1. An overview

A. B. PITTOCK

If we would discover the seat of those forces which produce . . . [the] difference in the dynamical status of the two great aerial oceans that envelop our planet, we should search for them in the unequal distribution of land and water over the two hemispheres. In one the wind is interrupted in its circuits by the continental masses, with their wooded plains, their snowy mantles in winter, their sandy deserts in summer, and their mountain ranges always. In the other there is but little land and less snow.
Matthew Fontaine Maury, *The Physical Geography of the Sea* (1855)

1.1 Concepts and perspectives

The atmosphere and oceans respond to the unevenly distributed driving force of energy from the sun's radiation, storing, redistributing and re-emitting it in various ways. The dynamic and thermodynamic manifestations of these responses are seen, instantaneously, as 'weather'. Viewed over longer time spans these responses are described as 'climate', although there is no clear consensus as to where weather ends and climate begins.

Every quantifiable element of the weather, such as temperature, pressure and rainfall, varies continuously or discontinuously with time on all time scales, so that an essential aspect of climate is variability. The concept of climate thus includes the totality of variations in weather with time, yet there is no time span over which the moving averages and variabilities of the weather elements remain constant. Some meteorologists have defined climate in terms of the weather over 30-year periods, and the years 1931–60 have been regarded as the standard. This particular period, however, is not necessarily representative even of this century, and an examination of the highly variable records of countries such as Australia indicates that longer intervals are often necessary before estimated means and standard deviations of such elements as rainfall or temperature even approximate constancy.

Climatic change is likewise a difficult concept to define. Clearly it must include an element of continuing trend, or a discontinuity, in the average value or variability of some climatic element. Numerous statistical tests may be applied to determine the significance of trends or changes in a strictly statistical sense, but these tests usually make assumptions as to the statistical distributions and behaviour of the climatic elements being tested which are often only approximately true. It is also quite possible for certain properties, such as average annual rainfall, to remain constant while related properties, such as the seasonal distribution of rainfall, or its variability about the mean, vary significantly. The question as to whether a given variation in climate is a statistically significant change as contrasted with a manifestation of the normal 'random' variability of climate is in any case largely academic to the people affected, and the statistical answer will often depend on the time and space scales considered.

It should not be surprising therefore if various concepts such as climatic change and variability are sometimes used in different senses, nor that controversy should develop as to the 'reality' of a hypothesised climatic change. Such controversy assumes different aspects according to one's view-point and perspective. Meteorologists or climatologists working with the instrumental record of a mere 100 years or so, as they must in most of the Southern Hemisphere, are working on a time scale dominated by short-term variability in which longer-term trends are difficult to establish with any statistical certainty.

The time scale of most interest to agriculturalists, economists, planners and politicians is perhaps even shorter, of the order of decades. On this time scale a run of several bad years constitutes a major event of increasingly disastrous proportions as world populations increase and the margins between food production and consumption, or water supply and water use, decrease. To people involved at this practical level, the perceived consequences of a supposed climatic change may be seen to be so great as to justify shifting the onus of proof from those who hypothesise change to those who hypothesise no change. From this perspective 'social responsibility' may well run counter to a conservative interpretation of 'scientific responsibility', and 'caution' may demand that decision-makers allow for the possibility of climatic change rather than dismiss its likelihood. Similar differences in perspective, with their implicit value judgements, run through many debates on scientific issues of practical significance (e.g. see Weinberg, 1972).

Palaeoclimatologists consider time scales ranging from centuries through millennia to hundreds of millions of years. On these time scales the evidence of major climatic changes is irrefutable, although difficult to quantify both as to precise timing and the range and exact nature of the changes. Here controversy often centres on the precise climatic interpretation and scaling of secondary evidence derived from such sources as tree rings, pollen deposits, geomorphological features, or isotope ratios which are the result of many complex physical or biological processes.

Cambridge University Press & Assessment
978-0-521-17226-4 — Climatic Change and Variability: A Southern Perspective
Edited by A. B. Pittock , L. A. Frakes , D. Jenssen , J. A. Peterson , J. W. Zillman
Excerpt
More Information

For those unfamiliar with palaeoclimatological terms, it is perhaps as well to explain the meanings attached to terms such as 'ice age', 'glacial' and 'stadial', and to set these in some time perspective.

Geological evidence shows that during the 4,700 million years of Earth's existence it has gone through several 'ice ages' each of which lasted a few million years. Between these events there were no ice caps on Earth. The most recent ice age, the Quaternary Period, began about 1.8 million years ago and continues today. During this ice-age period the quantity of ice at high latitudes and in mountainous regions has waxed and waned in a complex manner at least partly related to global-scale climatic variations. There have been a number of long periods (of the order of 10^5 years each) during which the ice volume and its geographical extent were greater than at present. During several of these there was at least three times the present amount of ice. These colder periods should more properly be termed 'glacial stages' (although they are sometimes referred to as 'ice ages'), and the warmer times between them 'interglacial stages'. Over the last half-million years or so, the interglacials have occupied much less time than the glacials.

Shorter cold periods with smaller ice volumes than the full glacial stages are called 'stadials', and the warmer intervals between them 'interstadials'. These variations are superimposed on the longer-term fluctuations of glacials and interglacials.

Typical palaeoclimatological curves exhibiting these features will be found in Sections 3.1, 3.4, 5.1 and 5.2. Time spans for various named geological Eras, Periods and Epochs will be found in standard texts such as Flint (1971), Schwarzbach (1963) and Frenzel (1973). With the exception of Fairbridge (Section 5.1), the present book deals with the Cenozoic Era (~ 65 million years ago to the present), and particularly the Quaternary Period which encompasses the Pleistocene Epoch and the post-glacial Holocene (or 'Recent') Epoch. The latter includes the most recent historical times and the years of instrumental records.

1.2 The Southern Hemisphere Aspect

Despite the excellence of much recent work on climate and climatic change emanating from the Northern Hemisphere (e.g. Schwarzbach, 1963; Royal Meteorological Society, 1966; Flohn, 1969; Lamb, 1972*a*; Frenzel, 1973; US Committee for GARP, 1975; World Meteorological Organization, 1975*a*), coverage of Southern Hemisphere climate has in general been rather small. The geographical, historical and cultural reasons for this bias are understandable, but the consequences in terms of a true global understanding of climate are serious. This is of global rather than merely regional concern, because the nature of the global ocean–atmosphere system is such that a complete understanding of climatic behaviour in one hemisphere is not possible without an understanding of that in the other, and the two hemispheres are different in a number of important respects.

The reasons for Northern Hemisphere bias in the literature are not merely northern parochialism and the remoteness of the Southern Hemisphere from the major centres of modern scientific culture, but also more fundamental limitations determined until the advent of meteorological satellites by a much smaller and more recent ground-based network of meteorological stations, and a much smaller area and latitudinal range over which to establish a land-based palaeoclimatic record in the south.

These limitations are now rapidly being overcome by the use of satellites (Barrett, 1974), isotopic analysis of ice and ocean-bottom cores, more refined techniques of tree-ring and pollen analysis and other methods which extract the maximum information from scanty and mainly non-glacial land records. The paucity of Southern Hemisphere data and palaeoclimatic sites has necessitated different approaches, for example, a growing emphasis on pattern analysis to determine the representativeness of particular sites and to help select sites for the most profitable deployment of scarce research personnel and resources.

Major differences between the Northern and Southern Hemispheres which have climatological significance stem essentially from the shapes and distribution of land, sea and ice as to latitude, longitude and altitude.

Only about 20% of the Southern Hemisphere is covered by land or ice caps as against nearly 40% of the Northern Hemisphere. Yet the Antarctic ice sheet, including the floating ice shelves, is about 14 million km^2 in area and contains more than 90% of all the world's ice. The additional area of Antarctic sea-ice varies seasonally from around 4 million km^2 in March to some 20 million km^2 in September. The total Arctic sea-ice cover, on the other hand, varies from a minimum of around 7 million km^2 in September to about 12 million km^2 in March and April.

Differences in the heat budget of the Arctic Ocean with its thin and partly seasonal ice cover compared to that of the permanent elevated Antarctic ice cap leads to winter air temperatures over the Arctic Ocean of about −35 °C as against temperatures down to −70 °C or lower over Antarctica. Since the temperature of the tropics varies little between hemispheres, the temperature gradient from the equator to pole, which is closely related to the intensity of the westerlies and the general circulation, is nearly 40% larger over the Southern Hemisphere than over the Northern Hemisphere. This is one major factor leading to the subtropical high-pressure belt in the Southern Hemisphere being on average some 7° of latitude nearer the equator than in the north and largely accounts for the asymmetry of the intertropical convergence zone or 'meteorological equator' (Flohn, 1969). Seasonal displacements of wind and pressure belts depend largely on direct heating of the atmosphere (i.e. on the 'sensible heat') as opposed to heating by evaporation and condensation of water (i.e. on the 'latent heat') and, as this is greater over continental land masses, seasonal displacements are on average greater in the Northern Hemisphere.

The so-called 'polar monsoon' regime of the subarctic, where polar easterly winds blow in summer and westerlies in winter, owes its existence to the pattern of land–sea distribution and has no counterpart in the south.

Other major circulation differences arising from the different land–sea distributions and topography of the two hemispheres include the greater relative importance in the Southern Hemisphere of mean zonal (east–west) motion as opposed to eddy motion (large-scale turbulence), and of transient eddies as compared to standing eddies (moving eddies or wave-motions as opposed to those more or less fixed in longitude) (Adler, 1975). Standing eddies consisting of two, or more often three, waves around each circle of latitude, with ridge–trough positions tied to the land–sea distribution appear to play a key role in the climate of the Northern Hemisphere. Variations in their intensity and precise location at middle and high latitudes may play a major role in climatic change. Lower latitudes of the Southern Hemisphere are also strongly influenced by three standing waves associated with Africa, the Indonesia–New Guinea region, and South America, but at higher southern latitudes one and two waves appear to dominate, variously said to be due to the influence of the Andes and the Antarctic Peninsula, the eccentricity of the Antarctic ice cap, or to the dominance of the southeast Asian archipelago region in exporting energy from the tropics (van Loon & Jenne, 1972; Vonder Haar, 1968).

These and other significant interhemispheric differences could provide vital clues to the mechanisms underlying global climatic change. A key element in unravelling this question may well turn out, therefore, to be the degree of synchronisation and the time lags between climatic variations in the two hemispheres. In the absence of positive feedback processes and major storage of heat, atmospheric and oceanic transports of heat will tend to smooth out temperature differences between similar latitude zones at a rate depending on the magnitude of the transports between them, and probably of the order of a few years at most. Oceanic and ice-cap storage terms, which differ greatly between hemispheres, will introduce major lags, and feedback processes due most likely to albedo differences between land, sea, and ice, snow, or cloud cover may maintain even longer-term differences.

Field evidence as to time lags between hemispheres both on the time scale of the major glacial–interglacial sequences and on that of the instrumental record are thus of great diagnostic significance, so that the Southern Hemisphere record is indeed vital to the global picture. Recent evidence (Sanchez & Kutzbach, 1974; Tucker, 1975; Salinger & Gunn, 1975; Burrows, 1975) throws considerable doubt on the supposed parallelism of the Southern and Northern Hemisphere instrumental records (Mitchell, 1961, 1963), although broad parallelism in the late Quaternary Record does exist, albeit with time lags which could be as large as a couple of thousand years. Accurate absolute dating and fine time resolution is essential to answering this question on the palaeoclimatic time scale.

1.3 Intentional climate modification

A notable omission from the conference proceedings (apart from Flohn's brief reference in Section 3.7) was in consideration of *intentional* climate modification. In view of Australia's pioneering and significant efforts in cloud-seeding research, and the obvious benefits to be gained from increasing rainfall in a generally dry country, this omission is worthy of some discussion.

Research by CSIRO in Australia (Smith, 1974; Warner, 1974) and by other groups around the world has demonstrated that in the case of individual clouds having suitable characteristics, cloud seeding can increase precipitation. The same can be said for a small number of experiments aimed at increasing precipitation over areas ranging from 1,000 to about 10,000 km^2. However, the attitude of at least some of the workers in this field is well summed up by Hosler (1974) who in introducing a review on 'Overt Weather Modification' stated: 'Global weather modification and climatic change are not discussed, since the techniques employed thus far in overt weather modification present us with no physical reason for supposing that they affect anything on a grid larger than a few hundred kilometres.'

On the other hand, it could be argued that a significant increase in precipitation over a catchment area of 10,000 km^2 would significantly increase the runoff available for irrigation and thus be tantamount to a climatic change over the area served by such irrigation. Even so, the affected areas would remain small on a global scale.

Views of other workers as to the state of the art may be found in Hess (1974) and Sax *et al.* (1975). Amongst the most optimistic are Huff & Semonin (1975) who claim somewhat cautiously that in some circumstances 'successful cloud seeding operations could contribute occasionally to temporary alleviation of water shortages over portions of an extensive drought region'.

There has been considerable expenditure of money and effort in attempts to suppress hail and to modify hurricanes or tropical cyclones. However, the comparative rarity of these phenomena and the absence of adequate theoretical models of their behaviour have so far prevented any wide agreement being reached as to the effectiveness of the techniques used.

Grandiose engineering schemes aimed at climate modification, such as diverting rivers which flow into the Arctic Ocean, damming Bering Strait, or creating huge artificial lakes in the Saharan region of Africa, have been suggested. Southern Hemisphere examples include damming Drake Passage, creating an inland sea in Australia, and coating parts of the Australian desert with bitumen. Several of these proposals are hardly practicable, and the probable climatic consequences of each is not yet understood. Until suitably complex and realistic theoretical/numerical model experiments have been performed on these proposals they remain completely unproven and too uncertain in their potential effects to be undertaken with any degree of social responsibility (Kellogg & Schneider, 1974).

It is interesting, however, to note that preliminary studies and primitive attempts at such model experiments for certain Northern Hemisphere cases are beginning to be made (e.g. Vowinckel & Orvig, 1974; Gray *et al.* 1974; Rapp and Warshaw, 1974), and that the conclusions, while highly tentative, are not entirely negative. Perhaps this is an area worthy of more serious thought in a Southern Hemisphere context.

1.4 A problem for all humanity

Having stressed the Southern Hemisphere perspective and contribution to the problem of climatic change and variability, it is worth while to pause briefly to consider the unifying aspects of our subject, which crosses boundaries of nations, regions, disciplines and cultures.

The study of climatic change and variability requires the contributions of and interactions between not only meteorologists, geographers, geologists, oceanographers, glaciologists, mathematicians and statisticians, but also chemists, botanists, biologists, and even historians, archaeologists and economists. The subject is so fraught with complex physical, biological and cultural interactions and feedbacks that any worker from a single discipline must inevitably trespass outside his own area of expertise. If such a worker does so in isolation from other relevant expertise the result can too often be oversimplification and error. The very nature of climatic interactions therefore demands interdisciplinary approaches and exchanges at a scientific level.

Geographically speaking, climatic interactions are truly global in character, although subject to important local and regional modifications. Significant climatic variations other than those induced by topographic changes are never confined to single regions or locations, but occur as part

Cambridge University Press & Assessment
978-0-521-17226-4 — Climatic Change and Variability: A Southern Perspective
Edited by A. B. Pittock , L. A. Frakes , D. Jenssen , J. A. Peterson , J. W. Zillman
Excerpt
More Information

of global patterns of variation (see Chapter 4). In a world increasingly interconnected physically and culturally in terms of communications, trade, economics, food supplies, and political and ideological movements and conflicts, the influence of climatic variations in any particular region will have ever-wider implications elsewhere (see Chapter 7).

As world population edges closer to the limits of world food production and to the full utilisation of existing fresh-water supplies, profound cultural and philosophical questions are being raised as to the limits of growth (Mesarovic & Pestal, 1974), the ability of science and technology to provide viable 'solutions' to problems raised by growth (Crowe, 1969; Moncrief, 1970), and as to the proper relationship between humankind and nature. Should we accept the limitations imposed by the natural climate on food production and water supply, or should we go all out for the technological 'fix' of global-scale climatic engineering? If we do not choose to adapt to the natural environment and live 'in harmony with nature', as so-called 'primitive Man' is supposed to have done for millennia, do we not expose ourselves to great risks of global disasters brought on by global pollution and inadvertent, unanticipated, climatic modification? (See Chapter 6.) Could so-called 'Civilisation' generate a climatic disaster such as a melting of the ice caps or a new ice age? Might our survival, on the other hand, depend on human intervention to prevent just such events from occurring naturally?

These are profound human questions which go far beyond science as such to deep matters of philosophy and human values. The global nature of the questions demands global answers. Are we, as members of an intelligent species of beings who are still divided by nationality, ideology, race and religion, ready to provide the answers which are required of us at this stage in our cultural and historical development? I for one have my doubts, but for this very reason I hope the problems raised by climatic change and variability will be considered not only by scientists but by religious and secular philosophers, politicians, administrators and members of the public at large.

978-0-521-17226-4 — Climatic Change and Variability: A Southern Perspective
Edited by A. B. Pittock , L. A. Frakes , D. Jenssen , J. A. Peterson , J. W. Zillman
Excerpt
More Information

2. The physical basis of climate

2.1 The climatic system*

Subsequent chapters will summarise what is known of the climates of the past and the variability of the earth's climate through geological and historical time. If we are to appreciate the significance of these changes and begin to unravel their causes, we must first understand something of the processes that determine the nature of climate itself. The complete problem is enormously complex and is still far from solved. It is possible in this chapter to introduce only the broad framework. This must include at least the sun, the earth's atmosphere, the oceans, the cryosphere (ice masses and snow deposits), the land surface and the biomass. The sun is the ultimate energy source. Its influence on climate depends not only on the sun–earth distance but on other orbital characteristics such as the rotation rate of the earth and its angle of tilt to the sun. Differential solar heating of the earth–atmosphere system drives atmospheric and oceanic circulation systems which constitute the essential physical basis of climate.

The energy source

The sun is known to emit energy in various forms as electromagnetic radiation (radiowaves, thermal radiation, X-rays) and streams of charged particles including cosmic rays. The precise state of climate on earth may depend directly or indirectly on several of these but by far the largest part of the solar power output is in the form of thermal electromagnetic radiation in the wavelength range 0.2–5 micrometres. The total radiant power output of the sun is about 3.88×10^{26} watts which is equivalent to the thermal emission from a black body the size of the solar photosphere at a temperature of 5,790 K.

The radiant energy crossing a unit of area normal to the solar beam per unit time at mean sun–earth distance is known as the solar constant. Its value lies in the range $1{,}360 \pm 20$ watts per square metre (W m^{-2}).

* Editorial contribution.

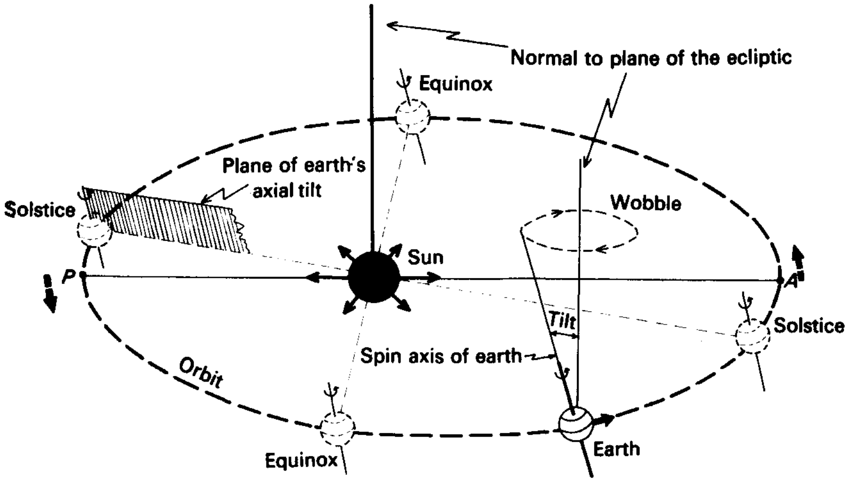

Fig. 2.1.1. Geometry of the sun–earth system. The earth's orbit, the large ellipse with major axis *AP* and the sun at one focus, defines the plane of the ecliptic. The plane of the earth's axial tilt (shaded) is shown passing through the sun corresponding to the time of the southern summer solstice. The earth moves around its orbit in the direction of the solid arrow (period one year) while spinning about its axis in the direction shown by the thin curved arrows (period one day). The broken arrows shown opposite the points of aphelion (*A*) and perihelion (*P*) indicate the direction of the very slow rotation of the orbit.

Sun–earth geometry

Figure 2.1.1 shows the main features of the sun–earth geometry that are of importance to climate. The earth moves on a slightly elliptical orbit around the sun, at present distant about 147.1 million km at perihelion and 152.1 million km at aphelion. This causes the solar radiation incident on the earth to wax and wane about 3½% either side of the solar constant in the course of a year. At present the incident radiation is strongest in January during the Southern Hemisphere summer.

The earth's axis of rotation is not upright with respect to the plane of its orbit (known as the ecliptic). This tilt, coupled with the earth's annual journey around the sun, leads to the normal march of the seasons. The earth is at one of the solstices (December, June) when the sun–earth vector lies in the plane of its axial tilt; at the equinoxes (March, September) when it is normal to this plane. The various orbital parameters change slowly with time as follows. Firstly, the elliptical orbit itself revolves slowly in space in the same direction as the earth's travel in its orbit, completing one revolution in space after an irregular interval that averages 96,600 years. Secondly, the eccentricity of the orbit (the difference between the sun–earth distances at aphelion and perihelion divided by their sum) varies as the orbit revolves in space with the same period of about 96,600 years.