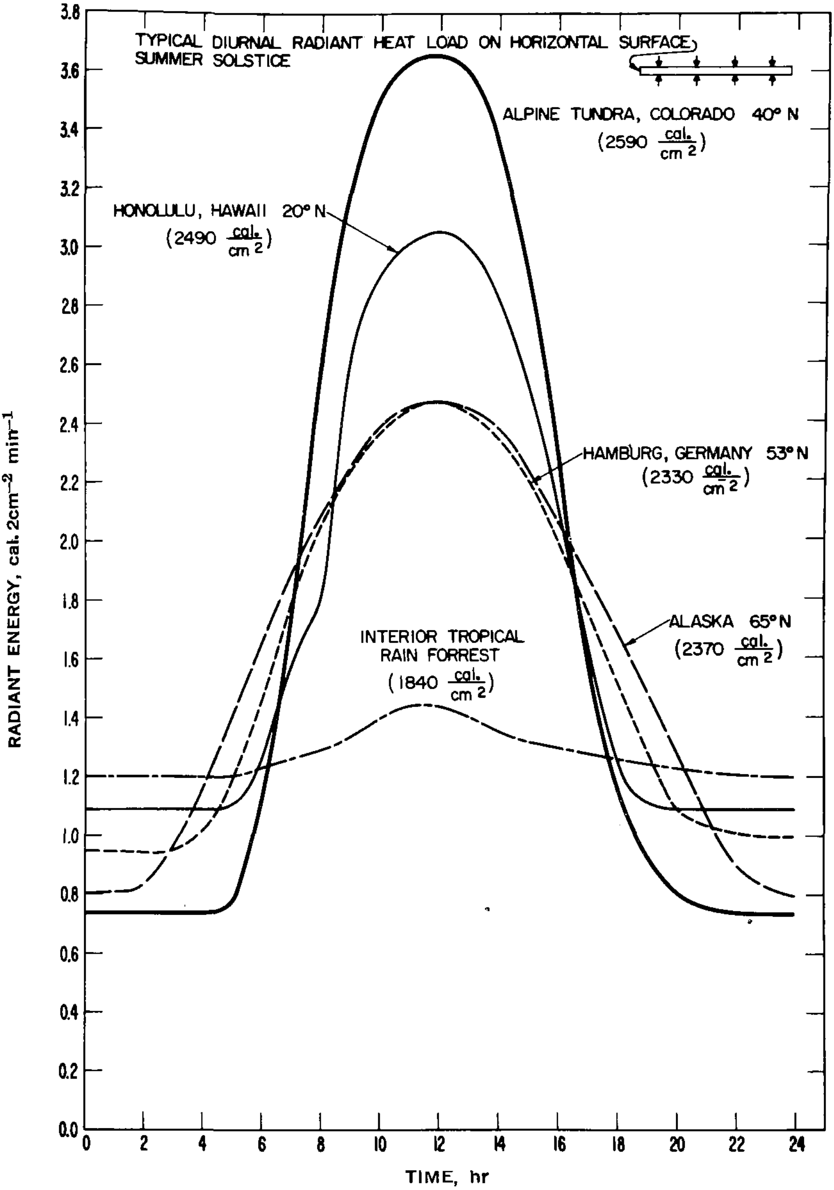

Figure 7 — Diurnal variation of total incident radiation on two surfaces of horizontal leaf for selected localities on earth.

Figure 8 — Composite of schlieren photographs of boundary layers of air.

cooler air beyond and from the moist air near the skin to the dryer air beyond. There is also a transition from air movement at a distance from the surface and zero air movement at the surface itself. I experienced the boundary-layer phenomenon in a sauna in Finland. The sauna is an extremely hot air bath. The air in the room was at 230°F, hotter than anything you ever believed it possible to experience and survive. You wear no clothes. You can withstand the heat because of the boundary layer, which acts like a buffering zone, a cushion against the hot air. Heat is being conducted from the very hot air into the cooler skin. You can remain there only a finite length of time because, as that heat is conducted in, you get hotter and hotter. Your capillaries dilate and you get redder and redder. Sitting there in the sauna, you burn if you blow on your skin. The burn is painful and can produce a blister, because you destroy the boundary layer when you blow on the skin and you entrain hot air to the surface.

The boundary layer, then, couples you, and any other organism, to the air and the air temperature, to the humidity of the air, and to the wind. The properties of the air have meaning only in terms of the transfer of energy across this boundary layer. Unless you consider the boundary layer, the question of air temperature has no scientific significance.

LEAF TEMPERATURE

Figure 9 shows some examples of measured leaf temperatures. The air temperature is indicated by a solid line. Leaf temperature is often 8 or 10°C above air temperature and has been observed as much as 20°C above air temperature. We have hundreds of examples of leaf temperatures from 10 to 20 degrees above air temperature. We made a very interesting discovery while working in the Sierras last summer. We were measuring the temperatures of the leaves of Mimulus, a plant that grows in water, that is, in very moist soil. Up at timber line at 11,000 feet the air temperature was 20°C and the leaf temperature 28°C. We took a series of measurements at various sites along a transect down the west slope of the Sierras; we finally reached the San Joachin Valley, where the air temperature was 38°C and the leaf temperatures were again 28°C. If I had been asked, I would have said the leaf temperature would be 50°C. Here was a magnificent example of homeostasis. The leaves of this plant remained cool by turning on transpiration by opening stoma and utilizing the water available to them. Now the important thing is this. The photosynthetic rate process for Mimulus has its optimum temperature at 30°C. The Mimulus plant was doing a beautiful job of keeping its temperature as much as possible at the favorable position for the rate chemistry to go on at its maximum rate. We don't know to what extent this process is true generally throughout the plant world, but we are trying to find out.

Figure 10 shows an idealized set of curves of the photosynthetic rate as a function of leaf temperature and light intensity measured in cal $cm^{-2}min^{-1}$. At low temperatures chemical rate processes go on slowly and so does photosynthesis. As the leaf temperature increases, so does the photosynthetic rate, until an optimum temperature is reached at which the photosynthetic rate is a maximum. At temperatures greater than optimum a destructive mechanism comes into the picture, and the molecules begin to break down faster than they are formed. Therefore, a very rapid drop in photosynthesis occurs on the high temperature side until a temperature is reached at which no net photosynthesis occurs—no favorable buildup of molecules, no generation or storage of food. Only respiration occurs, a burning up of food. I took this set of curves to follow the daily behavior of a plant in its climatic condition, evaluating the full energy-flow picture. Figure 11 shows the results.

The diurnal cycles of solar radiation, air temperature, and leaf temperature are shown, and, by use of the net photosynthesis curves given in Figure 10, one derives the double-peaked curve for photosynthesis. This result is very exciting, for such twin-peaked curves have been observed and not properly explained. A strong peak of photosynthesis occurs in the midmorning hours, followed by a very unfavorable condition toward midday, because the leaf is too hot. Then another peak occurs in the late afternoon. Not only are there two peaks, but they are asymmetric. I went to the literature to investigate this double peak, and this is what I found. During the early morning hours in midsummer in the midwest the air gets warmer, and the temperature and photosynthesis increase very much in phase. The plant gets good strong light intensity at the time it reaches its optimum temperature; but then it gets too hot, and even though the light intensity stays high, the temperature gets substantially too high. The result is that photosynthesis falls during midday. Then in the afternoon, the sun begins to drop very symmetrically with its morning rise, but the air temperature does not. There is a lag, and the air stays hot until very late in the day. Then, when the air temperature begins to fall, the light intensity has gone way down and even though leaf temperatures now become more favorable, the photosynthesis is low because of low light intensity. That is the reason for the afternoon peak being very small and the morning peak very strong. Figure 12 shows what a search of the literature revealed.

Some of the examples in Figure 12 are not photosynthesis, but growth, which is closely related. When a single broad peak of photosynthesis is shown, rather than a double peak, the curve represents cool days when the plant leaf does not become too warm. The exciting thing is that we can relate climate, energy, energy transfer, light, and temperature and predict some aspects of physiological response. These are bioclimatic effects, obtained by relative climate and physiology in a quantitative fashion.

Figure 13 shows hypothetical cases for a hot summer day and a cool summer day. The solar radiation in the open and the solar radiation in the shade on a summer day are given. If the summer day happens to be a cool day in which the maximum temperature is just about 20°C or if it happens to be a hot day in which the maximum temperature becomes almost 40°C, results for the photosynthesis of plants are dramatically different. These two days, a hot day and a cool day, have the same amount of sunlight, which is quite possible. If the day is cool, photosynthesis will go on at a very favorable rate. The total accumulated area under curve 1 is the total photosynthesis during the day and is very strong. The shaded leaf on the same day is not getting enough sunlight. The response is quite favorable (curve 2), but not as strong as that of the exposed leaf because of the reduced sunlight. On the hot day, the exposed leaf (curve 3), gets really quite hot in the sunlight; photosynthesis just gets going strong when the leaf becomes too hot and the mechanisms are destroyed entirely. No photosynthesis occurs throughout the midportion of the day. Then toward evening, just before the light has disappeared, the temperature has dropped enough to allow a little pulse of activity. But clearly this hot day for this particular plant would be dramatically unfavorable. The areas under curves 1, 2, 3, and 4 thus depict the differences in photosynthesis for exposed and shaded leaves on hot and cool days.

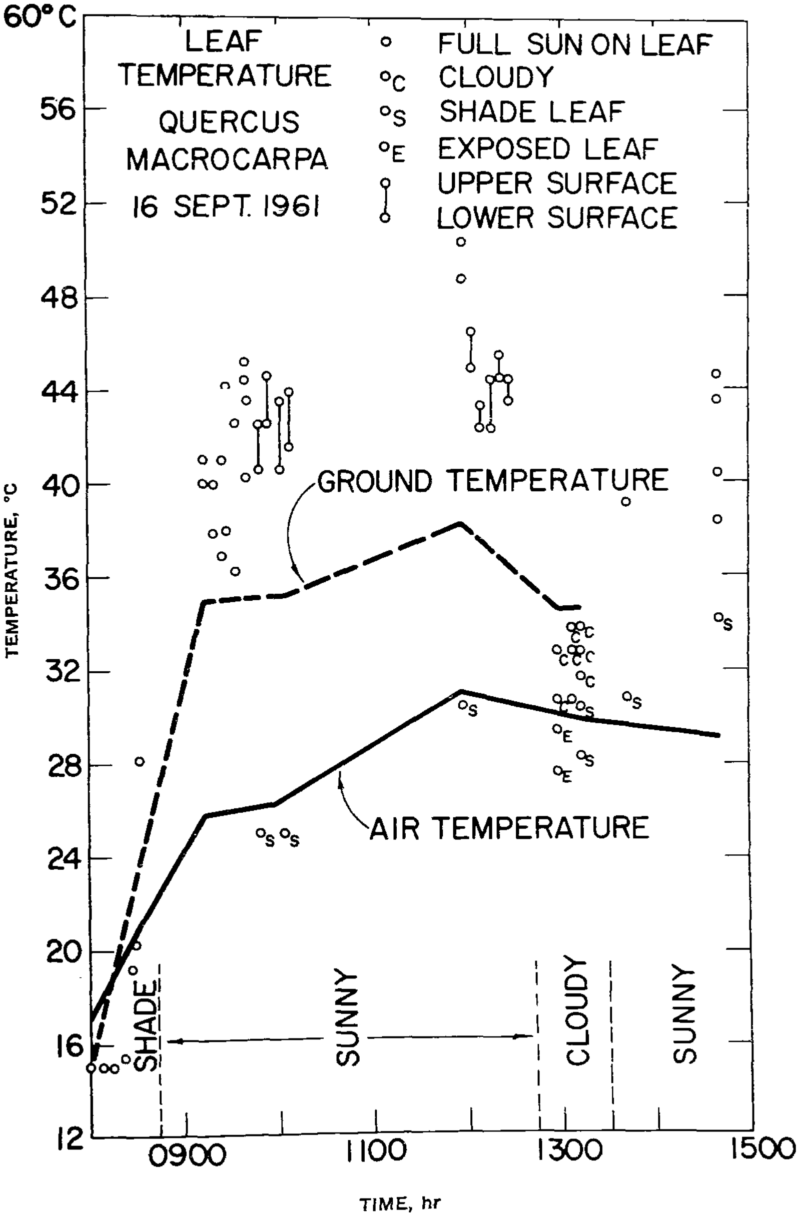

Figure 9 — Leaf, ground, and air temperatures as function of time of day.

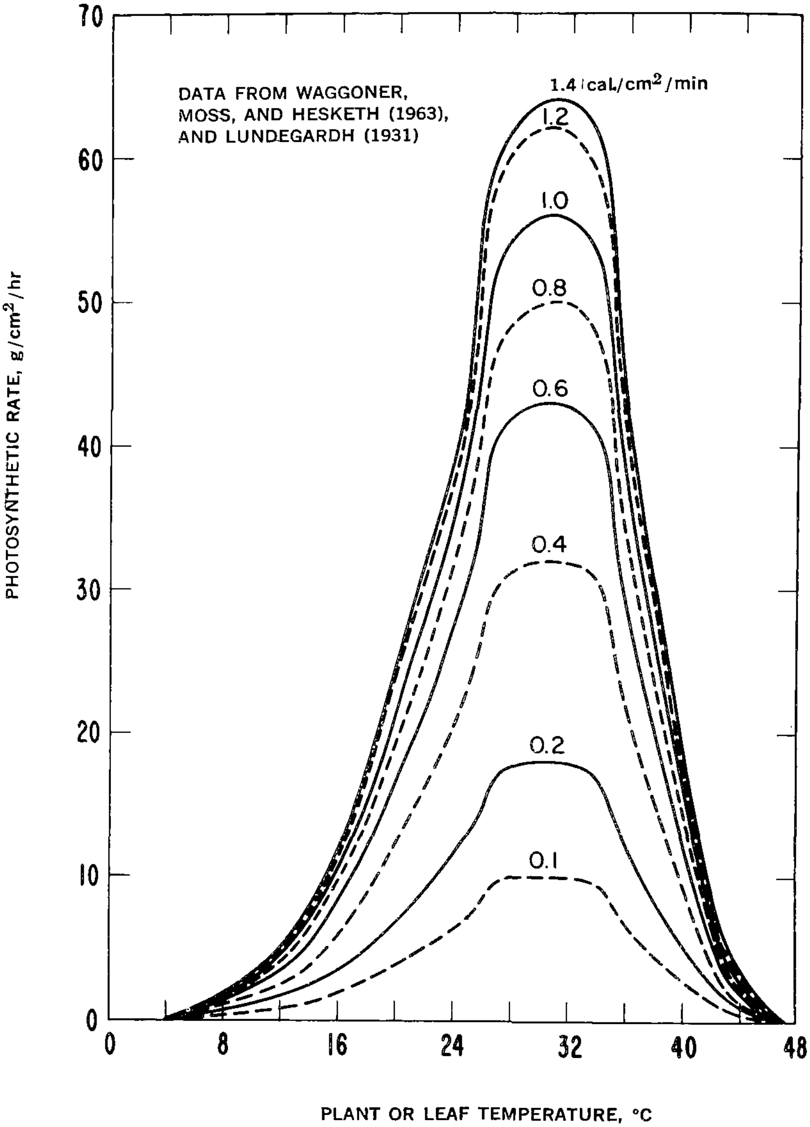

Figure 10 — Net photosynthesis of corn as function of plant temperature and radiation intensity.

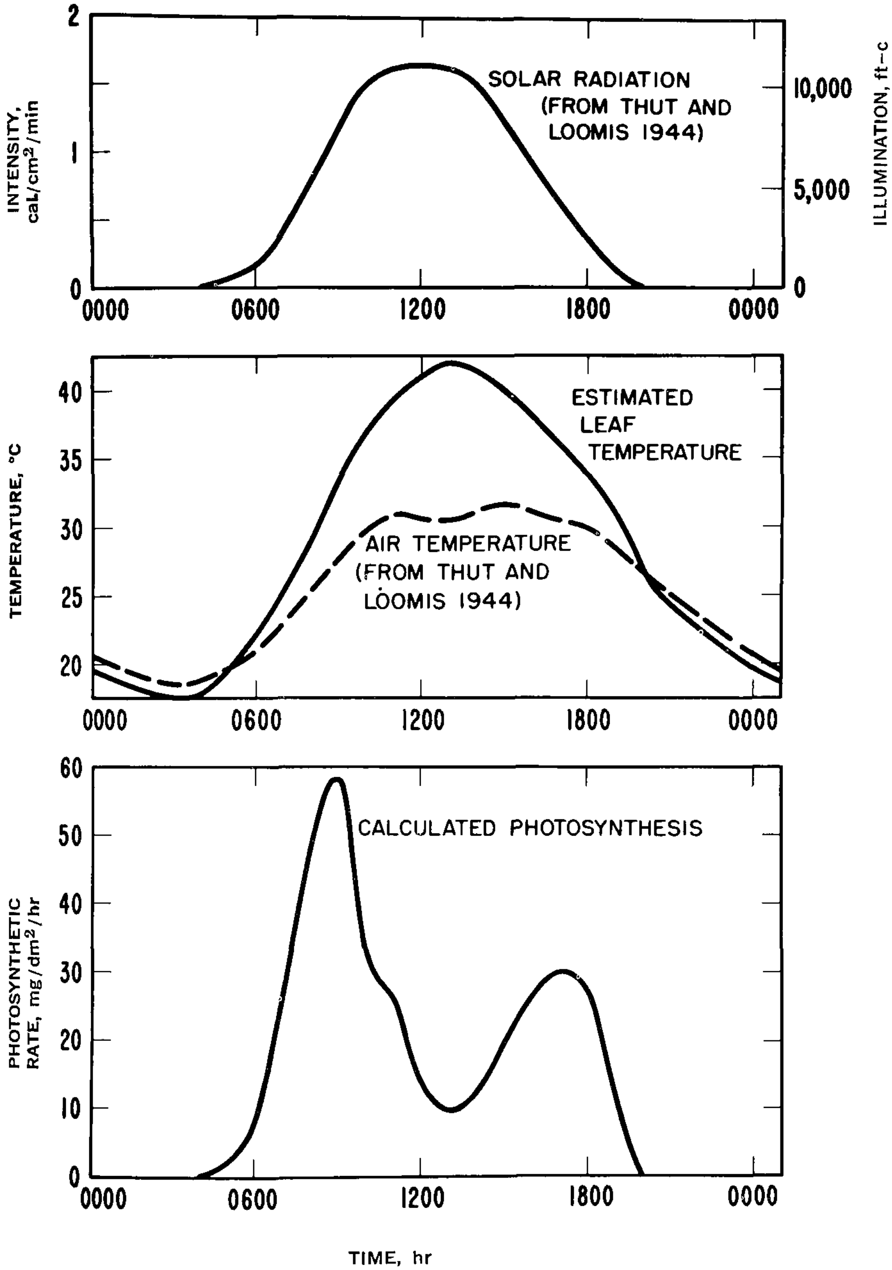

Figure 11 — Diurnal variation of solar radiation, air temperature, and leaf temperature and resulting net photosynthesis for leaf. Net photosynthesis is based on curves of Figure 10.

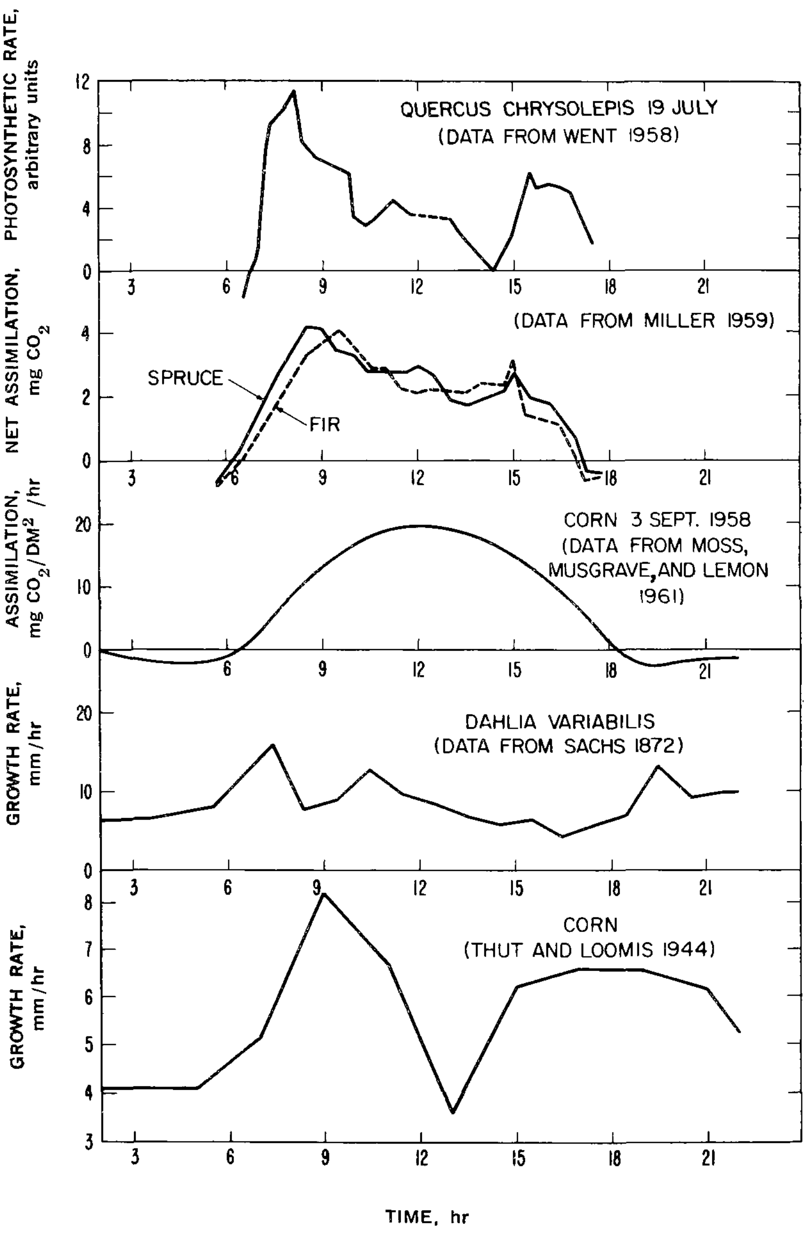

Figure 12 — Diurnal variation of observed or measured photosynthesis, assimilation, or growth rates of various plant species.

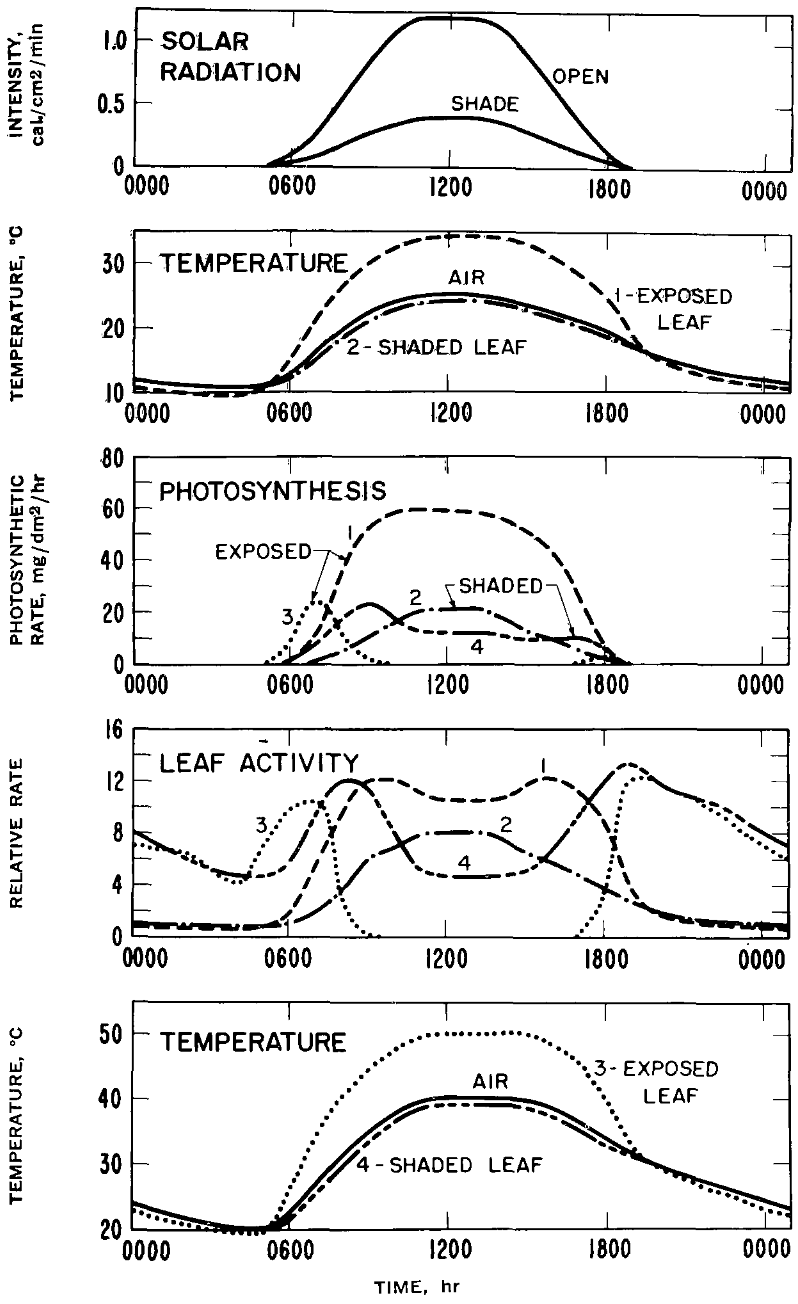

Figure 13 — Theoretically computed diurnal net photosynthetic rates and leaf activity for sunlit and shade leaves on cool and warm days respectively. Curves marked 1 and 2 are for sunlit and shade leaves respectively on cool day. Curves marked 3 and 4 are for sunlit and shade leaves on warm day.

CONCLUSION

By studying climate in terms of energy, by doing this quantitatively and evaluating the factors very carefully, one can get very exciting ecological implications. If you consider a different plant that has a different set of photosynthetic curves with different shapes and different optima, then the plant will behave quite differently in the same environment. When we ask questions of bioclimatic significance, we must know for what purpose. Are we interested in photosynthesis? In growth? In something else? We must ask specifically what we want to know in order to evaluate the climate and its influence on living beings.

DISCUSSION

Question: One thing that fascinates me as a chemist is the nature of the microchemical environment (I'm not using this term in the normal sense) of a leaf with all these radiation forces. Would this force a pattern of chemical composition on the atmosphere immediately around the vegetation? Do you know of any work of this sort?

Answer: We are concerned about this. Recently we have worked out, for instance, the resistance to diffusion through the stoma into the dry air beyond. The moisture regime near the plant surface changes as transpiration responds to the energy and light budget. At the same time CO_2 is diffusing in. So then the question is "Is a CO_2 deficiency occurring near the leaf surface?" Some work has been done at agricultural experiment stations where they measured the CO_2 in crops and showed dramatic diurnal changes.

Question: Yes, I'm aware of these. But these changes are in a reasonably large inter-space, aren't they?

Answer: Well, they are, but they are related, of course, to what is happening in the boundary layer.

Question: Some people think that carbon dioxide is an air pollutant and measure it as such. What is your viewpoint on that?

Answer: Well, I would never define carbon dioxide as an air pollutant. But this depends on what you mean by pollutant. I think that CO_2 should be measured for many other reasons; it is a dramatically important gas.

Question: Can you tell us about this fabulous photographic technique?

Answer: Yes. It's very simple, actually. Use a point source of light, a concave spherical mirror, not a parabolic mirror. The mirror forms a sharp point image at the radius of curvature. It's best if the source is at the radius of curvature, something like 10 feet. In our experiment the mirror was 8 inches in diameter. Then at the point at which the image is formed, place a knife edge formed of a razor blade or sharp piece of metal. If everything is perfect, you can insert this at the focal point, and with the eye beyond it you can see the schlieren field.

Comment: This is the technique used in grinding lenses.

Answer: Yes, that's right. It's the same technique used for photographing the flow of air over an aerodynamic surface. It's called schlieren photography. It has enormous sensitivity because you have this large optical leverage. Now with any object, say a leaf that is warm and is giving off warm air, the index of refraction is a little different for that warm air than it is for the ambient air around it. The warm air bends some of those light rays, either toward or away from the knife edge ever so little. But it doesn't take much bending to be effective. Those rays bent toward it grow darker, and those away grow brighter. If you adjust it in neutral shade, then the slightest bend either way shows up beautifully. And that's why when you just put your hand in the field of view, you can see the flow of air. It's really dramatic. It leads to a whole new world of discovery, of interesting problems to explore. Look at insects in this and see what the insects are doing, butterflies, moths fanning their wings. All sorts of heat-transfer studies can be done. This technique has quite a lot of possibilities.

Question: Could you tell me whether the data that you obtained from such instruments as net radiometers are applicable to your type of biometeorological analysis?

Answer: Not exactly. We use them, but we modify them so that we can measure the direct component of radiation. I am very much interested in these streams of radiation individually and not in the net. Of course you can have two strong streams of radiation in which the net is some small value or two weak streams of radiation in which the net is the same value. Certainly the plant is going to be very much colder in the two weak streams than it is in the two strong streams.

Question: Would you explain just what sort of radiation instrumentation you do use?

Answer: We use net radiometers that have a shiny surface on one side. This makes them hemispherical, unidirectional receivers. I also use the Stoll-Hardy type of infrared radiometer. We use the Eppley type but with a polyethylene dome that we make ourselves. The Eppley radiometer, which is very good for solar radiation, does not measure the infrared. It does not measure anything beyond 3 microns.

Question: How do you measure leaf temperatures?

Answer: I measure leaf temperatures two ways. A very easy, accurate way to do it is with thermocouples. The other way is with an infrared radiometer, the Stoll-Hardy. Now the Stoll-Hardy device was designed for use in human physiology to measure skin temperatures. It is a very good laboratory device, but very difficult to use in the field. However, you can use it in the field with care. If you use it properly, it does a beautiful job. It is simply a device that receives the infrared radiation from the surface at which you point it. Then you interpret the temperature from the fourth power blackbody radiation law. We know the emissivity of plant surfaces quite well, so not much error is introduced by the emissivity. Again I really want to emphasize this point: when you measure temperature, ask what temperature means. Usually you measure not just for the sake of temperature, but for some resulting phenomenon, such as photosynthesis.

Question: What would your comments be concerning objects in the ambient air that are non-living objects, say dust particles in the air? Are you considering chemical reaction on dust particles, absorbed gases, and liquids?

Answer: The first thing that you would notice is that a small object in the air would be at air temperature. It can't depart from that temperature substantially, since a small object is tightly coupled to the air and its surface-to-mass ratio is very large.

Question: What would be the range of control of heat loss by plants in wind? You mentioned something about 5 degrees. What control of heat loss could a plant have over that range?

Answer: Plants have considerable control over their temperatures. The Mimulus plants certainly were dramatic with respect to their temperature. When the air temperature was 20°C, the plant temperature was 30°C. When the air temperature was 40°C, the plant temperature was 30°C. Nearby a live oak, just a few yards away, had a leaf temperature of 50°C when the air temperature was 40°C. The soil in which the oak was growing was not as wet, and the oak was not physiologically constituted to transpire like the Mimulus, which did a beautiful job in keeping its temperature down. So there is an example of 20 degrees difference. More often the range of control would amount to about 5°C. This becomes absolutely crucial. By the way, most desert plants are finely divided. The mesquite, the cat's claw, all these desert plants, are fine, fuzzy sort of things—feathery structures, right at air temperature. The Saguaro cactus, a large succulent on the desert, is coldest in the center at noon and hottest at midnight. This plant is designed with fins on the outside—these fins radiate heat and do a beautiful job of staying cool. Most of the temperatures inside the Saguaro were not very much greater than air temperature; when the air temperature was up in the 40's, the Saguaro temperature was 35° to 37°C. Surface temperature was above air temperature, but only on the very thick epidermal layer. These fins were radiating and doing a beautiful job. It was dramatic. The desert is very thrilling from a heat-transfer standpoint.

Question: From the viewpoint of air pollution would these movements around the plants have a relationship to pollution damage of plants?

Answer: Yes, they would, absolutely. And also in the transfer of spores and plant diseases. These motions would show up dramatically in pictures involving air pollution and transport of spores. The tobacco industry ought to apply this kind of analysis to the tobacco plant and the pineapple industry to the pineapple plant, because all plants have unique characteristics and the flow of air is different.

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