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Sybil P. Parker
Editor in Chief

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Preface

Organisms exist under the influence of external conditions which in total constitute the environment. The physical or abiotic component of the environment includes all the nonliving aspects; the biotic component consists of the organisms which interact with each other and with their abiotic environment. Any factor that disturbs the delicate balance between the two components causes a chain reaction that may end in drastic permanent changes.

The consequences of disturbing the balance of an ecosystem are well documented throughout history in the extinction of species . . . the devastation of floods and earthquakes . . . the depletion of natural resources . . . the deaths and crop losses from disease epidemics . . . and the widespread effects of pollution—the product of modern technology.

While evolution documents the successes and failures of species to adapt to changing environments, civilization attests to the human ability to implement environmental change. In either case, it is clear that not all changes are beneficial. Environmental science is concerned with evaluating these changes, considering both natural and human activities as distinct but inseparable.

The study of environmental science encompasses the fields of ecology, geophysics, geochemistry, forestry, public health, meteorology, agriculture, oceanography, soil science, and mining, civil, petroleum, and power engineering. Among the problems confronting environmentalists are land reclamation, eutrophication, desertification, climate modification, energy sources, urban planning, crop production, and pollution. Solutions to these problems will provide the foundation for the ultimate protection and preservation of our environment.

The *Encyclopedia of Environmental Science* treats all of these topics and gives an insight into the present state of knowledge, directions that must be taken, and laws and conservation practices required to deal with the problems. Coverage is complete and up to date in accessible, authoritative articles written for the general reader as well as the professional.

This edition of the Encyclopedia has been thoroughly revised and expanded. The more than 250 articles are organized in two sections—a section containing five feature articles on topics of broad, general interest, and a section of alphabetically arranged articles dealing with the basic scientific and technical concepts. Each article was prepared by a specialist. Many were written especially for this volume, and some were taken from the widely acclaimed *McGraw-Hill Encyclopedia of Science and Technology* (4th ed., 1977). The articles were selected and reviewed by the consulting editors and the editorial staff. There are 650 photographs, diagrams, charts, graphs, and line drawings to supplement the text; bibliographies for further reading; cross-references to guide the reader to related articles; and an analytical index for easy access to the information.

Sybil P. Parker
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Environmental Protection

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Environmental protection is the system of procedures which limit the impairment of the quality of water humans use, of the air they breathe, and of the land that sustains them. It includes the means to control the physical energies of ionizing radiations, nonionizing radiations, sound, air pressure changes, and heat and cold. Human activities produce wastes that are vapors or gases, solids, liquids, or energy states. Humans seek to disperse these to the open environment of water, air, or land. The receptors are all forms of life on Earth, with people the primary concern.

Three objectives. Environmental protection has three objectives. The first is to protect people from physiological damage from pathogenic organisms, from toxic chemicals, and from excesses of physical energies. The second is to spare humans annoyance, irritation, and discomfort from offensive conditions in water, in air, and on the land. The physical energies have a role in this second objective when there are excesses of noise, heat, cold, and even electromagnetic transmission interference disturbing radio and television reception. Uncontrolled insect and rodent populations may be more a source of discomfort, disgust, and fear than a real risk of disease transmission. The evident corollary is the provision of an environment which adds to comfort, pleasure, and productivity. Air cooling for summer comfort and cleanliness of recreational areas are examples of positive actions to meet the second objective. The third objective is to safeguard the balances in the Earth's ecosystems and to conserve natural resources. Many people strongly advocate that this should be the primary goal of environmental protection. Fortunately, the three objectives are not incompatible, although conflicts arise. The drainage of a swamp which is a breeding place for anopheline mosquito vectors of malaria obviously changes the ecosystem that has existed there. Thus there are differences of opinions on which environmental actions should be given priority when the three objectives are not compatible.

Assimilative capacity of the environment. When humans' waste loads on the water, air,

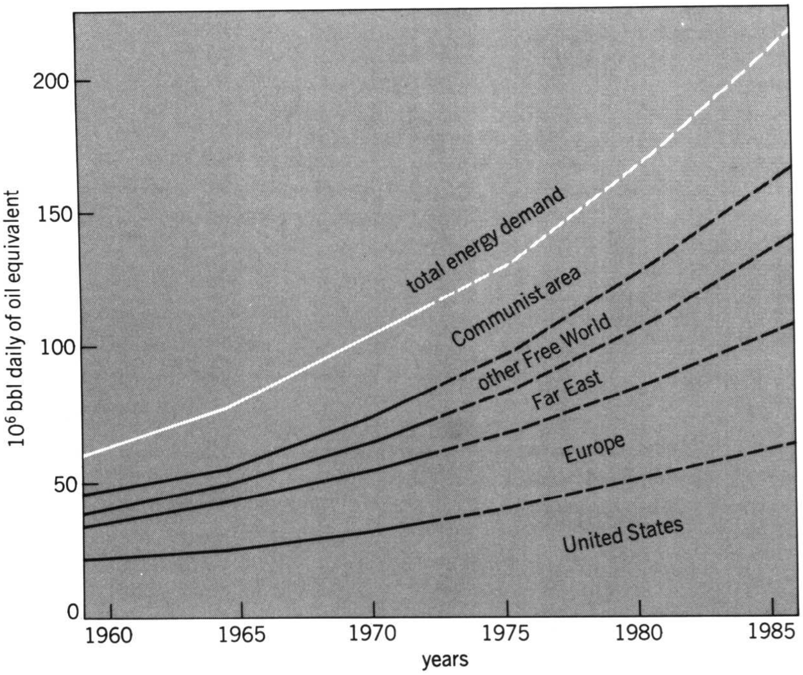

Fig. 1. Exponential rise of the world's energy demand from 1960 projected to 1985.

and land overwhelm the natural processes of assimilation of such wastes, pollution occurs. In the case of the physical energies, it is usually human or animal tolerance that is overwhelmed. The condition of pollution may jeopardize one or more of the three objectives of environmental protection. For example, the management of stream pollution is directed at all three objectives. Overwhelming the assimilative capacity of a local environment by human wastes is not only a recent phenomenon. English literature notes the foul air of London in the 17th century due to the burning of sea-coal. Samuel Coleridge viewing Cologne, Germany, at the end of the 18th century wrote: "The River Rhine, it is well known,/ Doth wash your city of Cologne,/ But tell me, nymphs, what power divine,/ Shall henceforth wash the River Rhine?"

Today's large urban-industrial areas with the massive use of individual internal combustion engines for transportation have both chronic and acute conditions of air pollution. The airborne waste loads exceed the capacity of horizontal and vertical air movement to disperse the materials. Additionally, conditions of inversion, stagnation, and ultraviolet radiation produce reactants from the primary pollutants. On land and in water, not all wastes are usable as a food for the natural biota; these are labeled nonbiodegradable. The chlorinated hydrocarbon pesticides are high on the list of persistent contaminants which change slowly in the open environment. It is this property that makes DDT an effective anopheline killer even 4 to 6 months after spraying on home interiors.

Increased energy use, production, and population. The human ability to produce prodigious amounts of wastes depends on energy use and on numbers of people. James Watt's improvement in 1769 on Newcomen's atmospheric engine broke the energy limits of human and animal muscle, wind, and water power. The capacity to do work had been in those bounds since humans' start on Earth. The steam engine was soon moving boats and then trains, and driving factory machinery. About 100 years later, petroleum became a fuel and made the internal combustion engine possible. Almost concurrently, electricity became another magical energy. And finally there developed nuclear energy, with which society has not yet come to terms. Human energy uses started their exponential climb with Watt's invention. The curve rises slowly through the 19th century and the first half of the 20th. The exponential character of the curve becomes drastically marked about 1950, not only for the United States but for the world.

Obviously energy use is for a purpose, for producing goods, for transportation, and for people's comfort and convenience. Expressed in some suitable units, these uses of energy also trace exponentially increasing curves (Fig. 1). Human population itself exponentially increased through the 19th century and continues to do so (Fig. 2). All of this accelerated human activity produces more wastes. The capacity of the open environment to assimilate the wastes remains essentially static. The result is an erosion and change of the original ecosystem when the waste loading continues an unabated rise. The wastewater discharges of New York City, Boston, and Baltimore increased during the 20th century to surpass the dilution and assimilative capacity of the receiving waters. Rivers have been overwhelmed by the cumulative wastes as the water moved downstream (Figs. 3 and 4). The Ohio, the Rhine, and the Danube cannot cope with the multiple sources of wastes along their courses. Segments of the Mediterranean Sea are threatened. The limiting meteorological characteristics of the Los Angeles area resulted in photochemical smog when gasoline-fueled automobile emissions skyrocketed after World War II (Fig. 5). However, Los Angeles is no longer unique in smog pollution.

Options for control of pollutants. To keep the balance, the alternatives are: eliminate the source; eliminate the waste; treat the waste to reduce the deleterious load on the open environment; or augment the environmental capacity to assimilate the waste. All of the alternatives are applied in one way or another to manage liquid wastes, solid wastes, airborne wastes, and the excesses of physical energies. Abatement action is taken to prevent injury to humans and animal and plant life, to protect property and resource values, and to limit conditions that are offensive to people apart from

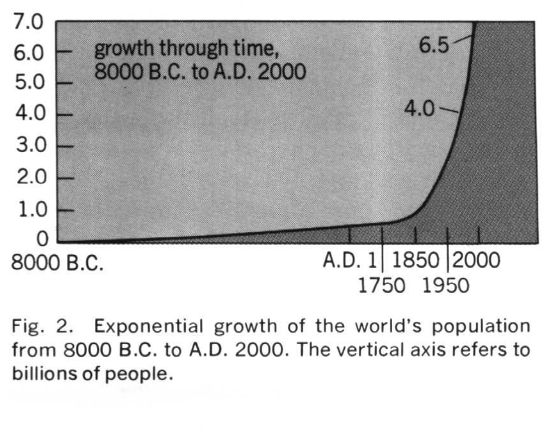

Fig. 2. Exponential growth of the world's population from 8000 B.C. to A.D. 2000. The vertical axis refers to billions of people.

Fig. 3. Potomac River below Key Bridge, Washington, DC.

physiological damage. Abatement of wastewater effects began in England and Germany toward the end of the 19th century. The purposes were to maintain the quality of streams for downstream water users, to protect fish life, and to add in some measure to the prevention of waterborne infectious diseases. Water source selection and water purification, along with the sanitary management of human excreta, are the primary environmental controls of waterborne diseases. By the turn of the century, municipal sewage was being treated in some places in the United States. The devices used were coarse screens, septic tanks, and later Imhoff tanks in combination with intermittent sand filters. Primary settling then came into use.

The work at the Lawrence Experiment Station of the Massachusetts State Health Department in the 1890s and the U.S. Public Health Service at Cincinnati in the 1920s provided the scientific bases for sewage treatment and stream pollution control. Consulting sanitary engineers such as Allen Hazen, Leonard Metcalf, and Harrison P. Eddy made important contributions during the first decades of this century. University research began in the 1920s by George Whipple and Gordon Fair at Harvard, Charles Gilman Hyde at Berkeley, Harold Babbit at the University of Illinois, and William Sedgwick and Murray Horwood at the Massachusetts Institute of Technology. Airborne wastes received less attention, although F. G. Cottrell of the University of California developed and applied an electrostatic precipitator to control sulfuric acid mists and vapors at a Du Pont sulfuric acid plant near Berkeley, CA, in 1907. For the most part, air pollution efforts up through World War II were directed at smoke and dust control.

The mainstay of wastewater treatment is biooxidation (Fig. 6). Trickling filters, activated sludge, and stabilization ponds depend on the same natural process as a well-aerated stream. That process is the biological feeding, primarily by bacteria, on the carbohydrates, proteins, and fats in the wastewater in the presence of ample oxygen. The settled solids, or sludge, are separated and made the food of anerobic organisms in sludge digestors. Sewage sludge is an example of removing a waste from a mainstream and then having to deal with it further. The same holds for removing particulates from an airstream or from flue gas. The captured material requires further handling. There are always possibilities of recovery of the isolated material for economically useful purposes.

Governmental action. In the United States, governmental action in environmental protection began in the 19th century with municipal services of water supply, sewers, street cleaning, and solid waste collection. Slowly, as the need arose, these extended to sewage treatment and solid waste incineration or ocean dumping. Beginning in Massachusetts, state health departments developed sanitary engineering divisions. Their functions were both advisory and regulatory. State health department laboratory services for the quality of drinking water began before World War I. After that war,

Fig. 4. Scum and foam from a paper plant on the Androscoggin River, fall 1969.

the laboratories became an instrument for defining stream pollution conditions and sources. State health departments established design and operational standards for water and sewage treatment plants.

The U.S. Public Health Service issued its first Drinking Water Standards in 1914. Although these had the force of law through the Federal power over interstate and foreign commerce, hence on the drinking water provided for passengers on common carriers, states and cities varied widely in how they followed the standards.

Without specific Federal legislation, the Public Health Service was the source of national action in environmental protection for the first 60 years of the 20th century. Its activities extended to all phases of environmental protection, including industrial hygiene, vector control, and milk and food sanitation. It carried on basic research, extensive field studies, demonstration projects, model code and standard development, technical assistance, and help in staffing and training. A notable Federal participation in environmental protection came in the depression years from 1934 to 1940. The Public Works Administration funded the construction of water and sewer systems, water and sewage treatment plants, and solid waste incinerators. The Works Progress Administration funded labor-intensive contruction of small-town sewers, antimalaria drainage, and privy-building. The first sign of Federal legislation on environmental protection was a 1948 water pollution control act to provide loans to municipalities to build sewage treatment facilities. The act was never funded, but it was a sign of things to come.

After World War II, the exponential growth of the national economy, of energy use, and of waste loads gained astonishing momentum. The population shifts from farm to urban and from urban to suburban were accelerated. Through the 1950s and 1960s, matters of water and air pollution and land abuse, including solid waste dumping, became direct experiences for American families. Septic tanks failed, recreational waters were dirty, normal seasonal stagnant air became polluted air, passing vehicle exhaust became a personal assault, pesticides became suspect—indeed there were doubts cast on the blessings of technology. With a few exceptions, the states were not politically capable of moving effectively even against water pollution. In a state, the vested interests of the municipalities and industry were too strong. Legislative initiative moved to the U.S. Congress despite accomplishments of control of water and air problems in such states as California, New York, and Oregon. Air quality had improved in St. Louis, Pittsburgh, and New York City with the change from coal to oil for heating, a significant source reduction.

Congress was in tune with the growing popular concern for environmental quality as it passed new legislation and amended old laws. The principal ones dealing with water, air, solid wastes, and general objectives from 1960 to the present are:

Air:
- Clean Air Act of 1963 (PL 88–206)
- Motor Vehicle Air Pollution Control Act of 1965
- Air Quality Act of 1967 (PL 90–148)
- Clean Air Act of 1970 (PL 90–604)
- Energy Supply and Environmental Coordination Act of 1974 (PL 93–319)
- Clean Air Act Amendments of 1977 (PL 95–96)

Water:
- Safe Drinking Water Act of 1974 (PL 93–523)

Water pollution:
- Water Pollution Control Act of 1965 (PL 89–234)

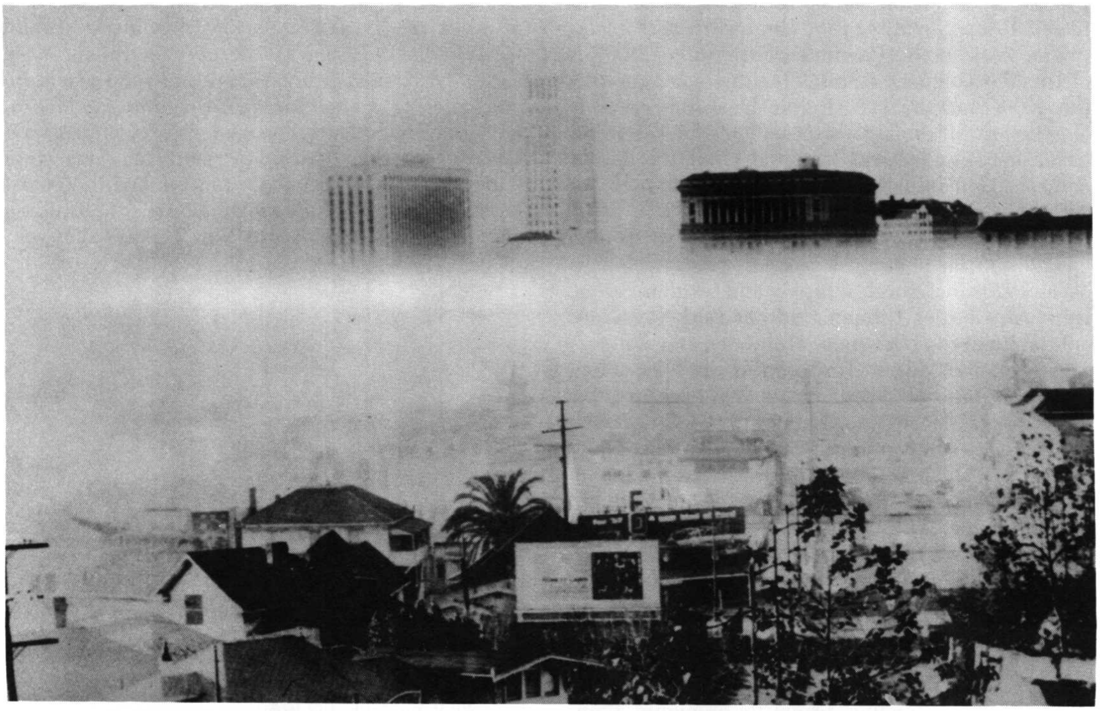

Fig. 5. Low-lying belt of photochemical smog in Los Angeles, CA.

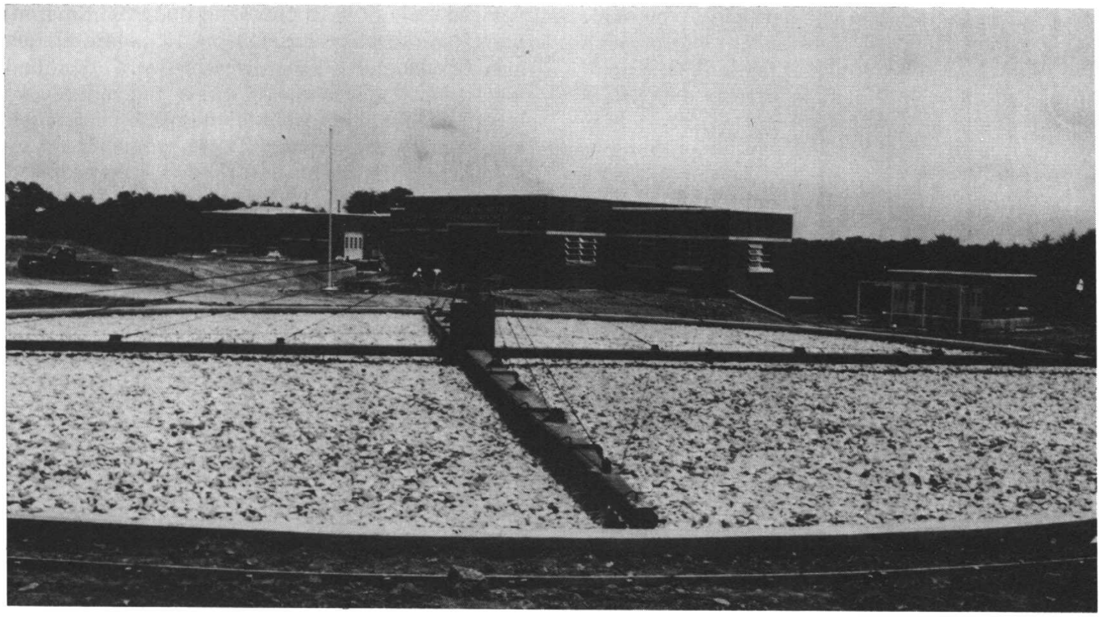

Fig. 6. High-rate trickling filter at Burlington, NC, for use in biooxidation process for organics in wastewater.

- Clean Water Restoration Act of 1966 (PL 89–753)
- Water Quality Improvement Act of 1970 (PL 91–224)
- Federal Water Pollution Control Act Amendments of 1972 (PL 92–500)

Solid wastes:

- Solid Waste Disposal Act of 1965, Title 1 of PL 89–272
- Amended Resources Recovery Act of 1970 (PL 91–512)
- Marine Protection, Research and Sanctuaries Act of 1972 (PL 92–532)
- Resources Recovery and Conservation Act of 1976 (PL 94–580)

General objectives:

- National Environment Protection Act of 1969 (PL 91–190)
- Occupational Safety and Health Act of 1970 (PL 91–596)
- Toxic Substances Control Act of 1976 (PL 94–469)
- Council of Environmental Quality created under NEPA, 1969

Environmental Protection Agency. The initiatives of environmental protection in the United States have passed to the Federal government. The National Environmental Protection Act (NEPA) consolidated all Federal activities on air and water pollution, solid wastes, pesticides, noise, and environmental radiation in a new organization, the Environmental Protection Agency (EPA). Many states followed suit by organizing all or most of the environmental protection work in an independent or autonomous unit. States follow the EPA leads as surrogates to keep out direct Federal intervention and to qualify for various forms of monetary subsidies. When the subsidies go to local projects, the state agency is the control gate. An extensive and sometimes intensive bureaucratic process has evolved to move the authorities and mandates of Congress to EPA, sometimes directly and sometimes through the states to the point where the problem can be defined and solved.

Congressional mandates of specific reductions of pollutants by specific dates have deprived the EPA and its surrogates of flexibility. The Clean Air Act of 1970 made it law that by 1975 automobile exhaust emissions on new cars were to be reduced by 90% compared with 1970 levels. That was not accomplished. There was an extension to 1979. The 1977 Amendments to the Clean Air Act postponed compliance stepwise to 1979, 1980, and 1981. The Federal Water Pollution Control Act Amendments of 1972 require that there be zero discharge of pollutants to the waters of the United States by 1983. Unless there is some remarkable definition of "zero," the law will not be obeyed. The EPA has a very strong legal approach in its procedures. Hearings, petitions, and appeals abound. Regulations are numerous and often lengthy. Administration channels flowing from local government or industry through the states to regional offices to Washington are choked with paper. Relations with direct clients in industry are not different.

EPA regulations, standards, and requirements are nationwide. In some instances, national standards are meritorious and necessary, as for drinking water quality or automobile exhaust. Requirements for specific means of implementation can be wasteful such as wastewater treatment without consideration of the natural assimilative capacity of the receiving waters. The intent to require granulated activated carbon filters at water purification plants to reduce trihalomethanes whether they exist or not, or whether they can be reduced by other means, is a wasteful procedure. The requirement of high-efficiency flue gas cleaners on all coal-burning electricity-generating plants without considering coal quality is another example. Bans are a seemingly complete administrative solution to a problem substance. The EPA has used the ban on a few pesticides and one herbicide. The implementation of the Toxic Substances Control Act of 1976 may lead to wider use of the ban. One unfortunate result of these procedures is that professional judgment of scientists and engineers is removed from the analysis and solution of problems at the scene.

Nevertheless, much has been accomplished. Environmental protection in governmental agencies is firmly institutionalized. It has greater strength and support than ever. Pollutant sources are being controlled. Many streams and air sheds are showing improvement. Ocean dumping has been greatly reduced. Solid wastes are being managed much better than in the past. Air loading of particulates, hydrocarbons, and carbon monoxide on a national scale has been reduced. State agencies for environmental protection have been strengthened.

The environmental movement. The years on Federal legislation listed above indicate that congressional action did not lag behind the environmental movement. The long-established professional societies such as the American Water Works Association, the Water Pollution Control Federation, the American Public Health Association, the reoriented Air Pollution Control Association, and the American Public Works Association worked steadily through the years to intensify environmental protection. In 1962 Rachel Carson's book *Silent Spring* produced a wide public awakening on the nature and consequences of environmental pollution with persistent DDT residuals and their effect on ecosystems as a model. Existing conservation organizations such as the Audubon Society, the Wilderness Society, the National Wildlife Federation, and the Sierra Club became active participants in environmental concerns. New groups have been organized such as Environmental Action, Natural Resources Defense Council, the Friends of Earth, and the Environmental Defense Fund. Two significant events of the environmental movement were Earth Day in April 1970 in the United States, and the United Nations conference of official governmental delegations and numerous unofficial groups in Stockholm, Sweden, in the summer of 1972.

This United Nations Conference on the Human Environment resulted in the creation in 1972 of the United Nations Environmental Program (UNEP), with headquarters in Nairobi, Kenya. Its mission is education and dissemination of information. Its view of the environment is broader than that stated in this article. There is great concern for the advancing deserts, for forest disappearance as the wood is cut for fuel and as land is cleared for crops, and for preventing the overuse of ground and surface water sources. Global ecological and climatological changes and endangered animal species concern UNEP. Health matters of environment remain with the environmental health staff of the World Health Organization, which has had a productive program since 1950 and an enviable reputation among international agencies and its client nations.

From biological to chemical hazards. Environmental protection began about 100 years ago as specific communicable diseases were identified with water, milk, food, and insect and rodent vectors. The activities were identified as sanitation and sanitary engineering. These problems are by no means laid to rest. They are now overshadowed by the threats, real and alleged, of toxic chemicals in the open environment. Epidemiological evidence for human injury is substantial for some 600 toxic substances known to produce specific pathology in the workplace, namely, occupational diseases. Effects on the general population from infancy to old age have been identified in acute episodes of environmental contamination. Examples of air pollution episodes are: Donara, PA, in 1948; London in 1952; and Seveso, Italy, in 1976. Fish from mercury-polluted waters caused poisoning in Japan at Minamata, 1953–1960, and Nigata, 1964–1965. Infants suffered severe brain and nervous system damage from methyl mercury passed from the fish to the mother through the placenta to the fetus. Japan also provided the evidence of the toxicity of polychlorinated biphenyls (PCB). A leaking heating system contaminated rice oil. From 1968 to 1973, 1200 cases of "yusho," the oil disease, were attributed to the mishap. Again placental transfer from mothers with yusho damaged their children. The infants were small at birth and below normal in subsequent growth and development.

Low-level intakes through a lifetime. The matter of low-level intakes of known or suspected toxicants through a life of 65 to 75 years cannot be resolved by present toxicological and epidemiological information or methods. Decisions on the use and control of such substances cannot be made solely on existing scientific evidence. These issues are politically and socially sensitive and highly emotional when laboratory animal tests indicate the possibility of the substances being carcinogenic, mutagenic, or teratogenic. The continued use of saccharin, which has been found to be a weak carcinogen in tumor-susceptible strains of rats, is a dilemma, as no satisfactory alternate is presently available; yet many people benefit from the substitution of saccharin for sugar. Two things are evolving from these situations. One is the increased effort to know more fully the biochemistry of cancers so that susceptible people can be identified. Another is the recognition of risks and benefits and the developments of methods to make such judgments. Many are made implicitly. The American people accept 50,000 motor vehicle deaths per year as a fair exchange for their automobile use. Energy source choices may be forced upon them that will impair environmental quality or possibly heighten environmental risks. A well-informed people is required to understand the stakes in such risk-benefit judgments.

[EMIL T. CHANLETT]

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Precedents for Weather Extremes

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The weather varies on time scales ranging from seconds to geological ages, and on space scales ranging from the microscopic to the area of the whole Earth. The climate at any place is determined both by the average of the weather and by its variability.

Extremes of weather must be viewed in the context of where, at what time of year, and in what climatic period they occur; how long they last; and what area they cover. A temperature of 30°C is more unusual in Scotland than in England; and a foot of snow is far less likely in South Carolina than in New Hampshire. Not only is snow less likely in summer than in winter, but if the climate at some location became drier and warmer, snow would become a rarer, more extreme event even in winter. Thus the likelihood of a particular weather extreme can vary in time as well as in space. Also, persistent extremes are rarer than transient ones: a New York heatwave is unlikely to last for 2 months without a break. And many extremes are more likely to cover small areas than large ones: the whole of India is never flooded simultaneously, though droughts are very extensive in some parts of the world, such as the Sahel zone of western Africa.

The incidence of extremes, defined in accordance with recent experience, will change not only if the average changes but also if the variability or standard deviation changes. For example, for a gaussian distribution of growing-season temperature, if the mean temperature is 18°C and the standard deviation is 1.02°C, 2.5% of seasons will be warmer than 20°C and 2.5% will be colder than 16°C. If the mean decreases from 18 to 17°C, the corresponding 2.5% criteria will be 19 and 15°C and the likelihood of extreme cold, as defined by values less than 16°C, will increase to 16.3%. Similarly the likelihood of extreme warmth (over 20°C) will decrease to less than 0.2%. However, if the mean remains 18°C but the standard deviation increases from 0.98 to 1.5°C, the probabilities of extreme warmth or cold will both rise to 9.2%. Finally, if the mean falls to 17°C and the standard deviation rises to 1.5°C, the probabilities of extreme warmth and extreme cold will become 2.3 and

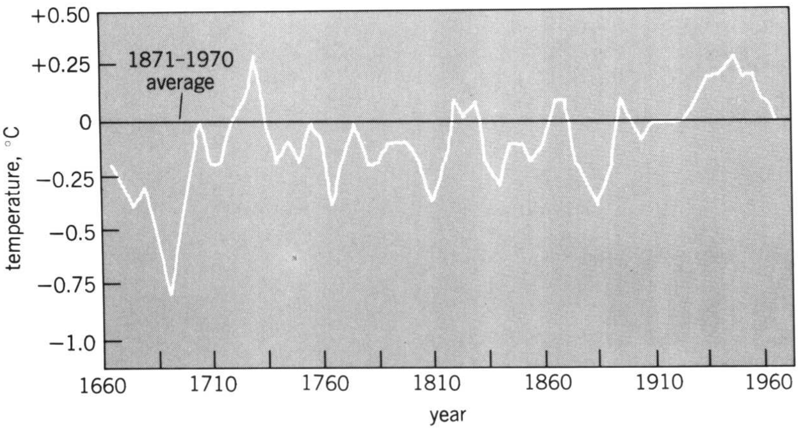

Fig. 1. Five-year means of Northern Hemisphere temperature anomalies estimated from central England temperature.

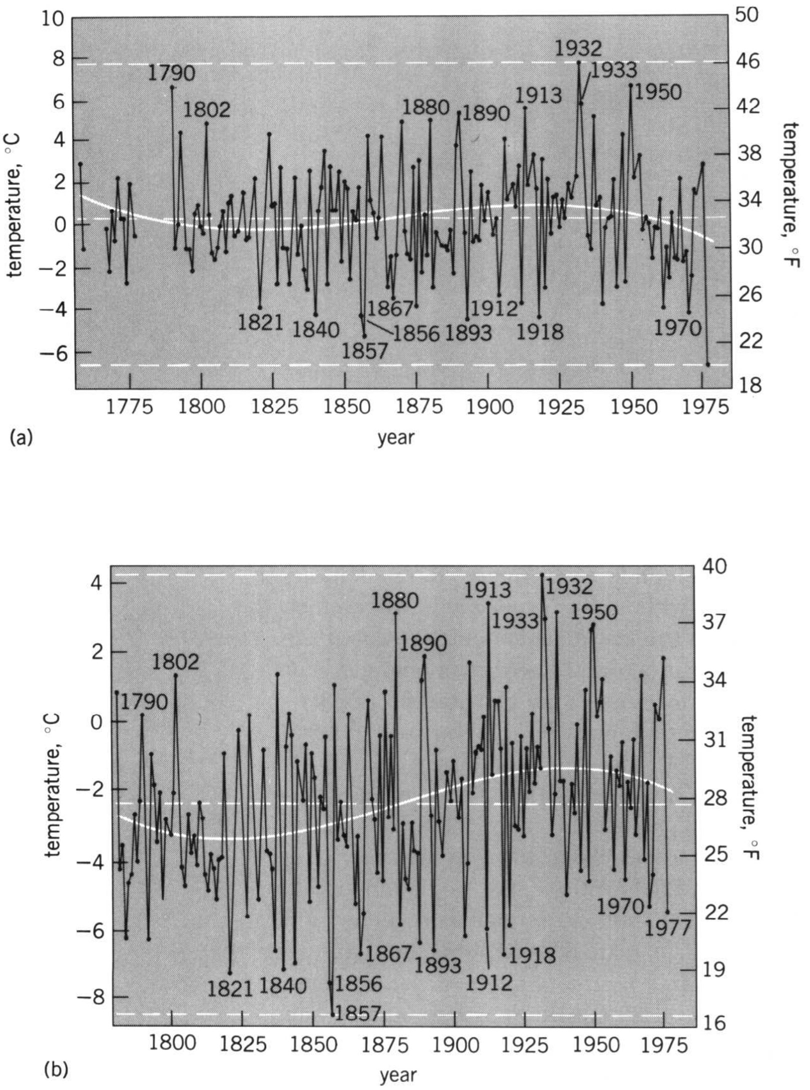

Fig. 2. Long-term average January temperature for: *(a)* Philadelphia, PA (1758–1977); the smooth trend line is a third-order polynomial least-squares fit; *(b)* New Haven, CT (1781–1977); the trend line is a third-order polynomial least-squares fit. *(From H. F. Diaz and R. G. Quayle, The 1976–77 winter in the contiguous United States in comparison with past records, Mon. Weath. Rev., 106(10):1393–1421, 1978)*

25.2% respectively. For rainfall the distribution is usually skew, and not gaussian, and a realistic example would be more complex. But the general principle stands: the likelihood of extremes, as judged by present standards, depends on whether the average or the variability, or both, is subject to change. If such changes can be predicted, the forecast can be used to estimate the magnitude of future extremes. Otherwise, the best approach is actuarial: one assumes that extremes are as probable in the future as they have been in the past, and plans accordingly.

CLIMATIC CHANGE

The study of climatic change includes the movement of the average and also of the variability about that average. It is usual to try to separate changes due to natural causes from changes caused by human activities. A necessary basis for these studies is an understanding of the mechanisms whereby the various components of the climatic system interact. These components include the atmosphere, the oceans, the polar ice and snow, and the vegetation on the surface of the Earth.

Natural climatic change. Possible causes of past and future natural climatic change are the following.

Variations in solar radiation. The most important variation would be a change in total energy. Prior to about 1970, the solar constant, which is about 1370 W/m², was known only to an accuracy of 1%, and claims that it oscillated by about 0.1% of its magnitude following the 11-year sunspot cycle may have been premature. The supporting data may have reflected changes in the transparency of the atmosphere related to variations in the ultraviolet portion of the solar beam affecting the stratosphere by changing the quantity of ozone there. Recent measurements from Mariner spacecraft did not detect a variation of as much as 0.03% in the solar constant as a result of sunspots or the surrounding bright faculae. It would appear therefore that, based on the most up-to-date data available, there is no reason to expect any significant change in the solar constant in the foreseeable future.

Variations in Earth's orbit. In the 1930s M. Milankovitch documented periodicities of 96,000 years in the elliptical shape of the Earth's orbit (that is, the orbit becomes alternately more circular or more elliptical), 40,000 years in the tilt of the Earth (that is, there is a cycle in the highest latitude at which the sun passes overhead in summer, at present about 23½°N or S), and 21,000 years in the relation of the seasons to the distance of the Earth from the Sun (that is, the Earth is at present nearest to the Sun in the Northern Hemisphere winter, but in 10,000 years' time it will be farthest at that season). These orbital changes will affect the amount of solar radiation available at a given latitude at a given season, and may therefore affect the climate. Evidence on past ice ages, particularly from cores drilled in seabed sediments, has supported oscillations in climate on about these time scales. However, the changes are too slow to be capable of influencing the Earth's climate within the time scale of human generations.

Variations in transparency of atmosphere. Volcanic dust, when injected into the atmosphere in large quantities, will reduce the amount of solar radiation reaching the Earth's surface, so that after periods of intense volcanic activity the Earth may be expected to cool. However, it is observed that the dust usually clears from the stratosphere within a few years and from the troposphere in a few weeks, so unless volcanic activity is sustained, the changes induced will not be long-lasting. Moreover, the dust, by absorbing outgoing long-wave radiation, may counteract the loss of solar input and thus prevent cooling of the Earth. Observations following the eruption of Mount Agung in Bali in 1963 suggest that the troposphere cooled (because of reduced insolation) and the stratosphere warmed (because of increased absorption by the dust). M. K. Miles and P. B. Gildersleeves found volcanic dust to be a possible partial explanation of temperature changes over the Northern Hemisphere in recent years.

Since volcanic activity cannot yet be forecast, neither can its consequences for the climate.

Changes in albedo. It has been postulated that if the area covered by snow and ice increases, more solar radiation is reflected and the Earth cools; as a result, more precipitation falls as snow, the area covered increases further, and the cycle is repeated in an amplifying cascade until glaciation become extensive. Conversely, according to this concept, a decrease of snow and ice cover could lead to a warmer Earth. The fact that this has not happened in historical times is a result of the strong domination of climate by the annual radiation cycle: the largest regional winter snow or ice anomalies fail to survive the following summer; on the other hand, the reduced insolation in winter always allows new ice and snow fields to form.

The physical effect of increased snow cover, in terms of its influence on the Earth's total radiation balance, is probably small in comparison with the effect of color changes (due, for example, to destruction of forests by fires, or to spread of deserts) in low latitudes, where amounts of radiation available to be absorbed or reflected are much larger.

Interactions between atmosphere and ocean. The dynamics of ocean-atmosphere interaction are only partially understood, and a complete description of such interactions would require an account of the links between the upper and lower layers of the ocean, which are even less understood. However, ocean-atmosphere interaction appears to be important in regard to variations in climate on all time scales, and there are clear indications of its relevance to changes on time scales of a few years. Examples of the latter are the Southern Oscillation and the associated El Niño, and the severe winters in North America and Europe.

Human-induced changes of climate. The wastes of human activity can have an effect on climate over a period of time.

Carbon dioxide. It is estimated that industrial emission of carbon dioxide, combined with reduction of the Earth's vegetation cover by humans, has already resulted in an increase in carbon dioxide in the atmosphere from 260 to over 330 parts per million, and it seems likely that it will reach 400 ppm by the end of the century. Since carbon dioxide absorbs outgoing long-wave radiation, the temperature of the atmosphere may be expected to rise. The average global warming for a doubling of carbon dioxide in the atmosphere is generally estimated at about 2°C. This value includes the effect of a resulting increase in water vapor content which enhances the warming by further absorption of outgoing long-wave radiation.

Any global climatic change is likely to affect also the wind-flow patterns causing regional differences in degrees of warming or cooling, and changes in rainfall. These interactions within the atmosphere will be substantially modified by the oceans. The extent to which the oceans may absorb excess carbon dioxide is as yet unknown, and could delay significant climatic changes until well into the 21st century.

Dust and other pollutants. Human activities induce pollutants from fires and chimneys, and also a change in soil erosion and dust-raising by the wind (such as in the dust bowl of the United States in the 1930s), but estimates of the extent of the pollution vary widely. Dust and other pollutants in the lower atmosphere reduce both insolation and outgoing radiation. The changes may or may not balance, and it is uncertain whether the amount of dust is significant in relation to natural quantities.

Alteration of albedo. Removal of forests and denudation of vegetation by overgrazing increase the proportion of solar radiation reflected and lost to space (the albedo), and local changes in climate may be considerable. If the areas affected are large enough, the total radiation budget, and therefore the climate of the Earth, may be influenced.

Heat input or thermal pollution. Heat input from human activity in some cities is already as great as that from solar radiation, but the areas affected are globally insignificant. The total world heat input from human activity is only 0.01% of that from the Sun, and is unlikely to reach 0.5% within the next 100–150 years. However, concentrated local heating (of hundreds of millions of megawatts) may result in circulation changes far downwind.

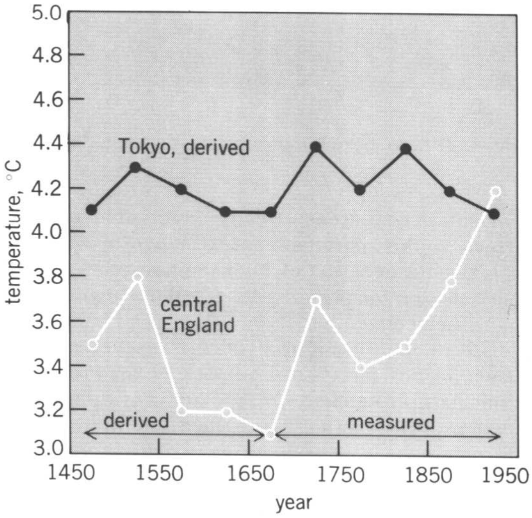

Fig. 3. The 50-year averages for Tokyo derived winter temperatures and central England winter temperatures. (*From B. M. Gray, Japanese and European winter temperatures, Weather, 30(11):359–368, 1975*)

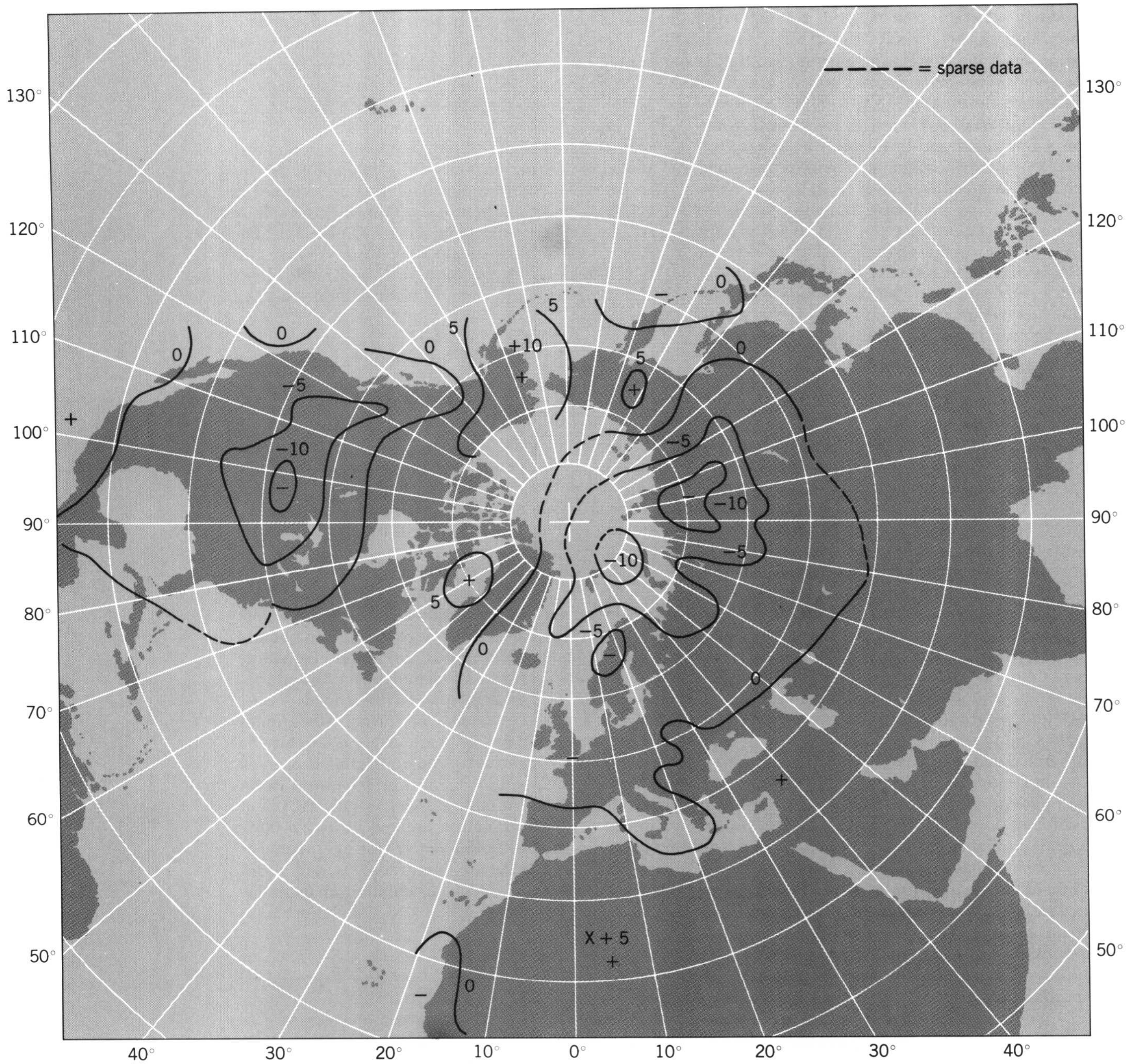

Fig. 4. Difference of temperature (labeled contours) from normal, Jan. 1979 (°C). X+ 5 indicates a+5°C maximum.

Central city areas already experience weather which, in the historical context, must be classified as extreme in terms of high temperatures. There may also be local increases of rainfall because of increased convection.

Future expectations. There is as yet no firm basis for any forecast of climatic change resulting from natural causes. Extrapolation of apparently regular cycles cannot be justified scientifically until their causes have been established, and until their existence has been recorded for a sufficiently long time for their stability to be confirmed. So far the first condition is fulfilled only for annual and shorter-term oscillations, and the second in respect of 2-year and shorter time scales, and for the long-term changes of the Earth's orbit.

The effects of human activity are already evident in local climates, especially in cities. There are good reasons to expect significant changes on a global scale due to increased carbon dioxide, but even these may not be detectable before the end of the century, and the global patterns of changes in temperature and rainfall cannot be forecast with any certainty.

For the time being, therefore, the best estimate that can be made regarding the future expectation of weather extremes must be based on past experience.

CLIMATE AND WEATHER IN THE RECENT PAST

If the future expectation of climatic extremes is to be based only on evidence from the past, it is necessary to examine the record to establish the period of time which can give a statistically reliable base for these expectations. It is immediately apparent that the standard period of human memory, or one generation (30 years), is too short. Over the whole period of instrumental records, neither the average nor the incidence of extreme events has remained stationary. Therefore it is necessary to allow for the possibility of extremes which have not been observed recently but which did occur further back in time. Up-to-date trends of temperature or rainfall could be used as a guide in this respect without a specific climatic forecast being made.

Temperature patterns. Figure 1 shows a Northern Hemisphere mean temperature series since 1660 derived from temperatures in England and from correlations between these and variations elsewhere. Notable features are the coldness before about 1700 and the peak warmth about 1940; the recent cooling is probably still continuing, and this suggests that future extreme weather of the severity experienced in the 17th and 18th centuries cannot be ruled out (as exemplified by the winters 1976/1977, 1977/1978, and 1978/1979 in the United States). However T. P. Barnett has emphasized the spatial variability of temperature fluctuations, and the hemispheric temperatures in the data-sparse earlier years in Fig. 1 are not firmly established. The information for populated areas in the 19th century and earlier does sometimes, but not always, support the pattern indicated in Fig. 1. Mean January temperatures in the eastern United States did follow similar trends (Fig. 2), but those in Japan did not (Fig. 3). The local urban heating effects have been removed from Fig. 3 but not from Fig. 2, so the real recent cooling in the eastern United States may have been greater. An overall change of hemispheric temperature will involve change of wind-flow patterns, bringing temperature changes in opposite senses in different places. This was shown clearly by H. van Loon and J. Williams. Figure 4 illustrates the pattern of temperature differences from normal in the month of January 1979, which had unusual wind circulation features.

Wind-flow patterns. Variability and trend in wind-flow pattern are illustrated in Fig. 5, which shows surface pressure differences, Azores minus Iceland, for summers and for winters since the 1860s. If the difference is large, the Azores anticyclone (high-pressure area) and Icelandic depression (low-pressure area) are strong and in their normal position, and there are strong westerly winds between them, which often affect Europe; but if the difference is small, the high and low, and the corresponding westerlies, are weak or displaced. The summer graph shows little trend, though sometimes there are successions of years of high- or low-pressure differences. The winter graph shows a decreasing trend since 1920, again with successions of years of low or high differences; but recent years with low values are not unprecedented in the light of the earlier years shown (for example, 1881, a very severe winter in northern Europe). In neither graph is there a clear change of variability.

Another interesting measure of atmospheric circulation is the difference in the height of the 500-mb (50-kilopascal) pressure level over the northern Rockies and over the southern Hudson Bay. When this difference is large, especially in winter, with the Rockies value higher, the west of North America experiences drought and central parts experience cold. Eastern parts may be snowy or wet; the circulation much further afield may meander more than usual (likely low values in Fig. 5*b*), with consequential changes over the hemisphere. Figure 6 shows a sequence of the winter height differences. The cause of the high values is not certain, but ocean temperatures in the Pacific may be important. In the light of the earlier parts of Fig. 5*b*, the record in Fig. 6 is too short to indicate that the 1977 value has never been exceeded in historical times.

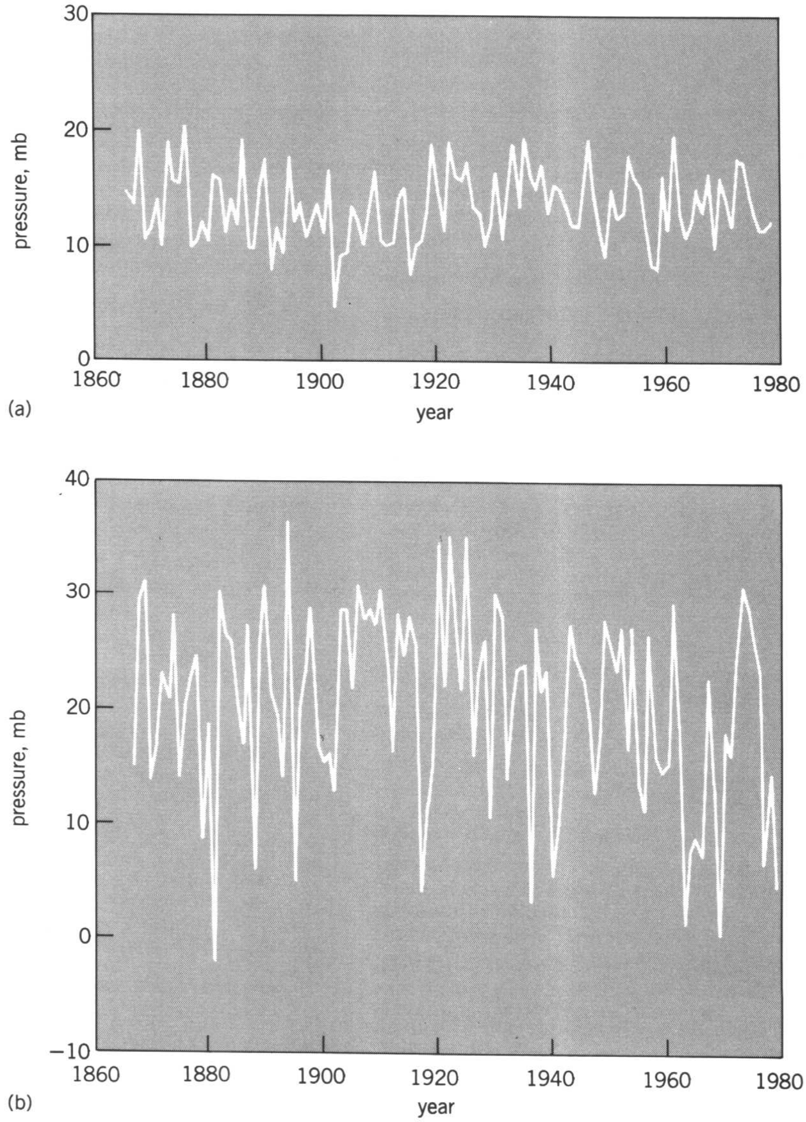

Fig. 5. Pressure difference, Ponta Delgada (Azores) minus Stykkisholman (Iceland), for (*a*) summers, 1867–1978, and (*b*) winters, 1867–1979; 10 mb = 1.0 kilopascal.

Changes of variability. Changes in mean temperature and circulation are thus well documented; but the position is less clear where changes of variability are concerned. J. K. Angell and J. Korshover have found evidence for a recent increase of variability in many parts of the world; but R. A. S. Ratcliffe and coworkers found no trend toward increased variability over the past 100 years when they considered surface pressure over the Northern Hemisphere and pressure, temperature, and