SCOPE 27 - Climate Impact Assessment

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21 Historical Climate Impact Assessments

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21.1 INTRODUCTION

The dictum that the past is the key to the future has frequently been used to justify scientific research (see de Vries, Chapter 11). It is particularly appropriate to the present study. Climate is one of the many complex and subtly changing elements of the environment upon which human societies depend for their survival. Precisely because of this complexity and subtlety, it is difficult to determine the degree to which climatic fluctuations affect society. To give a recent and well known example, there is still considerable controversy concerning the Sahelian famine of the late 1960s and early 1970s. Some hold that this was the direct result of climatic variation, while other see the causes in the underdeveloped economic infrastructure of the countries affected, external interference in those countries' affairs, or simply in inflexible techniques of animal and crop husbandry.

One can argue that, by looking at the ways in which climate has affected societies in the historical past, it should be possible to identify more precisely the potential impacts (and successful adaptive strategies) that present and future climatic fluctuations can have on human societies. Such studies are free from contemporary political controversies and other obscuring factors.

> Global and regional climate changes will affect different societies and different segments within societies in a wide variety of ways. One means to determine the range of impacts is to undertake case studies on ways in which families, political institutions, and social sectors such as agriculture have been affected by changing or varying climates .... Historical case studies of climatically vulnerable areas such as Iceland and the Great Plains of the United States may be particularly useful in understanding societal adaptations.
>
> (American Association for the Advancement of Science, 1980,14.)

It is the purpose of this paper to suggest ways in which such case studies might be carried out and to discuss some of the existing work in the field.

Although most historians, historical geographers and archaeologists have long recognized the possible importance of the impact of climate on human affairs, the literature reveals considerable disagreement about how seriously the possibility should be taken. It is generally accepted that short-term (intra-annual, annual and interannual) variations in climate and weather, having an immediate effect on harvests and other economic activities, are relevant to short-term economic fluctuations. But long-term climatic influences (on time-scales of decades or more) have been commonly regarded as of little or no historical interest, on the basis of one or more of the following assumptions: first, that climate has been essentially stable in historical times; second, that the magnitudes of past long-term climatic shifts, though striking from a scientific point of view, have been too small to warrant their consideration as significant variables in the processes of economic and social change; third, that the resilience and adaptability of past societies has been sufficient to absorb the effects of periodic short-term climate-induced stresses and so to minimize the cumulative effect on longer time-scales; fourth, that lack of detailed information on past weather and climates and imperfect understanding of the complex processes of climate-history interactions precludes any serious study of the subject.

Nevertheless, for a long time, a minority of historians and larger numbers of archaeologists and natural and environmental scientists have been convinced of the importance of climate as a major independent variable affecting the development of human societies. The most extreme exponents may be labeled climatic determinists, of whom Ellsworth Huntington (1907, 1915) is the best known. Although the term `climatic determinism' does not necessarily imply a belief that the whole course of history is explicable in terms of climate (Pearson,1978), it certainly implies that climatic factors have been among the most important influences on the development of civilizations (see Riebsame, Chapter 3). Such views are still held today, for example by Chappell (1970), and in a less extreme form by Bryson and Murray (1977), Lamb, and others. For example, Lamb has asserted that `climatic history must be central to our understanding of human history' (1969, 1209).

Others have been more cautious, eschewing grand generalizations about the significance of climate in world history, yet strongly urging recognition of the importance of climatic factors in particular areas and periods. Among historians they include Utterström (1955), Braudel (1949, 1973), and more recently Parker and Smith (1978) and Parker (1979); but these contributions, though interesting, are marred by methodological weaknesses (see; for example, the extensive criticisms of Utterström by Le Roy Ladurie, 1972, 8–11).

In recent years a new breed of historians interested in climate–history interactions has emerged. These scholars, of whom Pfister (1975, 1978, 1981, 1984), de Vries (1977, 1980 and Chapter 11), Post (1977, 1980) and Parry (1978, 1981a,b and Chapter 14) are some of the most outstanding, admit the possible importance of climate variations on human affairs both in the long and short term, make serious attempts to investigate the possibility with the aid of all the available methodological resources of history, economics and climatology, but demand the highest standards of proof. In particular, these historians have been able to impart to climatologists the importance of a rigorous analysis in evaluating climate data found in historical documents, together with an appreciation of the complexity of climate–society links. Their work has transferred the study of climate –history impact onto a higher plane of methodological rigor.

A review and synthesis of the methodologies for historical climate impact study is therefore appropriate. We begin this chapter with a discussion of the underlying philosophy related to *explanation* in the historical climate impact context. We then discuss briefly the problems of data availability, on both the societal and climate side, before introducing a model-oriented framework for climate impact studies. The major statistical tools which can be used for testing impact models, together with some of the pitfalls which one should strive to avoid, are then described. Alternative strategies, less axiomatic and more empirical in their approach, are seen to play a valuable supporting role, but these must be used cautiously. Having described the methods available, we then consider more specific examples of historical climate impact divided into short, medium and long time-scale effects. Some of the most convincing studies are those of marginal areas, and those which consider the issue of climate as only one of many factors in the milieu of potential determinants of societal impact. We therefore devote considerable space to discussing human adaptation to climate stress. Finally we present a brief, selective summary of a number of published climate impact studies, with the important features of these studies categorized in terms of our recommended methodological framework.

21.2 METHODOLOGY

21.2.1 Philosophical Assumptions

A philosophical issue basic to the study of the impact of climatic variations on human societies is on whom the onus of proof should lie. It is plain that climatic variations must have had *some* influence on economies and societies. Hence, some writers feel justified in accepting and extrapolating poorly substantiated `demonstrations' of the importance of climatic effects in particular cases, and casting the onus of disproof on the sceptics. The importance of climatic influences cannot be assumed, however, and to demand, either explicitly or implicitly, that the burden of proof should lie with those who doubt the importance of climatic effects is inadmissible.

Notwithstanding this, because we are dealing with human behavior, which eludes quantification, the concepts of `proof' and `explanation' in the historical context should not be assumed to be the same as in the context of the physical sciences. It would be unfair to demand precisely the same standards of generality, definition of model, or even statistical rigor in studying the linkages between climate and society as one might require in other disciplines.

21.2.2 The Problem of Data

One difficult question which anyone attempting to investigate possible climate–history links in particular cases must ask is whether the available data are sufficient to justify the attempt. The amount and variety of available data on past climate and weather is extensive (reviewed in Wigley *et al.*, 1981). However, the kinds and quality of data which may satisfy the purposes of scientists seeking only to extend the climate record back in time may be inadequate for the purpose of demonstrating climate–history interactions. The latter purpose often demands detailed information about individual seasons, months, even weeks, and such data have been, unfortunately, absent or sparse for large regions of the world until the very recent past.

Data on the complexities of human economic and social activities are also highly variable, both in quantity and quality, in different locations and at different periods; and, in general, the further back into the past one penetrates, the fewer are the available data. It is impossible to summarize the extent of the available information on the varieties of human activity most likely to have been affected by climate. A few examples taken from Western Europe, a region whose history over the past thousand years or so is relatively well documented, will illustrate the problems.

Grain production is and has been an activity of major economic importance. Over large areas and for long periods, a considerable proportion of cereal production and distribution was controlled by large-scale secular and religious landholders whose activities are comparatively well recorded. Much information on grain production accordingly survives. Yet, for the purposes of the economic historian, it suffers from many imperfections. While abundant grain *price* data exist (e.g. Beveridge, 1921, 1922, 1929; Bowden, 1967), information which bears more directly on agricultural productivity is much less common. In fact, its very scarcity has led Hoskins (1964,1968; see also Harrison, 1971) to use price data to reconstruct, year-by-year, the quality of the harvest. As Appleby (1980), de Vries (1980, especially pp. 620–621) and others have pointed out, this may be valid in a simple `closed' agricultural economy, but it is highly debatable for developed, open economies. Flohn (1981), using data from Titow (1960, 1970) has demonstrated a yield-price link for medieval England (1211–1448); but examples from fifteenth-century Netherlands (Tits-Dieuaide,1975) and eighteenth-century Switzerland (Pfister,1975) show more complex relationships, and there are many instances in England from the sixteenth century onwards of harvest failures which were not reflected in price increases (Appleby, 1980). Of course, price data, although imperfect as a proxy for harvest data, may be used directly as an economic indicator which might in turn be statistically related to climate. Anderson (1981) exposes the pitfalls which simplistic analyses along these lines might encounter, but some excellent examples of a *rigorous* approach are given by de Vries (1980) and Lee (1981).

As another example, demographic data, in many ways fundamental to an understanding of social change, are distressingly sparse and imprecise. In many parts of Europe before the sixteenth or seventeenth centuries, the available information suffices only to indicate, with considerable margins of uncertainty, gross trends in population. Nevertheless, some excellent demographic studies have been undertaken. The scholarly and detailed study by Imhof (1976) on population in the Nordic countries during 1720–50 is a notable example. (In this study, Imhof claims a close connection between climatic variability and mortality through disease.) On the whole, however, demographic data become abundant and satisfactory only in the nineteenth century.

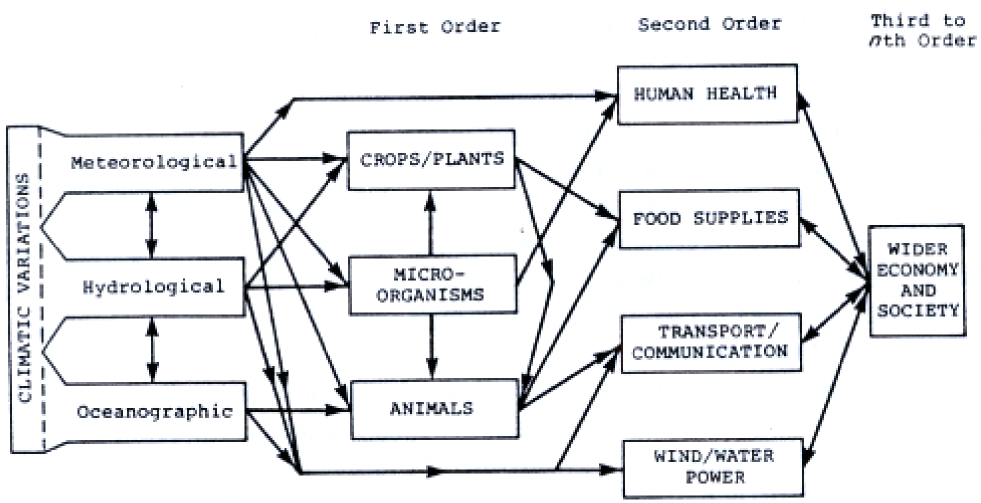

Figure 21.1 First- and higher-order effects of climate on aspects of society. As the particular impact becomes more removed from the climatic `cause', more and more interactions intervene to disguise and modify the link. The two-way arrows in the last links symbolize possible adaptive feedback processes. (Reproduced by permission of Cambrige University Press from Ingram *et al.*, 1981, Figure 1.2)

For localities outside Europe the problems are, in many cases, even greater. This is not to say that no data adequate to investigate climate-history links are available, but it is as essential to be aware of the gaps and problems in the record of human activities as it is to recognize the imperfections in the climatic evidence. It must be accepted that, for many parts of the globe over long periods, the data currently or potentially available on human activities which are likely to show a discernible climatic impact are so sparse or poor as to vitiate any attempt to demonstrate it.

21.2.3 Preliminary Models

In discussing specific examples of assessments of climatic impact, we must distinguish between effects on different time-scales. However, all attempts to identify and measure climate–history interactions must rest on models of the processes involved in order to identify, in general terms, how climate may be expected to affect human history. A simple model of a type which, explicitly or implicitly, underlies the majority of studies of climatic impact in the past is shown in Figure 21.1 (from Ingram *et al.*, 1981). Variations in the atmospheric circulation manifest themselves as meteorological, hydrological and oceanographical phenomena. These may have a direct (first-order) effect on biophysical processes important to man, including crop and animal survival and growth, marine and other aquatic life, and the activity of microorganisms capable of causing disease in plants, animals and man. In addition, they may have effects on aspects of the purely physical environment of importance to human societies; for example, causing rivers to freeze or flood. These direct biological and physical effects may have economic or social (second-order) significance, affecting food and raw material supplies derived from agriculture or animal husbandry; human health; the performance of machines (such as industrial and food processing mills) driven by wind and water; transport and communications; and military and naval operations. Depending on their magnitude, these effects may ramify into the wider economy and society (third to *n*th-order). For example, food shortages may (in association with other factors) lead to rebellions, which in turn may help to undermine political systems.

Such a conceptual model serves only to focus attention on the indirect and complex nature of the links between climate and the majority of economic and social phenomena, and to aid in the identification of relevant data. It does not include the many other variables which, apart from climate, might affect human activity; nor does it specify in detail which climate variables are critical for each activity.

These complexities, which are considerable, may be illustrated by reference to the effects of weather on agriculture, perhaps the most obvious link between climate and human activities. Different crops are sensitive to different climatic factors. In any particular study of the effects of climate on agriculture, it is necessary to establish precisely in what respects the relevant crops are sensitive to climate. This is not an easy task, since crops may respond to a number of climate variables and the response may be markedly nonlinear (McQuigg, 1975; Thompson, 1975; Starr and Kostrow, 1978; Wigley and Tu, 1983). Furthermore, the important variables and critical times are not always obvious, and the direction of the relationships between yield and climate may vary from place to place for the same crop. In southern England, for example, mild winters are an important determinant of good winter wheat yields today, but higher yields are also favored by cooler springs and summers, contrary to common conceptions. In England, too, cold summers have been correlated with higher hay yields (Hooker, 1922), whereas in Iceland precisely the opposite correlation holds (Bergthórsson, 1966, 1976). In low-lying areas of western Europe, rainfall, especially in winter, may be the most important climatic factor in determining crop yields (de Vries, 1980; de Vries also describes the -excellent work by Baars, 1973). Further information on crop-climate links in the historical past is given by Slicher van Bath (1977). Our understanding of these relationships can be put into perspective by noting that, today, even the best crop-climate models rarely account for much more than 50 percent of the variance when long-term technology trends have been factored out, although there are notable exceptions (for example, Bergthörsson's work [1966, 1976] on hay yields in Iceland). In evaluating climatic impact in the past, the links between yield and climate are generally even more diffuse. One should, therefore, take heed not only of any relevant crop-climate linkages established using modern data, but also of the possibility that past relationships may have differed from those of today.

It is obvious that climate is not the only variable affecting agricultural production. Account must also be taken of such factors as variations in the extent of land under cultivation and of the level of investment in seed, fertilizer, technology and labor; the possible effects of disease (which may or may not itself be influenced by climate); and even the intrusion of non-agricultural human activities such as devastating warfare. In any given case, the effects of climate will be masked by the operation of these other variables.

The complexities of the relationships between climate and all other human activities are at least equal to those affecting crop yields, and in many cases greater. In particular, it is evident that the more remote the relationship between climate and a given activity, the greater the number of complicating variables. A rebellion or grain riot, for example, is separated from a variation in the atmosphere by a complex mesh of causality.

21.2.4 Modeling a Climate–Society Link

In climate impact studies, the real issue is not whether the climate has had an influence, but to establish what and how strong the influence was, and whether it was of any real significance. Even strong identifiable primary impacts (see Figure 21.1) may be of little consequence if diffused by other non-climatic factors as they cascade through the socioeconomic system to second-, third and *n*th-order effects. The basis of any analysis, therefore, must be a reasonable model of the processes, including those which govern climate impact and those which might act to ameliorate such impact. Figure 21.2 gives a model framework which will be discussed further below. Development of a model helps to identify the variables which might be examined to define cause and effect, and to establish the realism of any cause-effect relationship, although the complexity of the model itself may be determined by the availability of data. As de Vries (1980, 608) points out, although an econometric model of the variables (including climate) affecting rye prices at Utrecht in the seventeenth and eighteenth centuries could be devised, this would be of little use because data on several of the key variables are lacking.

In many cases the problem is not only that of inadequate data, but also an imperfect understanding of the economic and social processes involved. The feasibility of constructing an adequate model depends on several factors.

1. The complexity of the task varies according to the number of economic and social variables included in the investigation. The extreme case would be to attempt to gauge the effects of climatic variations on all aspects of life in a given society. Less ambitious investigations, focusing on one or a small number of economic or social variables, are more realistic.
2. First- and second-order climatic effects (see Figure 21.1) can be modeled more easily than the links between climate and more remotely connected human activities. The more remote the activity, the greater the number of complicating variables, and the less easy it is to demonstrate a unique causal link.
3. The problems vary according to the geographical scope of the investigation. In general, it would appear easier to model the effects of climate for a small area than for a larger one. In studying a large area, such as an entire country, weather and climate patterns may vary markedly over the area, their influence will vary according to the varieties of regional landform and even local topography, and it may be necessary to take account of regional variations in economic and social structures. Smaller-area studies may involve fewer variables (they certainly eliminate the problem of the spatial variability of climate), but they may also transform *internal* compensating factors into *external* influences. Particularly in early-modern and more recent times, local areas cannot always be considered as isolated from the buffering effects of regional or international trade; indeed, such external influences may, in some circumstances, amplify rather than buffer local impacts.
4. It is plain that it is easier to investigate the effects of short-term (intra-annual, annual and interannual) climatic fluctuations. For secular variations the number and complexity of the factors masking any climatic effect, including technological development and changes in the structure of the economy, are normally so great as to defy rigorous quantification. This point is argued vigorously by de Vries (1980, 624-625) and Anderson (1981). Statistical problems are more difficult to eliminate in studies of long-term effects.

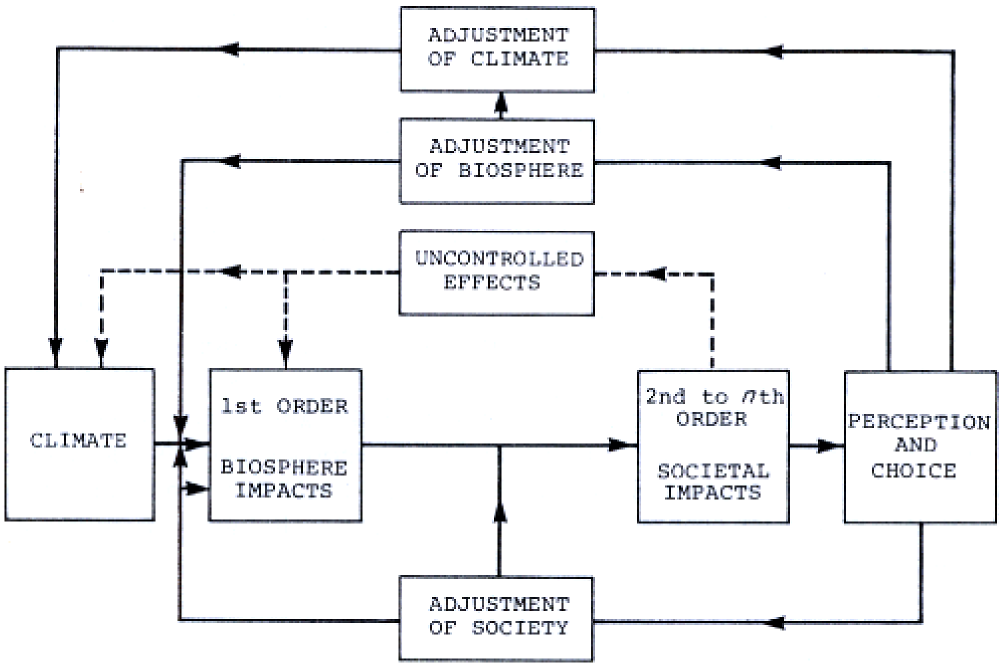

Figure 21.2 Conceptual model of the impact of climate on man and society showing some of the possible feedbacks via adaptive strategies. The box `uncontrolled effects' refers to all inadvertent, unplanned or uncontrolled modifications of the biosphere and/or climate (carbon dioxide pollution and acid rain are examples). `Adjustment of the biosphere' refers to changes in land use and/or deliberate exploitation of living resources. `Adjustment of climate' might include cloud seeding, although man's success in this direction has been equivocal. On a smaller scale, however, man has, for years, successfully adjusted the microclimate by building shelter belts, wind breaks and greenhouses, by combating frost with smudge pots, etc. `Adjustment of society', which covers a host of possible adaptive measures to perceived stresses, may lead directly back to influences on second- and higher-order impact variables, or, through the market economy and adjustments in demand, may lead to modifications of the way climate affects the biosphere or to direct changes of the biosphere. (Reproduced by permission of Cambridge University Press from Ingram *et al.*, 1981, Figure 1.3)

Marginal areas require specific mention. Marginal areas are those in which agriculture or other economic activities are conducted in conditions close to the climatic limits beyond which such activities are physically unviable. By definition, such marginal areas should be particularly vulnerable to the effects of climatic variation. In such circumstances, the number of complicating variables may be smaller, and the impact of climate itself correspondingly easier to gauge. This applies regardless of the time-scale of the study. In studying the possible influences of secular climatic variation, marginal areas may prove valuable as `laboratory' test cases. If climatic impact is absent (or small) in such marginal situations, one might conclude that secular climatic variations in more environmentally sheltered societies may be safely ignored. If, on the other hand, the effects of such climate variations on marginal societies appear important, this will provide at least some basis for arguing the more general significance of climatic changes in human history and may encourage further consideration of the admittedly more complex cases of societies relatively well sheltered from climatic stress. These ideas are strongly urged by Parry (1978,1981a,b) and Ogilvie (1981).

21.2.5 The Preferred Strategy

The primary aim is to determine the magnitude and understand the mechanisms of climatic impact. To determine the magnitude of climatic impact, only a quantitative and rigorous statistical analysis will suffice. Our emphasis in this paper is on this type of approach. This should not be taken to be a condemnation of qualitative investigations of particular events, which can undeniably provide both useful insight into the mechanisms of climatic impact and valuable supporting documentation for quantitative analyses. There is no single methodological framework which can be used as a basis for all historical climate impact studies. Since the interactions between climate and society are so complex, the application of simplified models and quantitative techniques may give a false air of rigor and generality to such analyses, of which one should be wary.

Nevertheless, we consider the quantitative, model-oriented approach to be the basic skeleton on which historical climate impact studies should be fleshed. The method we advocate is first to construct a realistic (but not necessarily complex) model of climate–society interaction, and then to test such a model, using time-series data of chosen dependent (i.e. impact) and independent (i.e. climate) variables. The model itself may be constructed *a priori* (for example, based on modern agronomic data or sociological information), or may be derived from a preliminary analysis of the historical data (such as de Vries' analysis of butter prices at Leiden; de Vries,1980, 609–610).

For both model testing and preliminary analysis, three simple statistical techniques offer considerable scope: regression or correlation analysis, comparison of means, and the use of contingency tables. (For further details on the uses and abuses of statistics in climate impact analysis see Wigley,1983.)

21.2.5.1 Regression Analysis

The technique is to relate a dependent or predictand variable (Y) to a single or to a set of predictor variables (X_1, X_2, etc.) via an equation of the form

$$Y = a + bX_1 + cX_2 + \ldots$$

Generally, Y is the impact estimator (crop yield, prices, etc.) while X_i, are the climate variables. Although this is a linear equation, the predictors, X_i, may themselves be nonlinear functions (as are often used in crop-climate regression models). The predictors may, of course, be lagged variables: for example, mortality in a particular year may be related to climate in an earlier year or years. The regression coefficients *a*,*b*,*c*... are usually evaluated using least-squares techniques. The magnitude and significance of the relationship is determined by the multiple correlation coefficient, R . R^2, which is called the coefficient of determination, is a measure of the amount of variability of the predictand variable which is explained by the predictors.

The method is a commonly used statistical tool which is described in most standard textbooks but there are some points which need to be kept in mind in applying it to climate impact studies.

1. Results which appear to be significant can occur more easily by chance when the data analyzed are strongly autocorrelated (that is, when the value of a variable in year *n* is statistically correlated with its value in year *n* + 1). Price data, for example, tend to be strongly autocorrelated (even after long-term trends have been removed), so that spurious price-climate links might occur if the climate data were also autocorrelated. Such autocorrelation, even if not in the raw data, can be induced by considering moving-averaged data, or filtered data, so care must be taken when using such data.
2. Intercorrelated regressors—one of the major problems in regression modeling involving climate variables is that these variables are often strongly correlated—for instance, seasonal rainfall and temperature values invariably show strong statistical links. If predictors are intercorrelated, it is often impossible to interpret individual regression coefficients. Thus, the sign of the statistically determined regression coefficients may not be in accord with preconceived or independently determined ideas. Furthermore, regression analyses using intercorrelated variables tend to be unstable (for example, changing a single data point, or adding or subtracting a predictor, may change the regression coefficients dramatically). This latter problem may sometimes be circumvented using more elaborate techniques like principal components regression (see, for example, Gunst and Mason, 1980), but the difficulty in the interpretation of results is more difficult to avoid. The best advice is to be aware of potential problems and to make a judicious choice of climate predictor variables.
3. Autocorrelated residuals—the residuals are the deviations of the value of *Y* predicted from the regression equation and its observed value. Autocorrelation of the residuals is generally a sign that the original data were autocorrelated (point 1 above) or that the choice of model (that is, the form of the regression equation, or the variables used) was inappropriate in some way. A simple statistic, the Durbin-Watson statistic, can be calculated for any regression analysis in order to test for autocorrelated residuals. Caution is advised if the value of Durbin-Watson statistic indicates a statistically significant degree of autocorrelation in the residuals.
4. Multiplicity—if many regression models are derived, then the probability of obtaining a statistically significant result by chance increases. To select the single most significant relationship from a large number of trial relationships would be a procedure of dubious statistical validity.
5. Cause and effect—while regression analysis can demonstrate the existence of, and quantify, a relationship between variables, this does not necessarily prove a cause-effect link. Two correlated variables may have a common cause; this circumstance may arise when the climate data used in a relationship are derived from indirect evidence (such as yield data or the geographical distribution of crops, vines, etc.). When information comes from diverse sources the possibility of circular argument must be considered, particularly in medieval and earlier analyses. The value of regression or correlation results depends intimately on the realism of the model they are used to support.

21.2.5.2 Comparison of Means

For examination of possible climate impact relationships on longer time-scales, it may be sufficient to look for significant changes in the average value of an impact variable which parallel those expected on the basis of an impact climate model. An early example of this approach is Hoskins' test of Utterström's contention (1955) that `there may have been a fundamental climatic change in the mid-sixteenth century over most of northwest Europe which adversely affected the quality of harvests in the second half of the sixteenth century' (Hoskins,1964, 30). Let us accept the reality of a significant climate difference before and after 1550 (a point open to independent testing), and also accept Hoskins' (1964) price-derived harvest quality data (open to some doubt, as pointed out earlier). Hoskins compared the ratios of above-average to average to below-average yields for the periods 1480–1549 and 1550–1619, expecting to find a difference if there had been any climatic effect. This essentially amounts to comparing the average yields in these two periods. Hoskins found no differences and concluded that there was no influence of climate. His argument is, however, specious, and his comparison was a futile one because long-term trends had been removed from the price data before estimates of yield were made.

A slightly different application has been given by de Vries (1980) who compared average butter prices at Leiden for years with frosty Marches to those for other years over the period 1658–1757. He found a statistically significant difference, with prices in the `cold' years about 12 percent above those in other years. This technique, in which a sample is stratified on the basis of a climate character chosen according to an expected relationship (or model), may be useful in studying both short- and long-term impact.

The appropriate statistical test here is a *t*-test where the magnitude of the test statistic

$$t = \frac{|\bar{X}_1 - \bar{X}_2|}{\sigma\sqrt{1/N_1 - 1/N_2}} \quad \text{where} \quad \sigma = \sqrt{\frac{N_1 s_1^2 + N_2 s_2^2}{N_1 + N_2 - 2}}$$

is compared with the value expected by chance, on the assumption of no difference in means, using Student's *t*-distribution. Here $\bar{X}_1$, $\bar{X}_2$ are the means, s_1^2, s_2^2 are the variances, and N_1, N_2 are the sample sizes. An approximate method based on the Normal distribution may be used if the sample sizes are large (this is the method used by de Vries).

This particular statistical method can also give spurious results if either sample has any significant autocorrelation, although there are simple methods available to account for autocorrelation effects (see, for example, Mitchell *et al.*, 1966).

Autocorrelation problems are less likely to arise in the stratified sample application.

21.2.5.3 Use of Contingency Tables

In some cases, data may be available only in qualitative form and/or as incomplete time-series. These data deficiencies do not, however, preclude the use of rigorous statistical techniques for testing the *reality* of climatic impact, although quantifying the magnitude of the impact is still difficult. The appropriate technique is best illustrated with an example from Ogilvie (1981; see also Ogilvie,1984). As one aspect of her study, she examines the impact of climate on grass growth and hay yield in seventeenth- and eighteenth-century Iceland. The reality of a link in the twentieth century has been established using agronomic studies and regression analysis (see, for example, Bergthörsson, 1966, 1976). Contemporary historical documents suggest that grass growth and hay yields are adversely affected by temperature and rainfall during the growing season. Although only qualitative descriptive accounts are available, these can be tested by grouping them into cold, average and mild for thermal conditions (or wet, average and dry for precipitation) and poor, average and good for the grass growth or hay yield. An example comparing spring temperature and grass growth in the north of Iceland is given in Table 21.1 below. The table shows the observed number of occurrences in each joint category and the expected number of occurrences (in parentheses), obtained by multiplying the observed column and row frequencies together. The expected numbers so calculated are those which would occur if there were *no* relationship.

Table 21.1 Spring temperature and grass growth in northern Iceland, 1601–1780. Numbers denote number of occurrences, numbers in parentheses are estimates based on the assumption of no crop-climate relationship. χ^2 = 43.3; significance level better than 0.001.

Grass growth \ Spring temperature	Cold	Average	Mild	Totals
Poor	46(31.0)	9(18.1)	9(14.9)	64(39.3%)
Average	26(32.5)	30(18.9)	11(15.6)	67(41.1%)
Good	7(15.5)	7(9.0)	18(7.5)	32(19.6%)
Totals	79(48.5%)	46(28.2%)	38(23.3%)	163(100%)

$$\chi^2 = \sum_{i=1}^{9} \frac{(O_i - E_i)^2}{E_i}$$

A significant difference between observed and expected frequencies, based on the value of the test statistic (where the sum, $i = 1$ to 9, is over the number of boxes in the contingency table), indicates a relationship between variables. The value of χ^2 is tested using a χ^2 distribution. In this example, the χ^2 value is 43.3, highly significant and indicating a strong relationship. From Table 21.1 it can be seen that the observed incidence of poor grass growth following cold springs is much larger than would be expected if cold weather had no influence.

21.2.6 Alternative Strategies

21.2.6.1 Semidescriptive Case Studies

The difficulties of constructing detailed causal models to identify and measure climatic impact, especially for larger areas, a wide range of economic and social variables, and extended periods, prompts the use of less precise methods which may nevertheless be capable of yielding worthwhile results. One approach is the use of detailed semidescriptive case studies, of which the most notable so far completed are by Post (1977) and Pfister (1975, 1981). The method is to concentrate on particular periods of climate `crisis' in which atmospheric variations appear to have been associated with marked changes in the economy and society of a given area. As far as possible, the links between climate variations and the society in question are specified rigorously. Variations in crop yields are examined in relation to a detailed analysis of such meteorological variables as temperature and precipitation. However, at the point where rigorous modeling ceases to be feasible (on account of the large number of variables involved, the complexity of the links with climate, imperfections of the data, etc.), the case studies take on a more impressionistic character, hence the term `semidescriptive'.

Such studies can be immensely stimulating and perceptive. However, their value is inevitably limited to the extent that rigorous analysis is abandoned. In some ways, too, they may be misleading. Concentration on particularly acute periods of crisis may give a false impression of the importance of climate in human affairs. Although admittedly overstating the case, de Vries draws the parallel that `short-term climatic crises stand in relation to economic history as bank robberies to the history of banking' (1980, 603). Moreover, the descriptive element in the method can easily degenerate into the cataloging of detail after detail of disruption and misery. The abundance of such detail, and the use in the description of such essentially rhetorical epithets as `crippling', `threatening', `disastrous' (all of these examples are taken from Post, 1977) may, in the mind of the unwary reader, obscure the lack of a precise framework for gauging the importance of climatic impact. Semidescriptive studies, therefore, need to be carried out (and evaluated) with care. When properly qualified, however, they can shed useful light on climate–society links, suggest new hypotheses, and add considerably to any parallel quantitative study. They can, further, frequently lead to the discovery of important new climatological and socioeconomic data. Pfister's meticulous work (1981) on Switzerland in the Little Ice Age is a perfect example of the positive attributes of studies of this kind.

21.2.6.2 Occam's Razor

Anderson's work (1981) suggests an approach based on Occam's razor (the principle that, for the purposes of explanation, things not known to exist should not, unless it is absolutely necessary, be postulated as existing) in order to gauge the possible long-term importance of climatic variations in circumstances in which rigorous testing and assessment are not possible. The method is to scrutinize long-term social and economic changes and to examine how far they are explicable in non-climatic terms. The aim is to isolate possible explanatory lacunae which appear to require the invocation of climatic change as a relevant variable. If none is found, it may be concluded that climatic change was of negligible importance. Clearly, the method is highly subjective. Nevertheless, it may be valuable as a means of eliminating cases in which climatic change was almost certainly of negligible importance and focusing attention on cases where the issue of significant climate impact is more open to contention.

21.3 TIME-SCALES OF IMPACT

Climate impact studies in history may be classified according to the time-scale on which the impact occurs—short-term (annual or intra-annual); medium term (interannual); and longer-term (extending over periods of decades or centuries).

21.3.1 Short-term Influences

Short-term influences may be divided into two categories: the impact of isolated climatic events, including such phenomena as single storms or periods of storminess, and individual months or seasons of aberrant weather; and time-series analysis of the impact of seasonal or annual climatic fluctuations.

21.3.1.1 Isolated Climatic Events

Clearly, the impact of such events in normal circumstances is likely to be slight in relation to the totality of economic and other historical processes. However, there may conceivably be grounds for ascribing greater importance to a few isolated climatic events which happened to impinge on key historical situations. For example, it might be argued that the North Sea storms which helped to shatter the Spanish Armada in the summer and autumn of 1588 exerted an important influence on the course of English history.

The number of events which can plausibly be regarded as significant in this way appears to be small, and their level of significance is a matter of debate. For example, many factors contributed to the failure of the Armada in 1588, and the fleet had already been decisively defeated before bearing the main brunt of the storms. Even if the Armada had landed it is by no means certain that the subsequent history of England, far less that of Europe, would have been significantly altered (Parker, 1976). Thus, the argument that the storms had an important impact on human history is tenuous at best. In general, it would seem reasonable to regard the impact of isolated weather events on history as of fleeting and random importance only.

21.3.1.2 Seasonal and Annual Fluctuations

A much better case can be made for the importance of the short-term impact of month-to-month, season-to-season and year-to-year variations in the weather. Even historians sceptical of the significant impact of long-term climate changes commonly admit the importance of short-term variations (for example, Le Roy Ladurie, 1972, 119). Two widely accepted notions are that the economic history of *ancien régime* Europe is, through harvest success or failure, dependent on year-to-year climate fluctuations, but that this predominant direct effect of climate on society has diminished as society has become more industrialized in recent centuries (Braudel, 1973; de Vries, 1980, 601). Nevertheless, comparatively little research has been devoted to investigating in precise detail just how important such fluctuations were.

An attempt to fill this gap has been made by de Vries (1980) who correlated time-series of weather data with grain and butter prices, burial statistics, and transport data for Holland in the seventeenth to nineteenth centuries. His results throw some doubt on the traditional assumption that weather fluctuations were self-evidently of major economic importance. Many of his analyses show no statistically significant results, and those that do, show climate to account for relatively little of the `impact' variance. He suggests that, although the idea of weather-dominated economies may hold true for closed, technologically primitive subsistence societies, in most areas of early-modern Europe the level of economic integration—including trade, markets, inventory formation and even futures trading—was sufficient to loosen greatly the asserted links between weather and harvests and between harvests and economic life more generally (de Vries,1980, 602).

Two objections to this are immediately obvious. First, de Vries may have chosen the wrong variables to relate; in other words his original model may be faulty. He is, of course, well aware of this (the constraint of data availability has, in part, determined the choice of model). He has, for instance, in the case of butter prices, analyzed another model which gives more significant results (de Vries,1980). Second, Post (1980, 721) has pointed out that the case of the Netherlands considered by de Vries may be atypical because of the advanced and sophisticated nature of the Dutch economy relative to many of her contemporaries. This objection needs to be tested by rigorous statistical studies for less economically sophisticated areas of preindustrial Europe. At present, such studies are lamentably lacking.

Something of an antidote to de Vries' scepticism is offered by Lee (1981). He has considered the impact of meteorological variables on short-run fluctuations in births, deaths and marriages in seventeenth- to nineteenth-century England, a country which in the seventeenth century rivaled Holland's economic development and subsequently exceeded it. Lee found no significant relationship between vital rates and rainfall data, unfortunately available to him only in the form of an inhomogenous annual series from 1727 (Nicholas and Glasspoole, 1931; Wigley *et al.*, 1983). However, striking effects of temperature variation were apparent. Mortality was increased by cold temperatures in the months from

December to May (`winter'), and by hot temperatures in the June to November period (`summer'). The main effect of winter temperatures was contemporaneous, but for summer temperatures the effect was delayed by one or two months. (Lee speculates that low winter temperatures killed older elements in the population by means of rapidly lethal diseases, whereas hot summer weather tended to kill infants and small children through debilitating digestive tract diseases which took longer to cause death.) A 1 ˚C warming of winter temperatures would reduce annual mortality by about 2 percent; a 1 °C cooling of summer temperatures would reduce annual mortality by about 4 percent. Over the period 1665─1744 temperature explained a smaller proportion of the variance in annual mortality than did prices, but temperature and prices were equally important from 1745─1834. With regard to fertility the effects of temperature variation were more muted, about a quarter to a third the size of those for mortality.

Lee concluded that, overall, the effects of temperature variations on vital rates were quite striking (especially given the fact that the climate of England is relatively moderate), to the extent that he felt justified in speculating on the long-term implications of his results (see below). Lee's work exposes three factors which might have bearing on longer time-scale climatic impact. His analysis of grain price-mortality links shows that mortality increases occur mainly in the second and third year after a price maximum, and that contemporaneous mortality occurs only during price `events' above a certain threshold (an interesting nonlinear effect). He also shows that relationships are not solely the result of extreme events. Even when the most extreme cases are removed from the analysis, the links between prices and mortality still hold. This can be compared with similar results obtained by Palutikof (1983) for the impact of climate and climatic extremes on the level of industrial production in England over the past few decades: the links hold even after the most extreme events are removed. If links between climate and socioeconomic factors hold in general (that is, not just for extreme events) then the cumulative influence of such linkages might provide a mechanism for the long-term effects of climate on society. However, such a hypothesis would require stability of the climate impact linkage and Lee, in analyzing different time periods, finds that some relationships are manifestly unstable─for instance, the price-mortality link reverses in sign after 1745!

21.3.2 Medium-term Influences

In analyzing medium-term and long-term effects, a new modeling difficulty arises. Possible causal links mentioned and discussed above are invariably of a transitory nature, and a mechanism must be proposed whereby such impacts are translated to longer time-scales. For instance, this might occur if short-term events are so closely spaced or if their impact is sufficiently long-lasting that recovery from one event cannot occur before the next impact event. Alternatively, a relationship must be established where the impact is not solely the result of extreme events (such as Lee's relationship between prices and mortality).

In this light, a number of authors have considered the effects of clusters of extreme seasons or years, which would appear likely to have a greater impact than continuous weak effects, even though these might operate over a range of values of a particular causal parameter. Post (1980), for example, argues that, whereas preindustrial societies might to a large extent adjust to cope with annual fluctuations, after a *succession* of years of severe weather the systems of adaptation and adjustment would be overchallenged, leading to higher death rates and a decline in economic activity.

A number of recent studies have focused in detail on the economic effects of anomalous weather conditions on interannual time-scales. Pfister (1975, 1981) has analyzed conditions in Switzerland during the Little Ice Age period, especially in the years 1570─1600, 1768─71, and 1812─17. Bowden (1967, 630─633) has examined clusters of anomalous years in England in 1546─71 and 1618─25, periods similar to each other in that in each case a run of exceptionally good harvests was followed by a succession of crop failures. Unfortunately Bowden lacked complete data on climatic fluctuations, but his brief analysis is nonetheless suggestive: he concluded that a climatically induced sequence of bounty and dearth had the effect of impoverishing first one section of the community and then other sections, and thus seems to have provided the optimum conditions for the onset of trade depression.

The possibility that the impact of severe climatic events might be magnified when these events occur after a long sequence of good years has been suggested by de Vries (1980), but such a possibility would be difficult to demonstrate in a statistically rigorous manner. In support of de Vries' hypothesis, the severe winters of 1709, 1740 and 1795 in Europe, which all followed long periods of favorable climate, were times of considerable economic stress; yet 1729, 1766 and 1780, while climatically comparable, had minimal impact. Interestingly, in the former three years there was also a contemporaneous impact on prices──prices rose during the harvest year, seemingly in anticipation of a climate-induced harvest failure, which then led to a further increase in prices. The influence of perception and adaptive measures needs to be examined further, but the absence of any simple general relationship weakens the case for any possible medium- or long-term impact through the cumulative effect of shorter-term crises. A relevant example is given by Sutherland (1981) in considering the effects of adverse (though admittedly not spectacularly severe) weather in the 1780s on a community in Upper Brittany. In the face of droughts in 1782 and 1785─86 and of a poor harvest in 1788, the social and economic structure of the area around the town of Vitré proved remarkably elastic. The worst-hit victims of economic stress were infants and small children, who experienced high rates of mortality; but because general fertility was high these children could easily be replaced, and their loss from a social structural point of view was relatively insignificant. Other symptoms of a crisis in rural society were absent. Sutherland's conclusion is that `many peasant communities were not as vulnerable to the weather as we generally think' (1981, 434).

Another viewpoint is presented by Post (1983a,b) who strongly emphasizes the important issue of the relationship between climatic stress and disease, in particular the spread of epidemic diseases. Post calls for further research to ›specify the pathways along which the common infectious diseases spread in premodern and preindustrial Europe' (1983a,159), as a way of discovering more about the role of climatic change in both economic and demographic spheres. In his own work, Post finds a link between climatic variability and the high incidence of infectious disease in 1740s Europe, but suggests that this was social rather than physiological; epidemics arose primarily through the social disorder that was largely a second-order effect of climatic stress (1983b). The effects of climate on human and animal disease incidence have also been examined by Ogilvie (1981), Pfister (1984) and others. There is considerable scope for further work on climate–disease interactions, both in terms of quantification of cause and effect and in terms of interpretation in a wider social context (see Escudero, Chapter 10 of this volume). There are, further, important instances of disease-related crop failures (such as the European potato blights in the 1840s [Lamb, 1977; Grigg,1980] and the effects of *Fusarium nivale* on spelt and rye in Switzerland [Pfister,1978]) which have been associated with both medium- and shorter-term climate fluctuations.

Opinion on the medium-term influence of climatic stress is thus divided. Any attempt to come to an overall conclusion would be premature because not enough detailed studies have been carried out. As in the case of short-term climatic influences, the need for further research is obvious.

21.2.3 Longer-term Influences

The possibility that climatic change is an important independent variable affecting the course of human history over extended periods of decades or centuries is a seductive one, and there have been a number of attempts to prove the connection. Utterström (1955), for example, argued that climatic changes may well have been of `decisive' importance in influencing population movements in medieval and early modern Europe. Braudel (1949) hinted that the economic and social difficulties which were experienced in the Mediterranean area at the end of the sixteenth century, and which heralded the slow decline in the economic importance of this region in the seventeenth century, were partly caused by climatic change. Subsequently he stressed the importance of climatic change for the whole of Europe: `the "early" sixteenth century was everywhere favored by the climate; the latter part everywhere suffered atmospheric disturbance' (Braudel, 1973). More recently, Parker (1979) has firmly asserted a relationship between the `crisis' allegedly observable in the economy and society of seventeenth-century Europe and climatic 'deterioration'—the ultimate blame for which he rashly seems to attach to sunspots!

Suggestions of long-term climate effects have provoked scepticism and even sharp criticism. Le Roy Ladurie (1972, 292–293), noted the relatively small magnitude of long-term climate variations in Europe since about AD 1000 and questioned whether `a difference in secular mean temperature ... [of about] 1 °C [could] have any influence on agriculture and other activities of human society, especially given the fact of human adaptation'. In response, Post has argued that it is misleading to concentrate on mean temperature values as such: `interdecennary or even *annual* thermometric values and precipitation levels are insufficient data for understanding the dynamics of ecological effects. The micro-aspects are essential: annual temperature means often conceal critically large seasonal variations, which frequently mask destructive monthly deviations' (Post, 1973, 728). This observation is supported by the evidence presented by Lamb (1977, 465; 1981) that in Europe, in the early onset stages of the Little Ice Age between about 1300 and 1450, and in the climax phase in the sixteenth and seventeenth centuries, the *variability* of the weather was particularly marked (see also Pfister, 1981). However, the evidence for these changes in variability is still inconclusive. It is self-evident, for example, that a depression of the mean temperature will produce a greater frequency of severe cold events if the variability, as measured by the variance, remained unchanged (Sawyer, 1980; Ingram *et al.*, 1981), so an increased frequency of extreme events need not indicate a change in variability, but may, nonetheless, amplify the effect of a change in the mean.

Secular changes in climate may well involve changing levels of variability and such changes may be more important than changes in the mean. Changes in variability may or may not be statistically related to changes in the mean; we need only assume that they can occur. Parry (1981a) explains how an increased frequency of extreme events (which might result from either a change in variability or a change in the mean) may have a magnified impact by dramatically increasing the probability of *successive* (or closely spaced) extremes. If the probability of an extreme month (or season) is, for example, 1/10 and increases to 1/4 as a result of a secular change of climate, then the probability of two successive extremes will increase from 1/100 to 1/16, a six-fold reduction in return period. The question of assessing the impact of longer-term climatic shifts may resolve itself, then, into the problem of measuring the importance of individual clusters of extreme weather events of the type discussed in the previous subsection, and devising some means of assessing the cumulative effects of a succession of such clusters. Given that the economic and social impact of even a single cluster is difficult to establish, and that on secular time-scales the effects of climatic stress will be obscured by a multitude of other variables, the practical problems involved in these operations are clearly enormous.

21.4 HUMAN ADAPTATION TO CLIMATIC STRESS

The relationship between climatic stress and economic and social life should not be conceived as a one-way process. Man is a highly adaptive animal, capable of devising and deploying a wide range of technologies and social strategies to cope with a wide variety of environmental conditions. In view of this fact, and given the comparatively small range of climatic variations in historic times, it may be assumed that past human societies have, to a considerable extent, had the potential to successfully adapt to changes in climate. Thus the interrelationships between climate and human society may be conceived in terms of a two-way model involving elaborate feedback mechanisms, a simple version of which is presented in Figure 21.2 (see also Kates, Chapter 1 of this volume).

Approaches to climate–history studies that seek to assess the impact of climate variations on human economic and social systems in the manner discussed in the preceding section frequently obscure the processes of human adaptation to climatic stress. Depending on whether the particular researcher's aim is to advocate or to reject the importance of climate in human affairs, the processes of adaptation may be either neglected as an embarrassing complication, or emphasized in order to argue that worthwhile assessments of climatic impact are inordinately difficult.

An alternative approach is to focus attention on the processes of adaptation (or *failure* to adapt) explicitly. This antideterministic approach has been advocated by de Vries (1980, 625–630), and is well represented among papers in Wigley *et al.* (1981). Such studies make it clear that societies subjected to climatic stress must not be regarded as passive victims of external forces, but rather that such stress is in the nature of a challenge to which a variety of responses are possible. This allows a more subtle appreciation of the role of climate in human affairs.

From this point of view, cases in which societies appear to have been seriously damaged by, or even totally succumbed to, climatic stress should not be taken to demonstrate the determining influence of climate. It is essential to consider ways in which these societies might have coped better, and to focus on the political, cultural and socioeconomic factors which inhibited them from doing so. Such studies are potentially of great relevance to the problems of the modern world. Identification of the factors which prevent successful adaptation could well aid planners in their attempts to avert future disasters.

This question has been explored by Mooley and Pant (1981) in their discussion of the socioeconomic impact of droughts in India over the past 200 years. They argue that the extent of human suffering and mortality occasioned by Indian drought was largely conditioned by inflexible and exploitative systems of social and economic organization, in part the result of foreign rule in the period before independence (1947). They suggest that changes in agricultural practices and in other aspects of the rural economy, complemented by planned programs to accumulate food reserves and cash funds to provide, when necessary, swift and effective relief in the drought-prone areas, could in the future significantly reduce the suffering occasioned by monsoon failure (see also Jodha and Mascarenhas, Chapter 17 of this volume).

Mooley and Pant's discussion is not specifically related to long-term climatic changes (on the contrary, they show statistically that the incidence of drought in India in the period 1771–1977 is random); and the climatic stresses which they studied, albeit enough to inflict immense suffering on substantial sections of society, were not of a severity sufficient to destroy the entire society. By contrast, McGovern's work on Norse Greenland (1981) deals both with long-term climatic shifts and the extinction of a substantial part of the Norse society.

McGovern argues strongly that, even in this manifestly marginal case, it would be wrong to explain the collapse of the more northerly of the two Norse settlements—the so-called `Western Settlement'—solely in terms of a deteriorating climate, or even of climate in association with other external pressures. The Norse could have survived by shifting the economic balance of their society away from stockraising towards greater exploitation of seals and other marine resources, and by adopting the use of elements of Inuit eskimo culture and technology (skin boats, clothing, etc.) in order to facilitate the shift. But instead of pioneering these adaptive strategies, the evidence suggests that the political and religious élite in Greenland persisted in maintaining existing and increasingly inappropriate economic and cultural patterns. Their failure as flexible managers of the community's scanty resources was the ultimate cause of the extinction of the Norse colonies.

The question of adaptation can be approached from other directions. In cases where marked climatic stress appears (in terms of gross economic or other indicators) to have had little impact, it may be valuable to investigate the processes of adaptation whereby the climatic stress was minimized or absorbed. Again, the insights which might be derived from such studies could prove valuable in the context of present-day planning.

A significant contribution to the study of such adaptation has been offered by de Vries (1980). He focuses primarily on economic responses and specifically on changes in agricultural practices and technology. He suggests (pp. 625–626) that certain changes in agricultural practices, such as variations in crop mixes, may sometimes be interpreted as adaptive strategies developed in response to climatic stress. It is possible, for example, that the tendency towards crop diversification in midland England in the period 1550–1650 (hitherto explained in terms of shifts in demand towards cheaper grains, induced by a reduction in the purchasing power of much of the population; Skipp, 1978, 44–49) could represent farmers' attempts to reduce their vulnerability to a climate which had become more frequently threatening towards winter crops.

The approach by Sutherland (1981) is more general. He focuses not on changes in agricultural practices, but on the complex of social mechanisms which enabled the Vitré area of Brittany in the 1780s (and by implication other peasant societies) to cope with climatic stress. In Vitré the poor were cushioned by secondary sources of income which were only partly dependent on the grain harvest, while employment for farmhands continued to be available throughout the period of meteorological stress. The richer peasantry, with substantial grain surpluses even in bad years, actually benefited from the high prices associated with poor harvests. In addition, relief systems for the poor and other charitable mechanisms, such as the willingness of landlords to postpone or waive demands for rent, helped to distribute the costs of climatic stress. Overall, a range of social and economic factors was responsible for absorbing the shocks administered by the climate and helped to maintain the social fabric more or less intact.

These approaches leave a number of questions unanswered. It is not clear how climatic stress-induced adaptations can be distinguished from other elements of technological and economic change, except in certain specific cases. In most cases the problems of detecting adaptive strategies would appear to be analogous to, but possibly even more complex than, those involved in identifying and measuring climatic impact. In those studies where adaptive or cost-distributing factors have been shown to have been effective (for example, Sutherland, 1981) there remains the vital question which such an analysis inevitably provokes: what were the limits to the society's capacity to absorb stress? In other words, what degree of meteorological adversity would have been required to precipitate serious social and economic dislocation?

To generalize from these specific comments, it is plain that in order to advance the study of human adaptation to climatic variations to the point where the findings may be of real use to modern planners, it will be necessary to try to specify more clearly what degrees and types of climatic stress impose the greatest problems of successful response, and to seek to identify more rigorously the key features of more- and less-adaptive societies. To do this it will be necessary to attempt extensive cross-cultural comparisons. A preliminary step in this direction has been taken by Bowden *et al.* (1981) in a comparative study of agriculture in the US Great Plains in the period AD 1880–1979, the droughts in the Sahel region of Africa between 1910–15 and 1968–74, and the societies of the Tigris-Euphrates valley over six millennia. They discuss the complementary hypotheses that, over time, societies adapt to cope with `minor' climatic stresses (defined as events with a return period of the order of less than 100 years), but that thereby they do little to decrease, and may actually increase, their vulnerability to `major' stresses of rarer frequency.

Because of inadequate data, the results from the Tigris-Euphrates study proved inconclusive and the part of the hypothesis relating to `major' stresses could be handled only on a speculative level. However, it is argued strongly that both the Sahel and the US Great Plains have become less vulnerable to ›minor' climatic stress. In the case of the Great Plains, wheat yield evidence was analyzed to discover whether the lessening of vulnerability could be explained by reference to developments in agricultural technology; the analysis failed to substantiate this possibility. Both in the Sahel and in the Great Plains the key factor in reducing vulnerability appeared to be the integration of each area into a wider economic system. The sufferings of the Sahel in 1968–74, though massive and perhaps partly precipitated by political rather than climatic factors (García, 1981), were, nonetheless, alleviated by external aid. On the Great Plains, distress was reduced after about 1930 when the Union as a whole accepted the responsibility of providing relief for drought-afflicted areas, thus in effect sharing the costs of climatic stress. It proved possible to absorb even a `major' climatic stress, the drought of the 1930s, in this way. Massive Federal relief ensured that the potential catastrophe of these years took the form of a large ripple through the national economy, rather than a tidal wave of disaster located in the Great Plains region itself. However, Bowden *et al.* caution that in the future there may prove to be a limit to the effectiveness of such integrative mechanisms.

Ingram *et al.* (1981) have noted an important point which emerges from the study by Bowden *et al.* This is that newly settled regions (such as the Great Plains in the late nineteenth century) and areas where the economic system is subjected to rapid modification (as in the Sahel in the twentieth century) face particular problems of vulnerability to climatic stress. In such unfamiliar circumstances the nature of the climatic regime, and its likely hazards for the type of economic system which is being implemented, may be poorly understood and mismanagement (leading sooner or later to disaster) is particularly likely to occur. The same point has been emphasized in a paper by Smith *et al.* (1981) on climatic stress and Maine agriculture in the nineteenth century. Here, a brief warming period in the 1820s raised unrealistic expectations that the region could support large-scale commercial agriculture, and the process of adjustment to the normal cooler conditions which soon reasserted themselves was a painful one which took several decades to accomplish.

The complex question of human adaptation to climate is one whose systematic study has only just begun. The value of this field of endeavor is obvious: apart from its intrinsic interest, it is of major relevance to the problems of modern world planning. Further research is urgently required. The studies so far completed, though limited in their scope and achievement, are of considerable interest and have added a major new dimension to the climate impact debate.

21.5 REVIEW OF HISTORICAL CLIMATE IMPACT STUDIES

One of the main concerns of this chapter is to describe a methodology or framework for historical climate impact studies. To do this we have synthesized what we consider to be the best elements of other physical and social scientists' work, and our own views. To complement this framework we now consider briefly and selectively some of the published historical climate impact analyses available in the literature. The majority of these are specific case studies, but we have also included McGhee's (1981) review of archaeological work. In trying to summarize the important features (both good and bad) of past studies, we have, admittedly, introduced an element of unfairness by categorizing these works using a set of rules with which the workers themselves may not agree. Nevertheless, our summary provides an integrated review which is a guide, not only to the types of study carried out in the past, but also to the quality of these studies, and to the pitfalls which future workers might strive to avoid.

Our summary is presented in Table 21.2. It is far from comprehensive, not least because there is a vast pool of studies (using this word loosely) which we consider to be little more than poorly documented and generally unsupported speculations, and which, perforce, warrants neglect. In addition, works which have been subsequently superseded have also been omitted.

The studies considered below fall into three broad categories:

1. Climatic factors used casually to support an argument.
2. Climatic factors seriously considered, but in insufficient depth to permit an assessment of their influence.
3. Publications concerned solely with the impact (or lack of impact) of climate on historical societies.

We have categorized these studies under the following headings.

Reference number and author

The complete bibliographic reference is given in the general reference list.

Time period studied

Time-scale of impact

Short, medium or long—defined above. Some studies cover more than one time-scale.

Region

Main variables examined

These are subdivided into socioeconomic impact variables and climate variables according to the following number scheme:

Society	1	Agriculture

	2	Demography
	3	Economy
	4	Industry-technology-transport
	5	Politics
	6	Culture
	7	Adaptability
Climate	1	Temperature
	2	Precipitation
	3	Other

Data quality

Also subdivided into socioeconomic and climatic data; `n.a.' stands for `not applicable'.

Conceptual model used

Our identifiers here are measures of the realism and complexity of the model used (or implied). A *causal* model is one which considers only cause and effect, with little or no consideration of other possible causes or complicating factors. In some cases such a model may be appropriate, but generally this category implies an oversimplified analysis of the problem. A *realistic* model is one where a reasonable attempt has been made to place the problem in a firmly based conceptual framework, often with some thought given to adaptive measures.

Table 21.2 Summary of selected works on historical climate impact assessment. See text to explanation of numerical identifiers of variables and statistical methods

No.	Author(s)	Period	Time scale	Region	Variables used		Data quality		Model	Stat. methods	Inferred strength of link	Comments
					Society	Climate	Society	Climate				
1	Abel (1966)	13–19th c.	short	Europe	1–5	1,2	good	suspect	none	2	weak	a classic work on agricultural history
2	Bell (1971)	~2000 B.C.	long	Egypt	1–7	3	good	good	none	2	strong	a thorough study by a non-historian (see also Bell, 1970)
3	Beveridge (1921)	16–19th c.	short	Europe	1	3	good	good	none	*	strong	*relationship based on coincidence of cycles
4a	Bowden et al. (1981)	0–6000 B.P.	long	Mesopotamia	1,2,4,5	1–3	suspect	variable (often suspect)	causal	2	moderate	
4b		1890 on	short/med.	USA	1–3,7	1–3	good	good	realistic	2	moderate	
4c		20th c.	short/med.	Sahel	1–3,5,7	1-3	good	good	causal	2	moderate	
5	Brandon (1971)	1340–1444	short	SE England	1	1–3	good	good	realistic	2	moderate	
6	Braudel (1949, 1973)	4th c. B.C. to 20th c.	short	Mediterranean	1–7	1-3	good	good	none	1	weak but important	one of the first historical works to take climate/society links seriously; mainly restricted to 16th c.
7	Bryson and Murray (1977)	various	short to long	numerous	1,2,6	1–3	variable (often suspect)	variable (often suspect)	none	1,2	strong	far reaching, but generally unconvincing
8	de Vries (1980)	14th c. on	short/med.	W Europe	1–3,7	1–3	good	good	realistic	3	weak or none	one of the most important papers on the subject
9	Hoskins (1964, 1968)	1480–1759	short	England	1	2	poor (yields deduced from prices)	poor	none	2	strong	see also Harrison (1971)
10	Kershaw (1973)	1315–1322	short	England	1	2	variable	good	none	1	strong	
11	Lee (1981)	1540–1840	short	England	2	1,2	good	good	none	3	weak but important	an important paper on demography and climate
12	McGhee (1981)	0–5000 B.P.	long	numerous	1,6,7	1–3	good	good	n.a.	n.a.	weak or none	review of archaeological work
13	McGovern (1981)	10–15th c.	med./long	Greenland	1–3,5–7	1-3	good	good	n.a.	n.a.	indirect	an important work on adaptability
14	Mokyr (1977)	18/19th c.	short/med.	W Europe	1,3,7	unspecified	n.a.	n.a.	*	n.a.	weak	*an economic model with climate as a fundamental forcing factor
15	Ogilvie (1981)	9–18th c.	short/med.	Iceland	1–7	1–3	good	good	realistic	3	moderate	one of the most detailed and rigorous climate impact studies available
16	Parry (1978)	14–18th c.	med./long	Scotland, Scandinavia	mainly 1	1–3	good	variable (mainly good)	realistic	2	moderate	a major work on marginal societies (see also Parry, 1981)
17	Pfister (1975, 1981)	16–19th c.	short/med.	Switzerland	mainly 1	1–3	good	good	realistic	2	moderate	an important and detailed study (see also Pfister, 1978)
18	Post (1977)	1815–1819	short	W Europe	1–7	1–3	good	good	none	1,2	strong	an important and detailed study (see also Post, 1980)
19	Puiz (1974)	16–18th c.	short/med.	Geneva	1	1,2	good	suspect to good	none	1,2	strong	
20	Shaw (1981)	Roman period	long	N Africa	1–3,7	1–3	good	good	n.a.	n.a.	none	demolishes some myths
21	Utterström (1955)	16–19th c.	long	W Europe	mainly 1,2	1–3	fair to good	suspect to good	none	1,2	strong	an important, but dated, early work on climate impact
22	Walton (1952)	18th c.	short/med.	Scotland	1,2	1–3	suspect	good but local	realistic	1,2	moderate	
23	Whyte (1981)	17th c.	short/long	Scotland	mainly 1	1–3	good	good	realistic	none	weak	
24	Wright (1976)	14–16th c.	long	a Derbyshire village	1,2,4	1–3	suspect	suspect	none	2	weak	

Statistical methods employed

Very few studies have employed rigorous statistical methods. In some cases, where a strong correspondence between impact and climate supports a well thought-out conceptual model, a detailed statistical analysis may not be necessary; but such cases are rare. We have classified statistical methods as:

0 none
1 a single coincidence
2 qualitative parallels drawn
3 rigorous statistical methods used
n. a. not applicable

Inferred strength of link(s)

This category gives the strength of the relationship(s) as claimed in the original reference. The descriptors used are self-explanatory. A *claimed* link does not necessarily mean that the link has been convincingly demonstrated; in fact, according to our criteria many such claims are subject to considerable doubt.

Comments

21.6 CONCLUSION

Viewpoints on the extent to which past variations in climate have affected societies are polarized. A number of physical scientists (and a few historians) are unshakeable in their belief that climate *must* have affected society in the past, and would be quick to quote standard examples such as the decline of the Roman empire, the failing of the Norse settlement in Greenland, the influence of the Little Ice Age in Europe, and so forth. Few rigorous studies have been made of these textbook examples, however, and closer examination shows the `demonstration' of climate's importance to be based often on deficient or inadequate data, oversimplified arguments, and/or a tendency to ignore nonclimatic factors. Historians, on the other hand, tend to the opposite viewpoint. With notable exceptions they have chosen to ignore the possible importance of climate on the development of society.

Of the more detailed studies, the most convincing have been those dealing with short time-scales (such as the work of de Vries and Lee, and some of Pfister's work) or with marginal societies (in particular the studies by Parry and Ogilvie). All of these analyses have involved clearly defined impact variables and have used reliable, quantitative data. Each study has produced results which are specific to the time and place considered, and it is difficult to draw any broad conclusions from them. This is, in fact, the essence of the difference in viewpoints noted above. Historians tend to eschew broad generalizations, partly because it is the detail, the differences from one case to another, which is central to historical research. Physical scientists, however, tend actively to seek broad generalizations.

What, then, can be learned from historical impact studies? Perhaps the most important message is to maintain an open and moderate stance, to accept and try to account for the complexities of society, and, especially, to give due consideration to the flexibility of the social system and to the many possible modes of adaptation to imposed stress which are available from the level of the individual up to the level of the whole society. Equally important are the lessons to be learned from examples of the failure to adapt.

Human nature has changed little over the centuries; crops are still affected by the vicissitudes of the weather, and many parts of the world today have parallels with seventeenth- to nineteenth-century Europe. Each case study tells us something which may be of value today in building up our body of information of societies' experiences and perceptions of, and reactions to, external stresses, and a continued research effort into all three aspects of impact is demanded.

Modern climate impact studies are manifestly interdisciplinary in nature, and historical impact studies, by virtue of their historical perspective and requirements of the historian's expertise, are even more so. There is a temptation to classify a study by the ground that it attempts to cover rather than by the disciplines deployed. In this sense there have been many interdisciplinary historical climate impact studies, spawned mostly by the intellectual wanderings of scientists or historians perhaps bored with the myopia of specialization. For such wanderers

> there are great risks [in] invading an unfamiliar turf [since] ... the complications of the new subject may not conform readily to the insights the newcomer brings from some other discipline. (McNeill 1981, 642)

We end this review, knowing full well that we, as individual authors, are guilty of such trespasses, with an appeal for more rigorous and truly interdisciplinary studies, studies in which individual expertise from different fields is brought together by closely collaborative efforts. In no field is the need for this so great as in historical studies of the impact of climate on societies.

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