THE USE OF ANALOGIES IN ASSESSING
PHYSICAL AND SOCIETAL RESPONSES TO GLOBAL WARMING

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Executive Summary

The use of analogies and analogical reasoning has been at the center of attempts to understand what future climate change might be like and provides a glimpse of some aspects of physical and societal responses to climate change at the regional level. Proper use of analogies (even if only to educate or to create awareness) can take some degree of uncertainty out of the societal side of the global climate change quesiton. The paper briefly discusses the meaning of analogy and the debates that have been going on for centuries in philosophical and scientific circles about the merits of analogies. Possible uses of analogies are categorized as follows: for general education, to generate hypotheses, to parameterize complex processes, to forecast future states of physical and social systems, to generate policy options and to fulfill a psychological need. Analogies are most useful when the purposes behind their construction are made explicit. Examples are taken from physical and social science publications related to global warming to demonstrate the levels of dependence on analogies. The High Plains of Texas provides an example of societal responses to changing environmental and technological conditions. This region is at the southern most dry margin of the North American Great Plains. Several scientists have suggested that the agricultural heartland of the United States will become more arid with a global warming. Yet, inhabitants of this region have been coping with fluctuating climatic conditions and changes in the regional water balance on a variety of time scales from seasons to decades. Focusing on one region at different points in time provides us with a relatively “clean” analogy with respect to societal resilience in the face of a variety of environmental, societal and technological changes. The assessment concludes that the use of analogies and analogical reasoning has been central to our understanding of many facets of the physical, social and humanistic aspects of the regional impacts of global warming. Analogies must be used with care and the purpose(s) for their construction must be made explicit. Historical analogies can provide useful insights into how well prepared societies are to cope with environmental change, allowing societies the opportunity to capitalize on their strengths and to minimize their shortcomings. One could conclude, then, that the use of historical analogies has a future in researching most aspects of the global warming issue.
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Introduction

The purpose of this paper is to improve our understanding about the levels of dependence on the use of analogies in the physical and social sciences with regard to the regional aspects of the global warming issue. Because current atmospheric general circulation models (GCMs) are not yet able to produce credible, reliable regional detail of the consequences of global climate change, environmental and societal impacts researchers have sought other ways to gain a glimpse of possible future regional climatic changes and their impacts. The use of analogies (and analogical reasoning) has been at the center of attempts to understand what future climate change might be like and provides a glimpse of some aspects of societal responses to climate change at the regional level. These glimpses are only first approximations of impacts and responses, but they can aid societies at all levels of economic development in their attempts to identify their strengths and weaknesses, opportunities and limitations in coping with change. Proper use of analogies (even if only used to educate or to create awareness) can take some degree of uncertainty out of the societal side of the global climate change question.

What is an Analogy?

Analogy has been defined in Webster's dictionary as an “inference that if two or more things agree with one another in some respects they will probably agree in others.” This general definition provides the basis for variations in the widespread usage of this concept. Mazlish (1965, 5) suggested that “[a]nalogy is the most primitive and, at the same time, one of the most important forms of reasoning.”

Analogies are composed of a base and a target (Gentner, 1983, 156). The base is what we already know; the target is what we wish to know. As Hunt (1989, 622) suggests, “known facts about the base are then used to make predictions about yet unobserved relationships in
the target problem.” Analogies can be based on functional as well as structural similarities. The appropriateness of the use of a specific analogy in a specific situation has been difficult to assess. Should one, for example, evaluate the appropriateness solely on the basis of the number of similarities in structure and function or on the importance of those similarities? Davies (1988, 230–1) captured the essence of this problem, noting that “One approach to the analogy problem has been to regard the conclusion as plausible in proportion to the amount of similarity that exists between the target and the source . . . . Others have suggested that the strength of an analogy be based on . . . relevance as an important condition on the relation between the similarity and the conclusion.” “Good analogical reasoning,” to quote Jamieson (1988, 81), “does not concern the number of similarities two objects share but rather the significance of the similarities.” The appropriateness issue remains a central point of controversy in assessing the utility and value of analogies as a scientific methodological tool. Regardless of the criteria one uses to determine the appropriateness of an analogy, the use of analogies remains widespread.

The word “analogy” is usually modified by different adjectives which have given it either a negative or a neutral meaning. Adjectives such as shallow, spurious, false, superficial, vague, facile, weak, prescientific, mundane, dubious and extraneous are common. Collectively, they expose a prevailing skepticism about the function as well as the utility of analogy in scientific inquiry. The adjectives that are not pejorative, such as historical, explicit, statistical, and expository, are less common and, in general, convey a neutral meaning. Thus, for the most part analogies are looked upon with great suspicion.

Analog (or analogue) is often used as a synonym for analogy. Webster’s dictionary defines analog as “something that is similar to something else.” Some people use it to describe one of the components of an analogy. Perhaps because of its association with computers, the word analog appears to carry with it a more quantitative connotation than does analogy. While these two terms are viewed as distinct, they have frequently been used interchangeably to describe the same phenomenon. Scientists writing about climate have not been consistent in the use of these terms. They have, however, in recent years tended to use “analog,” as
opposed to analogy, in their search to identify warm periods in the earth's history that could serve as regional proxies of future climate changes expected to result at the regional level from a CO₂-induced warmer atmosphere.

In addition to analog, other words whose meanings sometime overlap with that of analogy include homology (similarity of structures), simile (a figure of speech comparing two unlike things that is often introduced by "like" or "as"), isomorphism (same structure), family resemblance and metaphor ("a figure of speech in which a word or a phrase literally denoting one kind of object or idea is used in place of another to suggest a likeness or analogy between them"). To a specialist, such as a philosopher or a linguist, these words have distinct and separate meanings. Many scholars have sought with varying degrees of success to discuss the differences between these concepts (e.g., Hesse, 1966, Gerhart and Russell, 1984; Kittay, 1987). Yet to many of us, the differences in meanings are not always so clear.

As a result of persistent doubts about the value of analogies, their usage in scientific inquiry has been a source of debate for many centuries. Zashin and Chapman (1974) assessed the uses of analogy and metaphor by political philosophers, beginning with Plato and Aristotle. Mazlish (1965, 4) succinctly discussed the aversion of several philosophers and scientists to over-reliance on the use of analogical reasoning. Hobbes, for example, felt that the use of analogies inhibited scientific thought because it did not provide the precision of mathematics. Galileo sought "... to avoid the misunderstandings derived from false analogies." Hume observed that "... wherever you depart ... from the similarity of cases, you diminish proportionally the evidence, and may at last bring it to a very weak analogy, which is confessedly liable to error and uncertainty."

Similar views persist. von Bertalanffy, a biologist and general systems theorist, perhaps typified this line of thought when he suggested that "[a]nalogies are scientifically worthless. Homologies, in contrast, often present valuable models, and therefore, are widely applied in physics. Similarly, General Systems Theory can serve as a regulatory device to distinguish ... meaningless similarities [analogies] and meaningful transfer of models [homologies]" (1960, 85). von Bertalanffy's strong dislike of analogies is shown, for example, by his statement that "the
famous simile of society and an organism ... camouflage[s] actual differences and so lead[s] to wrong or even morally objectionable conclusions" (1960, 14). Thus, after more than two millennia of discussion and controversy over the utility of analogies (and metaphors as well) to scientific thought processes, the issue is nowhere near being resolved. In the meantime, analogies are constantly appearing implicitly as well as explicitly in research and scientific discourse.

Some physical scientists concerned with the atmosphere have also expressed doubt about the utility of historical analogies for improving our understanding of how societies might best cope with the regional impacts of climate change. They argue that climates of the future will not be like climates of the past. Therefore, history can provide little in the way of reliable guidance or insights to policymakers seeking to develop climate-change-related policies. Yet, one could effectively argue that societies (institutional structures and functions) often change slowly and, therefore, societal reactions to environmental change in the near future would most likely continue to be similar to those of the recent past.

In this section a brief discussion of analogy was presented to provide a foundation for later discussion on various aspects of the use of analogy in the global warming issue. Section I, which follows, addresses the use of analogical reasoning and analogies (or analogs) in assessing the physical aspects of the global warming issue. The second section (II) focuses on the search in the physical sciences for regional analogs to global warming. Section III addresses societal analogies and climate change. The next section (IV) presents a case study of societal responses to changing environmental and technological conditions with a focus on the High Plains of Texas. The concluding section (V) summarizes the contributions that can be gained by explicitly using analogies in social and physical science research on climate change.

Section I. Uses of Analogies

Before one can properly judge the value of a particular analogy, the purpose of the analogy should be made explicit (e.g., Kedar-Cabelli, 1988, 72). To this end, I suggest that analogies can
be used to fulfill several functions. While a person may understand why he or she constructed a particular analogy, others with whom he or she communicates will not necessarily be able to identify that purpose. While an analogy may be considered appropriate for its intended purpose, it may not be so when measured against other purposes to which it might be applied. Therefore, it is important that the original reason for resorting to the analogy be made explicit.

Analogies have been used (a) for general education, (b) to educate researchers in order to understand relationships and sensitivities and to generate hypotheses, (c) to parameterize complex processes, (d) to forecast future states of systems, such as the atmosphere or society, (e) to generate policy options or responses, (f) to fulfill a psychological need. These uses will be discussed, making illustrative references to different aspects of the global warming issue. The categories listed above are only meant to be suggestive, not exhaustive.

(a) General Education

Analogies can be used to educate non-specialists about some aspects of a complex situation by making reference to a different situation, about which they already have some information. These could be been referred to as "expository analogies" (quoted in Keane, 1988, 13). The greenhouse effect is such an example.

People know about greenhouses. They are protected, glass-enclosed, often carbon-dioxide-enriched environments. Plants in a greenhouse are kept in a controlled environment, protected from harsh climatic conditions. The idea that carbon dioxide, an atmospheric trace gas, traps heat in the atmosphere in an analogous way to a greenhouse was apparently first suggested in the early 1800s. Carbon dioxide in the atmosphere lets in shortwave radiation but blocks the exit of longwave radiation emitted by the earth.

Scientific consensus states that industrial activities such as the burning of fossil fuels, deforestation and food production processes, among other human activities, are producing large amounts of atmospheric CO\textsubscript{2} (as well as generating other greenhouse gases such as chlorofluorocarbons, nitrous oxides, tropospheric ozone, and methane). About half of the anthropogenically produced CO\textsubscript{2} remains airborne, acting to enhance the natural greenhouse
effect (eighty percent of which is due to water vapor). The more CO₂ and other greenhouse gases that are injected into the atmosphere, the more heat that will be retained. The greenhouse analogy suggests that carbon dioxide in the atmosphere acts like the panes of glass in a greenhouse to trap the heat generated by the penetrating sunlight. It also suggests that, if our production of CO₂ continues unabated, perhaps we could create to some extent a runaway greenhouse effect, producing on earth a much warmer atmosphere than is presently projected (see Schneider, 1990, 103).

There is little scientific doubt about the theory behind the greenhouse effect. This, however, is where the scientific consensus begins to break down. What a warmer atmosphere would mean, for example, for cloud formation which, in turn, affects global albedo at the top of the atmosphere which, in turn, affects global and regional temperatures and precipitation patterns is still not known with certainty. Other practical consequences of a greenhouse warming are also unclear. While the theory remains intact, the implications for regional climates, environments, and societies of enhanced greenhouse gas concentrations in the atmosphere remain controversial.

Even though scientists continue to use the greenhouse analogy, they are well aware of the dissimilarities between the analogy's base (a greenhouse) and target (a CO₂-enriched atmosphere). The glass enclosure, for example, prevents the warmed air from mixing with the colder air outside the greenhouse. This analogy holds when used as a heuristic device to educate the uninitiated reader on global warming. It is also extremely useful for communication. By citing the greenhouse analogy, one can easily convey the idea behind the end result of an atmospheric greenhouse gases buildup without having to go into detail about complex atmospheric physics, atmospheric chemistry, or even the industrial, social, or economic processes that lead to increased greenhouse gas emissions. The analogy, however, fails to educate us about the processes involved in the atmospheric greenhouse effect, a purpose for which it was not really intended.
(b) Education of Researchers

More sophisticated analogies can be identified to enable researchers to better understand changes in processes, interrelationships and sensitivities that might conceivably accompany a global warming. These analogies might be based on warmer periods, such as the Altithermal 4,000 to 8,000 years ago or the interglacial warming 125,000 years ago. Some scientists have used the warmest Arctic summers as an analog to identify the possible regional climatic consequences of a warmer atmosphere. Others have targeted summertime as a warmer earth analogy. Still others have used regional analogs by identifying existing regional climates that might be analogous to possible future climatic regimes in different regions (for example, a few degrees warmer global temperature might, decades in the future, create in Iceland the present-day climate of Scotland; see Parry et al., 1988).

Some scientists contend that there are no appropriate analogs to a global warming. Reasons usually cited include the fact that the boundary conditions (extent of sea ice, sea surface temperature distribution, vegetative cover, etc.) have changed so much and that climate change forcing factors (changes in albedo, amounts of atmospheric greenhouse gases, and changes in the solar constant or in the earth's orbital parameters) are so poorly understood for these earlier epochs that comparisons (e.g., analogs) are extremely risky. Others suggest that temperature increases induced by anthropogenically produced greenhouse gases will be unprecedented with respect to the level and rate of warming that could ensue. Yet, there are many prominent scientists who have searched the climate record of the earth (and other planets) in order to identify possible climate change analogies.

These conflicting views underscore the importance of being specific and explicit about the reasons why an analogy (or analog) was put forward in the first place. For the most part, historical (including geological) analogs have been presented as heuristic devices to enable researchers to test the sensitivities of a variety of components of the biosphere to changing atmospheric temperatures and not as forecasts of future states of the atmosphere. As Mazlish
(1965, 5) noted, analogy is often based at the outset on “an unanalyzed feeling of vague resemblance” and is, therefore, useful for forming hypotheses.

(c) Parameterization of Complex Processes

Analogical reasoning is a prominent part of general circulation modeling. GCMs are "numerical models of weather and climate systems based on mathematical equations describing complex physical processes. . . . Many meteorological processes are simplified or omitted entirely from these models" (Pittock and Salinger, 1982, 26). These computer models can be expensive and time-consuming to run. Modelers must work with a fixed number of grid points, which must represent average conditions for a specified area. One GCM grid point, therefore, might represent a grid cell several hundred square kilometers in area. Thus, these models are simplifications of reality. Because of this simplification, complex atmospheric processes occurring on all spatial scales, including sub-grid ones, must be parameterized. The WMO (1975, 19) has defined parameterization as “the expression of the statistical effects of various small-scale transport and transfer processes in terms of the large-scale variables explicitly resolved by the model.” Where there is a lack of information about those processes, or where there is a need to reduce the complexity of the atmospheric processes to meet the computational as well as economic constraints of the computers or the models, parameterization must be undertaken.

Analsogs are used in numerical modeling where there is a need to include important processes related to atmospheric circulation in the model. Some of those processes or phenomena may be well known but too complex for the needs or limited technical capabilities of the computers or the models. They must, therefore, be simplified. In other instances, the processes are not well known, yet they must be represented in the model in some form. As a result, there are simple base analogies that can be used to generate information about target analogies, or at least serve as adequate place holders in the models until those processes become better understood. For example, one reads about the “bucket” analogy for soil moisture in NOAA’s Geophysical Fluid Dynamics Lab’s (GFDL’s) GCM (Manabe and Wetherald, 1986;
Meehl and Washington, 1988). As another example, in the absence of reliable output from
a variety of emerging interactive air-sea models, simpler, analogous statements have been
used. GCM modelers have developed swamp models (simulates a fixed wet surface) and
slab oceans (upper ocean moves uniformly). Thus, parameterizing atmospheric and oceanic
phenomena is to a large extent dependent on the use of analogies to address spatial resolution
problems, representing in the models such atmospheric aspects as clouds, cumulus convection,
turbulence, boundary layer and diffusion processes, and rainfall. These analogies provide a
first approximation of the desired parameters. In fact, parameterization could be viewed as an
exercise in analogical reasoning.

Covey (1989, 23) has stated that “... all climate models ... contain a number of adjustable
parameters. These come from averaging over spatial and time scales which the model cannot
resolve, and also from leaving components of the climate system out of the model ....
Consequently there always will be a need for parameterizations, and inevitably some of these
parameterizations will be of doubtful validity.” As these parameters are redefined and adjusted,
as new knowledge of atmospheric processes is acquired, their role in the modeling process
becomes increasingly valuable.

(d) Forecasting

Heated debate, confusion, and skepticism is generated by the use of climate analogs (such
as those based on warmer periods, historical analogies based on societal responses to previous
environmental changes, and scenarios based on the output of atmospheric GCMs), as forecasts
of future regional climate. While an analogy may be used for any one of a variety of purposes,
a troublesome purpose is to use it to forecast a state of the atmosphere or of society several
decades into the future. It can, however, be used to make other kinds of projections about the
nature and ability of different types of societal responses to cope with a variety of plausible
(but not necessarily probable) future regional climatic changes.

There are many examples where such analogies have originally been suggested to generate
research hypotheses, only to be used later by others as forecasts. Wigley (quoted in Jäger
and Kellogg, 1983) has suggested that there is no analog to global warming in the 20th century climate record. Crowley (1989, i) suggested that there is no analog on prehistoric to geologic time scales that would suffice for insights into a future CO₂-induced global warming. Crowley was probably correct when he noted that "there may be no warm time period that is a satisfactory past analog for future climate," if he was talking about the lack of satisfactory geological analogs for the purpose of forecasting the regional impacts of a global warming. If he was referring to analogs as heuristic or hypothesis-generating devices when he noted that "... paleoclimate studies may provide important insights into climate processes" (1989, i), then he was also correct. The same can be said for Wigley's comment about no good analogs in the 20th century for global warming; a valid statement for forecasting but an invalid one if the 20th century analog is used for other research-oriented purposes. Thus, analogies are useful for generating scientific hypotheses or for improving scientific understanding of the processes that may take place with a global warming. They are not very useful as forecasts of future states of the atmosphere or society on which one might base specific policy responses to hypothetical regional climate changes.

Some scientists do explicitly provide reminders that their analogs are not predictions. For example, Jäger and Kellogg (1983) explicitly noted that "[n]one of these approaches can be used to make reliable predictions of the potential climate changes .... They can be useful, however, in showing the nature of climatic responses and in increasing understanding of the complex climate system." Yet, many scientists at one time or another have suggested policy actions based on the output of their modeling efforts (e.g., U.S. Senate, 1988, passim).

(e) Generation of Policy Options

"Analogies do not necessarily prove anything. They merely suggest a possibility" (Mazlish, 1965, 6). Plausibility of a physical or societal analogy is not a sufficient condition for use by policymakers, because several plausible but contradictory policies could be formulated based on different analogs drawn from the same pool of objective scientific information (see Martin, 1979). But, then, on which historical analog should a decisionmaker rely?
The use of an analogy to generate specific policies related directly to global warming is a risky business that must be undertaken with great care. Unfortunately, there are policymakers who are not reluctant to use these analogies as guides to or support for the formulation of specific policy options to cope with the hypothesized regional impacts of global warming. Often, specific analogies are chosen by politicians to support specific policy choices they favor. For example, a senator who seeks to enact a national energy plan might favor a specific global warming regional analog to underscore the need for such a plan. Making matters more difficult, there are a few scientists who portray their models’ output as being more reliable for use in the policymaking process than the models deserve. For example, the spectre of the return of the Dust Bowl days is often cited as a probable regional impact in the North American mid-continent of a global warming (e.g., Bernard, 1980).

While it is clearly within the realm of possibility that, given the normal variability of the region’s climate, such a situation could temporarily return in the future, it is a misapplication of the analogy to suggest that permanent Dust Bowl conditions may be in the region’s future.* Such analogies, however, can be used to identify policy needs in order to eliminate shortcomings in societal responses to environmental change. For example, the analogy of the Dust Bowl is a reminder that the region is drought-prone. It is a reminder that inappropriate land use practices can set the stage for desertification processes, if drought conditions were to return to the region. It is also a reminder that, despite the region’s favorable level of economic development, farmers have not yet been able to buffer completely their activities from the vagaries of weather.

Recently, Abrahamson (1989, 3) highlighted an official statement of the 1988 Toronto Conference on “Our Changing Atmosphere” that drew an analogy between the consequences of nuclear war and global pollution leading to global warming: “Humanity is conducting an unintended, uncontrolled, globally pervasive experiment whose ultimate consequences could be second only to nuclear war.” He noted that this analogy was not made by “idealistic,

* Since the 1930s, soil conservation practices have been undertaken in the Great Plains in order to avoid the desertification processes that were catalyzed in the Thirties by prolonged drought combined with inappropriate regional land use practices and economic depression.
scientifically innocent environmentalists” (1989, 3). The use of this analogy by the Toronto Conference organizers was intended to compare an unknown situation, the consequence of global warming, with a known worst-case scenario, a nuclear holocaust, in order to capture the attention of policymakers, the public, and especially the media, and to urge prompt policy action to address the global warming issue. This explicit analogy was apparently meant to evoke an implicit analogy. It was an apparent attempt to transfer all of the fears associated with the consequences of a nuclear war to the climate change issue and to adopt policies stimulated by those fears.

The nuclear war analogy could be cited as an example to identify a “dread factor,” with regard to societal impacts, much as physical scientists have suggested cataclysmic dread factors among plausible impacts of climatic change on the physical setting, e.g., the disintegration of the West Antarctic ice sheet or the rapid switch in ocean currents (e.g., Glantz, 1988, 57–81). Such changes in the physical system would greatly challenge societies to develop adequate response (coping) mechanisms based on dread factors.

Recent interviews with Toronto Conference organizers provide support for the assertion that the nuclear war analogy was invoked to “grab” the attention of the media. The consequences of a nuclear war are a worst-case scenario of societal impacts of human actions. For argument's sake, what if the organizers had favored a different, less severe, scenario such as the summertime analogy to global warming. Replacing the phrase “nuclear war” with “perennial summertime” would modify the Conference Statement to read as follows: “The consequences of global warming are second only to the consequences of a perennial summertime.” What effect, as a call to policy action, would this scenario (analogy) have on policymakers and the public?

(f) Psychological Aspects of Analogies

Yet another function that analogies can perform is the fulfillment of a psychological need. When confronted by unknown situations, analogies can provide us with a feeling of understanding. They provide a first step toward knowing or at least considering the unknown.
As Mazlish (1965, 7) noted, "[a]nalogy provides an 'original,' an archetype, offering us the secure feeling of a familiar experience." Zashin and Chapman (1974, 313) suggested that "it is not hard to see why analogies can be persuasive; they promise order and intellectual control." In this regard analogies comfort us by providing a bridge between the past (the known) and the future (the unknown).

Section II. The Search for Regional Analogs to Global Warming: The Physical Sciences

This section briefly discusses attempts to identify the regional impacts of global warming by using climate analogs. Such analogs include the following periods, each of which has been suggested as a global warming analogy: (a) the Medieval Optimum, (b) the Altithermal, and (c) 2.5 to 3.5 million years BP. Other attempts to identify global warming analogs include (d) summertime and (e) the use of the 10 warmest Arctic summers.

(a) The Medieval Optimum

Flohn (1981, 37) suggested that between 2000 and 2010 the global average temperature would increase by about 1°C, given continuance of the existing trends for carbon dioxide emissions to the atmosphere. He then proposed that the Medieval Optimum which occurred between about 900 and 1200 AD, the warmest period in the past two thousand years, could serve as an analog for climate impacts with a 1°C warming. The period was characterized by warm conditions in the mid-latitudes, an absence of sea ice in the East Greenland Current and a retreat of Atlantic sea ice north of latitude 80°N. In addition, Icelandic and Norwegian farmers were able to cultivate cereals up to latitude 65°N. The Caspian Sea level was several meters lower than present levels. Higher tracking cyclones in this period meant extended summer droughts and winter blizzards in Europe.

(b) Altithermal

The Altithermal (also referred to as the Holocene warming) occurred 4,000–8,000 years ago. It provides perhaps the most popular analog that has been suggested for about 1.5°C global warming. It has also been the most challenged analog. In the late 1970s, Kellogg used
paleo-ecological information to construct a map depicting regional climates during this period, which was considerably warmer than at present (Fig. 1).

![Map of the Altithermal Period](image)

Fig. 1 A reconstruction of the Altithermal (or Hypsithermal) Period of about 4,500 to 8,000 years ago, showing areas where the conditions were wetter or drier than now. The blank areas are not necessarily regions where no change occurred; information is incomplete (from Kellogg and Schware, 1981).

Flohn (1981), too, cited the Altithermal as an analog for identifying the possible regional implications of a 1.5°C global warming. He expected such a warming to occur between 2005 and 2050. Kellogg and Schware (1982, 1088) pointed out that Kellogg's Altithermal map "should not be taken as a prediction of what will happen, but rather a scenario of future climate describing what could happen."

Wigley et al. (1980) critiqued these reconstructions, noting that the data used are indirect and poorly dated, and Pittock and Salinger (1982) suggested that "what appears to be a synchronous spatial pattern may be a superpositioning of a number of episodes which all occurred at slightly different times." Wigley (1982, 2) also noted that the spatial coverage is generally poor with substantial data gaps over the land and the oceans. Another weakness of this analog is that the warming occurred only in summer (the winters were colder), whereas GCMs suggest that with a global warming, both summers and winters will be warmer, with winters warming to a greater degree than summers. According to Crowley (1989, 1), "This can be explained by variations in the seasonal cycle of insolation at the top of the atmosphere — the Milankovitch effect."
Schneider and Londer (1984, 325) also critiqued the use of the Altithermal analog, suggesting that the period was not one of universal warmth but of periods of climate changes. They questioned the use of this analog as a way to identify possible regional consequences of global warming, since the cause of warming during the Altithermal was probably not due to elevated levels of CO₂ (see also Pittock and Salinger, 1982, 36).

(c) 2.5 Million BP

Just before the last large-scale glaciation of the northern continents began, the earth was warmer and the Arctic was "substantially ice free." This period, the late Tertiary, had different boundary conditions (such as changes in vegetation, sea level, sea ice extent, mountain formation). Flohn (1981) has used this period as an analog for a 4°C temperature increase, creating an ice-free Arctic region. This analog has been challenged by Crowley (1989) with respect to potential regional climatic impacts resulting from an ice-free Arctic, because the boundary conditions have greatly changed. Crowley (1989, i) also felt that this analog would be misleading "because these warm periods had reduced polar ice cover, whereas future temperatures will be very warm but ice sheets will persist because of their large thermal inertia. Due to the different time scales for the atmosphere, deep ocean, and ice sheets, there may also be a significant non-equilibrium component to the climate response that may not apply to past warm periods."

(d) Summertime

A major scientific and political concern relates to variability. How would a global warming affect regional climatic variability? With a warming, will climate variability increase, decrease, or stay as it is today? Kellogg and Schneider (1978, 12) noted that "[w]e have a few hints concerning the variability of the patterns shown in a scenario, and arguments can be made for a decrease in variability. For example, one might say that it could be more 'summerlike' on a warmer earth and that therefore there would be a weaker general circulation and fewer extreme events. Indeed, variability of the current weather is known to be less in summer than in winter."
Reduced variability in certain regions would have major implications for regional strategies and tactics to cope with the impacts of future climate change at the regional level. Some scientists have suggested that an increase in extreme meteorological events would likely occur with a global warming (e.g., U.S. GAO, 1990, 10). Because of the importance and uncertainty surrounding the effects of global warming on climate variability, EPA funded research addressing the variability issue. Preliminary results suggest that the variability–global warming issue is complex and as yet unresolved, with contradictory results having been generated by different models' runs (Mearns, 1989). Studies continuing to address variability associated with global warming issues are now in progress (e.g., Mearns et al., 1990).

Climate variability is an extremely important aspect of global warming, thereby giving a high priority to the degree of determination of the appropriateness of this analogy. As Katz and Brown (1990, 1) have suggested that "... the frequency of [extreme] events is relatively more dependent on any changes in the variability than in the mean of climate." This has major implications for policy analyses that "rely on scenarios of future climate involving only changes in means" (1990, 1).

(e) Ten Warmest Arctic Summers

Jäger and Kellogg (1983; see also Williams, 1980) identified the 10 warmest Arctic summers in the 20th century and from this composite produced a picture of possible future regional climate anomalies in the northern and mid-latitudes under global warming. Their study was based both on a general belief that increased levels of atmospheric CO₂ would lead to an increase in the average global temperatures and on GCM output suggesting that the Arctic region would be much more sensitive than the mid-latitudes to increasing average global temperatures.

This approach of identifying regional impacts of global warming has been challenged for a variety of reasons. For example, Pittock and Salinger (1982, 41) have argued that "the use of a set of individual warm years in a 'scenario' is open to question because the warmth was presumably a result of internal dynamical fluctuations not a systematic change in the global
radiation balance.” In addition, they noted that using a set of years as opposed to a run of years does not allow for the cryospheric or the oceanic components of the climate system to come into equilibrium (1982, 55). Problems with this approach notwithstanding, the study did generate other studies based on the concept of a higher warming in the Arctic region than in the mid-latitudes, such as research taking consecutive years above and below the long-term regional temperature mean.

**Summary**

These examples are not exhaustive of the list of analogs used to identify regional as well as global climatic changes that might be associated with a global warming. Others include a search of the recent climate record for warmer fluctuations, such as the 1920s and 1930s (e.g., Aspen Institute, 1978), comparing composites of the five warmest and five coldest years (Wigley et al., 1980), a search of the global geological record (e.g., the Eemian 125,000 years ago) or of regional and local records (e.g., Pittlock and Salinger, 1982, and Kates et al., 1984, respectively). As an example of a scenario of possible soil moisture patterns on a warmer earth, Kellogg and Schware (1982) combined the results of three separate climate warming analogs — paleoclimatic reconstructions for the Altithermal, comparison of recent warm and cold years in the Northern Hemisphere, and a climate model experiment. The end result was yet another plausible climate analog, as shown in the following map (Fig. 2).

Each of these analogs or combinations of analogs possesses its own particular set of strengths and weaknesses. Each has been challenged as imperfect, if not misleading. As noted earlier, Crowley has suggested that there are no good paleoclimatic analogs and Wigley has suggested that there may be no 20th century analogs. On the other hand, scientists such as Flohn and Budyko strongly believe in the value of paleoclimatic analogs.* Flohn and

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* During the early 1970s, when there was considerable speculation about the return to an Ice Age, several analogs were also put forward — but for a cooling of the global atmosphere. These include the Younger-Dryas (10,800 to 10,000 BP) cold interval, a cooling which was most intense in Europe, especially northwest Europe and the British Isles (Schneider et al., 1987, 403), and the Little Ice Age which lasted for several centuries, ending about 1850.
Fig. 2 Example of a scenario of possible soil moisture patterns on a warmer earth. It is based on paleoclimatic reconstructions of the Altithermal Period (4,500 to 8,000 years ago), comparisons of recent warm and cold years in the Northern Hemisphere, and a climate model experiment. Where two or more of these sources agree on the direction of change, the area of agreement is indicated with a dashed line and a label (from Kellogg and Schware, 1982).

Budyko have independently established a sequence of analogs that track proposed increases in CO₂ levels and in global temperatures, matching them to previous warm periods. Flohn's perception of analogs is shown in the following chart (Table 1).

Table 1: A Global Warming Timetable

<table>
<thead>
<tr>
<th>If by about this time ...</th>
<th>2000–2010</th>
<th>2005–2050</th>
<th>2020–2050</th>
<th>2040–2080</th>
</tr>
</thead>
<tbody>
<tr>
<td>(Calendar years)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Atmospheric carbon dioxide and other trace gases reach ...</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(Parts per million)</td>
<td>430</td>
<td>492</td>
<td>610</td>
<td>880</td>
</tr>
<tr>
<td>Global warming could reach ...</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(Degrees centigrade)</td>
<td>1.0</td>
<td>1.5</td>
<td>2.5</td>
<td>4.0</td>
</tr>
<tr>
<td>Which corresponds with ...</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(years ago)</td>
<td>1,000</td>
<td>6,000</td>
<td>120,000</td>
<td>2.5–12 million</td>
</tr>
<tr>
<td>(Early Middle Ages)</td>
<td></td>
<td></td>
<td></td>
<td>Late Tertiary Period</td>
</tr>
<tr>
<td>(Peak Holocene Period)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(Last Interglacial Period)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Source: Flohn, 1981.
One general argument, usually cited against the reliability of historical analogs, is that the forcing function for contemporary global warming is increased carbon dioxide and other anthropogenically produced greenhouse gases, whereas the forcing functions of earlier times have not all been identified. For those situations in which the forcing functions have been reliably determined, the value of the analogs has been challenged outright. Kutzbach and Webb (1980) have challenged Kellogg's use of the Altithermal as a possible analog, because of differences in the earth's orbital characteristics. The position of the earth with respect to the sun was such that there would have been warmer summers and colder winters, as opposed to warmer temperatures in all seasons, which is expected to occur in a CO$_2$-induced warmer earth. An additional argument used against the search for historical climate analogs in the physical sciences is that the boundary conditions in the earlier periods were not the same as they are at present. Crowley (1989, 6) has recently suggested that analogies from the geologic past cannot provide useful analogs for global warming because "When all of these geographic effects are considered together, it is evident that, even if global temperatures were warmer, the regional climate patterns may have been significantly different than what we might experience in the future."

This section exposes the controversy within scientific circles over the search for appropriate regional analogs to climate change. It also underscores the widespread discussion about the value to the physical science research community of plausible analogs to climate change impacts. While several of these analogs might seem farfetched to the unsophisticated observer, they do play an important role in the search for improved understanding of global warming and its impacts at the regional and local levels. The discussion might also serve to warn the reader that specific regional policies based on any specific analog would be risky at best, given the scientific controversy that seems to surround each of them.

Section III. Societal Analogies and Climate Change

It is widely acknowledged that GCMs of the atmosphere are not yet very reliable at identifying regional climate changes that might result from global warming. While the
various GCMs are in moderately good agreement on projections of temperature changes, they agree much less on projections of precipitation and soil moisture. Yet policymakers require this regional and local information in order to make specific policies related to preventing, mitigating, or adapting to the impacts of global warming. While the modelers continue to seek to improve the reliability of their models for identifying regional climate change impacts, researchers interested in the societal (including policy) aspects of climate change have searched for other ways to undertake reliable, plausible regional assessments. Such approaches include (a) regional analogs, (b) CLIMPAX, and (c) historical analogies.

(a) Regional Analogs

Parry et al. (1988, 38–99) discussed the use of regional analogs as indicators of climate impacts. They identified analogous regions based on temperature and precipitation projections for a CO₂ doubling (according to the Goddard Institute for Space Studies [GISS] model) for each of their case study areas, as shown in the following map (Fig. 3).

![Map showing regional analogs](image)

Fig. 3 Present-day regional analogs of the GISS 2 × CO₂ climate estimated for the case study regions: Saskatchewan, Iceland, Finland, Leningrad and Cherdy regions (USSR) and Hokkaido and Tohoku districts (Japan).

They suggest that such analogs can be useful for interpreting the GISS 2 × CO₂ (i.e., CO₂ doubling) scenario, because: (i) They provide effective illustrations of regional impacts of climate change by serving “to highlight the magnitude of the future change in climate within regions in terms of the present-day differences in climate between regions.” Parry et al. (1988) suggest, for example, that Iceland’s climate under the GISS 2 × CO₂ scenario will be
similar to the climate of northeast Scotland today. (ii) They can be used as indicators of likely agricultural adaptations. Agricultural practices in analog regions "... are a useful indicator of the adaptive strategies to retune agriculture to altered climatic resources ..." (iii) They are useful as indicators of potential productivity, based on the assumption that current agricultural productivity in the analog region may be of similar magnitude to that obtainable under a changed climate in the study area.

Parry et al. (1988) note that there are many difficulties associated with the use of regional analogs along the lines they have proposed. The main problems stem from the existence of regional variations in environmental, management and technological factors. The severity of climate impacts will be affected by cultural practices and these are most likely to be different between the case study and analog regions. As Firey (1960, 145) noted, "[t]he resource composition of a habitat varies as much with the activities of the people who occupy that habitat — their techniques, beliefs, knowledge, and social organization — as it does with the physical properties of the habitat itself." Parry et al. (1988) also point out that climate changes will affect other factors that can favorably or adversely alter agricultural production such as latitudinal variations of daylight, water resources, soil fertility, soil erosion, plant diseases, and pests.

(b) CLIMPAX

The Climate Impacts, Perception, and Adjustment Experiment (CLIMPAX) was undertaken in the mid-1980s, based on the view that "empirical evidence can be incorporated into arguments about the impacts of future fluctuations" (Kates et al., 1984, 1). The experiment was an empirically based search for different types of past climatic fluctuations in the United States, some of which were then "chosen to emulate a CO₂ change or other scenarios of future climate" (1984, 1).

The study team sought to identify what they defined as "persistent periods (decades or greater) of climate variation or slow cumulative climate change." They referred to this as "the consecutive epoch analysis" (1984, 5). CLIMPAX focused on the meteorological variables
of rainfall and temperature. Kates et al. (1984, 7) suggested that “CLIMPAX offers a complementary approach to [simulations of expected climate change based on guesstimates of what might be expected to occur with a global warming, e.g., 1°C and 10% decline in precipitation] ... by identifying regions where changes similar to those projected actually took place over a sustained period.”

The study authors pointed out the possible weaknesses of their approach by noting that “… these empirical analogs differ from projected CO₂-induced climate change in very significant ways. The changes are almost instantaneous, are not sustained and cumulative as predicted in the CO₂ cases, and are smaller than changes projected by some models at high levels of CO₂ doubling ....” Another problem with this approach is that the relatively modest quantitative changes in meteorological variables over short time periods often prompt subtle changes in human behavior. These societal changes may not be identifiable until the fluctuation has passed, if at all. In addition, other intervening factors could make it almost impossible to attribute the changed behavior to relatively minor changes in climate statistics (on the attribution problem, see Katz, 1988).

(c) Historical Analogies

Historical analogies, like several other analog methods, provide an alternative to sole reliance on GCM-generated regional scenarios and can provide a first approach in attempts to ascertain the level of societal preparedness for the impacts of a global warming. As noted earlier, the various GCMs do not agree on the possible regional distribution of precipitation, although they are in somewhat better agreement on possible regional temperature changes (Hansen, 1988). A recent study by Adams et al. (1990), based on a comparison of the regional output of two GCMs, shows the different impacts that could be derived from a reliance on different GCMs.

Another approach, based on the use of historical analogies, has been referred to as “forecasting by analogy” (Glantz, 1988, 1990). This approach was proposed in the early 1980s in an attempt to identify potential responses to regional climate change by assessing
societal responses to changes in the water balance of the Great Plains. This approach does not attempt to forecast the future state of the atmosphere nor does it suggest that we can forecast the future state of society. It suggests that we can learn how societies have dealt with recent environmental changes (regardless of degree or rate of change) and apply that knowledge about societal responses to improve the way that societies might cope with such changes in the future. Historical responses can be used to identify societal strengths and weaknesses with the hope that the weaknesses can be addressed.

This approach is based on the premise that societies in the near to midterm future will likely conduct activities as they have done in the recent past, barring unforeseen shocks of a magnitude that would fundamentally alter their traditional patterns of interaction.* Decisionmakers can usually relate to real-world predicaments with which they or their predecessors most probably have had to cope (e.g., Neustadt and May, 1986). Thus, such studies have a reality about them that gives their findings a level of credibility that computer-generated futures scenarios lack.

The Dust Bowl days in the U.S. Great Plains in the 1930s has been proposed as an analogy to what might happen in the region with a global warming. This analogy has existed for at least a decade and has been cited as a worst-case scenario (Bernard, 1980; Warrick, 1984). It catalyzed studies that looked at changes in the water balance within the Great Plains region as a possible analog to societal responses to changes in the regional water balance (e.g., Glantz and Ausubel, 1984). Models now suggest that, with a global warming of the atmosphere, mid-continental areas in North America, southern Europe, and Siberia would tend to become warmer and drier (e.g., Manabe, 1988).

The spectre of a return of the Dust Bowl days is frequently used to spark concern about the possible long-term adverse effects of global warming. In a recent article on the possible impacts of global warming in eastern Colorado, the Dust Bowl image was once again invoked by

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* Recall that even the energy crises of the 1970s have not radically altered the way our society consumes energy, temporary response adjustments notwithstanding.
suggesting that "In a worst-case scenario, large-scale activity [such as the drying of vegetation and the exposure of fixed dunes to prevailing winds] on the high plains would create severe droughts that would make the Dust Bowl look mild..." (Rovin, 1990). It is a scenario to which many policymakers as well as farmers in North America can relate, having grown up with a recollection as well as a fear of a return of Thirties-like droughts and their socioeconomic and environmental consequences for the region.

The "forecasting by analogy" approach has since been applied to other environmental changes in North America (Glantz, 1988) and to marine fisheries around the world (Glantz and Feingold, 1990). These cases have also served to stimulate researchers in other climate-sensitive regions to undertake sensitivity analyses using their own climatic and environmental records. Similar studies have also been undertaken in Hungary (Antal and Glantz, 1988), Brazil (Magalhães and Neto, 1990), and Vietnam (Ninh and Hien, 1989).

Summary

The need for information on the regional aspects of global warming is very great, as the desire for policy action at all levels of social and political organization to prevent, mitigate or adapt to climate change also continues to accelerate. Researchers concerned about the possible societal impacts of a global warming are in the midst of searching for appropriate methodologies to address issues of concern to them. Analogies, when properly used, can provide some guidance to the search for policy responses to yet unknown future changes in regional climatic conditions.

Section IV. Texas High Plains Case Study

Scientists have suggested that with a global warming there would be an increase in dryness in the midcontinental regions of the midlatitudes around the world (e.g., Budyko and Sedunov, 1988; Meehl and Washington, 1988). They have come to this conclusion based on GCM model output, the 1920s–1930s warming, and paleoclimatic reconstructions for earlier warm epochs
in the earth's history. The U.S. Great Plains is one area that would be affected by such a situation.

The Texas High Plains region deserves special attention because it is on the climatic dry margin of the southern Great Plains. It serves to illustrate what could (not will) happen in other parts of the Great Plains. It can also serve as an analog to itself at different points in time (as opposed to forming an historical analogy between two different places at the same point in time). The case study is not used to forecast what climate change impacts in the region might be. It is used to generate understanding of regional responses to change.

For over one hundred years, the High Plains of Texas have developed economically as the direct result of judicious societal responses to changes in regional climatic (and, later, groundwater) conditions. In addition, as Firey (1960, 139) has noted, "[r]esource processes in the South Plains have been quick to respond to varying politico-economic decisions: to changed market relationships, revised governmental policies, new technical developments, etc." The most recent assessment of future options for use of the High Plains aquifer was the result of U.S. Congressional concern (e.g., Camp Dresser & McKee et al., 1982).

High Plains settlers began as cattle ranchers and as dryland farmers seeking to find, through trial and error, sustainable economic activities that would mesh with the region's climatic and other environmental conditions. Both ranchers and farmers were dependent for the most part on the vagaries of the weather. Recurrent drought, however, made such a dependence untenable over the long term. Because of recurrent, extended, severe drought, among other factors, inhabitants of the region who did not abandon their land have been forced to devise ways to cope with anomalous water supply conditions.

Some of the changes with which farmers and local governments have had to cope include the following: alternating short, as well as prolonged, wet and dry periods; severe decade-long drought that coincided with a worldwide economic depression; fluxes of weather-induced immigration and emigration; alternating periods of per-acre profits and losses over which they
had little or no control; changes in the types and prices of energy used in irrigation; and groundwater exploitation from discovery to depletion.

The waves of migration into the Texas High Plains were often sparked by a belief that rainfall could support agricultural activities at least at the local farm level. During wet periods, that was the case. Many new settlers were led to believe, as a result of overzealous if not unscrupulous advertising by land speculators and railroad companies, that local rainfall conditions would be enhanced by farming the land (e.g., Fite, 1956). However, whenever drought returned to the region, many settlers were forced to abandon their homesteads in search of more productive areas.

In specific response to droughts and to the realization that the region overlies portions of an underground reservoir called the High Plains Aquifer, farmers began to seek ways to tap the groundwater. Initially, in the last part of the 1800s, parts of the aquifer closest to the land’s surface were tapped with the use of windmill-driven pumps. These pumps were very important to the settlement of the Texas High Plains, because they provided homesteads with water for small agricultural plots and for livestock. Their rates of flow, however, were too low for the irrigation needs of large agricultural activities.

Thus, awareness of the underground water resource preceded, by decades, either the farmers’ ability or their desire to draw on the groundwater in quantities necessary for extensive irrigation. In addition, there was also a prevailing distrust of, if not an aversion to, irrigation. In the 1890s and the first decade of the 20th century, land speculators and town boosters sought to “sell” the value of irrigation in the hopes of enticing migrants to the region. In this period (1896 to 1907), however, rainfall was adequate for dryland farming, while the costs of installing irrigation facilities remained quite high. Also, there were still many technical problems associated with keeping irrigation systems operating.

A four-year drought that ended in 1911 renewed the interest in irrigation, especially sparked by land speculators who sought to push up the value of otherwise low-value, marginally productive land. Yet, factors such as high grain prices generated by World War I prompted
even more farmers to go into extensive dryland farming. Despite the fact that the decade of the
1910s was generally one of good rainfall and high commodity prices, the high cost of irrigation
and the lack of farm credit to poor farmers worked against the widespread adoption of irrigation
technology in the region. Green (1973, 118) used an analogy to suggest why irrigation did
not take off in the 1910s: "Like a surgically transplanted organ which had been too hastily
engrafted, irrigation was 'rejected' by the Texas High Plains." Irrigation development did not
fare much better in the 1920s because rainfall remained above average. In addition, because
prices for agricultural produce declined sharply after World War I, and because overproduction
was seen as the root of the problem, local and federal opposition to irrigation developed.

In contrast, most of the 1930s, with the exception of two years (1932 and 1937), were
drought-plagued (e.g., Worster, 1979). In the early part of the decade, there was a sharp
drop in prices for agricultural goods grown in the region because of the nationwide economic
depression. According to Green (1973, 123), the federal government through its Agricultural
Adjustment Act of 1933 aided distressed farmers with subsidies which many invested in new
mechanization of their farms. These factors prompted a major shift in regional attitudes toward
the exploitation of groundwater. New wells started to appear after 1934 as a reaction by farmers
to the harsh environmental conditions in the region during the Dust Bowl era.

By 1940 the High Plains of Texas had become the most important irrigated area in the
country. By the late 1940s, a major regional concern was the issue of groundwater control.
Would control of this resource in the High Plains of Texas go to federal, state, or local
authorities? High Plains farmers were as afraid of state control as they were of federal control.
As a result, the High Plains Underground Water Conservation District #1 was created in 1950
(see Green, 1973, 165–89).

Severe droughts in the southern Great Plains in the 1950s reminded inhabitants of the
vulnerability of their fields and their livelihood to drought and dust storms. In addition to the
implementation of conservation measures for water and land, these droughts also prompted
another sharp increase in the construction of wells for irrigation. Today, there are more than
70,000 deep wells tapping the Texas High Plains Aquifer. Expansion of irrigated acreage paralleled the increase in wells (Table 2).

<table>
<thead>
<tr>
<th>Year</th>
<th>Acres irrigated</th>
<th>Year</th>
<th>Acres irrigated</th>
</tr>
</thead>
<tbody>
<tr>
<td>1936</td>
<td>80,000</td>
<td>1959</td>
<td>3,887,000</td>
</tr>
<tr>
<td>1937</td>
<td>160,000</td>
<td>1964</td>
<td>4,094,000</td>
</tr>
<tr>
<td>1938</td>
<td>200,000</td>
<td>1969</td>
<td>4,507,000</td>
</tr>
<tr>
<td>1939</td>
<td>230,000</td>
<td>1974</td>
<td>4,485,000</td>
</tr>
<tr>
<td>1940</td>
<td>250,000</td>
<td>1978</td>
<td>4,542,000</td>
</tr>
<tr>
<td>1945</td>
<td>550,000</td>
<td>1981</td>
<td>5,203,000</td>
</tr>
<tr>
<td>1949</td>
<td>1,548,000</td>
<td>1984</td>
<td>4,575,000</td>
</tr>
<tr>
<td>1954</td>
<td>2,909,000</td>
<td>1989</td>
<td>3,943,000</td>
</tr>
</tbody>
</table>

Adapted from Lacewell and Lee, 1988, 131.

Several reasons have been given for the receptivity to irrigation in the Thirties and afterwards, including technological improvements in irrigation facilities, the emergence of preferred cash crops (cotton, grain sorghum, and winter wheat), and the availability of credit to farmers for developing irrigation plants.

Groundwater assessments at least as early as the 1950s were already alluding to the depletion of the aquifer, declining water tables, and the possible long-term consequences for the region of the mining of the underground reservoir (e.g., Hendrick, 1958, 1959; Firey, 1960). The predominant mindset of Texans on the High Plains had shifted from an earlier perception of an unlimited supply of groundwater (the region was once referred to as the “land of underground rain”) to one of the mining of the groundwater resource. Now, the longevity of this resource is no longer measured in terms of centuries but of generations.

Thus, over the past century, in response to harsh conditions (socio-economic as well as environmental), farmers have sought ways to insulate their livelihoods from the vagaries of weather. A combination of desire, need, technological innovation, and the availability of cheap energy prompted farmers to shift their dependence from atmospheric to underground water resources. Besieged by drought and depression, High Plains farmers turned to irrigation as a form of crop insurance (Green, 1973, 139). They became more adept at irrigating their fields
and more efficient at irrigation. They began to look at irrigation in a different light: it was for use not only in drought emergencies, but also to maximize crop production.

Inhabitants of the region, who began as dryland farmers and ranchers, passed into a phase of groundwater dependence. They are at present in the midst of a transition into an era of scarce, if not depleted, groundwater resources. This fact of groundwater depletion has prompted different responses. For example, some people in the region chose to abandon their land as their wells dried up or because the water table dropped, thereby increasing the energy requirements to pump ever-deeper water onto their fields. Resource managers in the region have been developing viable options to land abandonment. Tactical responses to the rapid decline in the water table have included a switch to crops with lower water requirements, a shift to dryland farming and the development of such new irrigation methods as surge flow, furrow diking, and low energy precision application (LEPA), and even the controversial scientific practice of cloud seeding (e.g., High Plains, 1979; see also Reisner and Bates, 1990, 115-22). Another tactical response of recent interest has been the possible use of plant-growth-regulating chemicals which can inhibit the moisture loss of plants by as much as 20 percent. There is also interest in the possibility of using precipitation captured by some of the 17,000 playa basins on the Texas High Plains as a potentially important source of recharge for the High Plains aquifer (see U.S. Department of Interior, 1987, Tx3-4). Each of these options has been designed to stretch out the remaining, but ever-dwindling, groundwater supply for a few more decades.

If only one word could be used to describe the economy of the Texas High Plains, it would be “resilient.” The region has undergone a variety of changes, some of which have been environmental, others have been technological, still others social and economic. Looked at collectively, these impacts have presented major challenges for survival to the region’s inhabitants as well as to regional governments. Societal responses to these and other socioeconomic changes suggest that the region will show a similar propensity toward adaptability in the face of the potential regional consequences of a climate change. With or
without a CO₂-induced global climate change, climate in this semi-arid region will continue to vary from one year to the next as well as on other time scales.

Can we learn from people in the region about how future generations in the same region might respond to conditions not wholly dissimilar to those faced by their predecessors? Can the Texas High Plains serve as a fruitful analog to the possible societal responses to climate change in other regions that might also be facing increasingly arid conditions? Assessing societal responses to environmental change in the High Plains of Texas at different points in time can provide an analog to itself as well as to other regions. It is important to note, however, that even the use of a region at one point in time as an analog to itself at another point in time will not enable the researcher to develop the perfect analogy. Times have changed. Cultural factors have evolved. Perceptions and attitudes about resources may also have changed.

Section V. Concluding Comments

Today, societies are increasingly concerned with the prospects of climate change. Will the atmosphere heat up, as many scientists predict, if societies continue to pursue activities that add greenhouse gases to the atmosphere? And if so, to what degree? At what rate? We have some estimates of how increased greenhouse gases loading of the atmosphere may affect global temperatures and the global hydrologic cycle; global average temperatures will most likely increase by a few degrees Celsius and the hydrologic cycle is expected to intensify (i.e., more evaporation, precipitation). However, most decisions are not made at the global level, nor can they be made based on global averages. They are made at local, regional, and national levels, for which regional information is generally required. Yet, to date, GCMs have been unable to provide reliable information to the climate impacts research community about the regional changes one might expect to accompany a CO₂-induced global warming. Historical analogies have provided another approach to identifying plausible regional response scenarios to future yet-unknown climate changes.
What Analogies Can Do

Despite the ongoing philosophical as well as practical debate on the value of analogies in physical and social scientific inquiry, it appears that carefully employed analogies can provide some insights into the possible regional implications of a global warming. In fact, it could be argued that they are useful in all stages of scientific inquiry with regard to this issue.

As noted at the outset, analogies have been used as heuristic devices both to educate the lay public and generate scientific hypotheses worthy of additional research. They have been used by modelers in attempts to improve their understanding of atmospheric processes under conditions of climatic changes involving both warmer and colder global average conditions and also to parameterize atmospheric processes, an essential part of general circulation modeling activities.

Physical scientists often cite their use of global models as providing their research community with sensitivity analyses of atmospheric processes and, therefore, climate under a variety of conditions. Similarly, analogies can provide researchers with a tool for undertaking sensitivity analyses of societal responses to changing environmental conditions.

Analogical reasoning and analogies are implicitly, if not explicitly, an integral part of human thought and communication processes. Analogies can be used to generate a first approximation of the regional impacts of a global climate change. They can also provide reasonable insights into possible societal responses to those impacts. We must state why such reasoning is used so that others will better know how to judge the appropriateness of the use of analogies in a particular context. We must accept them as important approaches to scientific inquiry and we must be explicit about their strengths and shortcomings.

What Analogies Cannot Do

Mazlish, like von Bertalanffy, warned the researcher that, when used carelessly, historical analogy can be a misleading guide to action. Mazlish identified two special problems with the use of historical analogies in the social sciences; fair sampling and self-fulfilling prophecy. With
respect to fair sampling, there is a greater possibility of achieving an adequate sample of cases in the physical sciences than in the social sciences. Thus, analogies in the social sciences are often based on only a few instances, so that their findings are somewhat more tenuous, and their usage in need of greater care. With respect to self-fulfilling prophecies, societies respond to signals they perceive in their environment. Thus, projections could turn out to be false or true depending on human perceptions of, or responses to, environmental change.

Analogies have also been proposed to suggest possible alternative futures and to stimulate specific policy formulation to cope with the adverse aspects of those futures. The latter, of course, is one of the aspects of the use of historical analogies in the global warming issue most fraught with risk. While all the other functions of analogies are directed toward improving our knowledge of a marginally understood climate system in terms of the impacts of feedback mechanisms in global warming projections, the forecasting function for purposes of specific policy action based on a specific analogy remains one of the riskiest applications of analogies (see, for example, Jäger and Barry, 1991). As physical scientists often provide reminders that the output of their models should not be taken as forecasts, social scientists too must remember that the output of the use of their analogies should not be viewed as forecasts, in the strict sense of the word, but as possible guides to action.

The Search for the Perfect Analogy

There is no perfect regional analogy to the global warming expected to occur during the next several decades. Important boundary conditions that affect atmospheric processes, such as the spatial and latitudinal extent of sea ice, the extent of vegetative cover including tropical forests, solar parameters, the earth's orbital characteristics and so forth, are constantly changing. It is necessary to recognize that analogies have different strengths and shortcomings for inquiry about societal capabilities to cope with environmental change. From the standpoint of societal impacts research, one can distinguish between first-, second-, and third-order analogies. Paraphrasing Galloway (1990, 7), one might refer to these as “downstream analogies.” First-order analogies provide direct insights into what we wish to know, such as, for example, a
glimpse of possible societal responses to regional climatic changes. The analogy should provide that glimpse directly. There are second- and third-order analogies as well. These are analogies that are based on the output of a preceding analogy. An example of a third-order analogy is as follows: a GCM-derived regional scenario for a doubled-CO₂ world would be used to identify possible regional climatic changes. Those regional changes are then used to identify ecological impacts analogs, which are in turn used to identify societal impacts analogs. Analogies derived in this fashion are subjected to cascading uncertainties; that is, the accumulation of uncertainty at each link down the chain of events from global and regional climate change to ecological impacts to societal consequences of those ecological impacts (see Kellogg and Schware, 1982).

This should not be taken to mean that analogies have no role to play in the search for how one might be affected by global warming and what one might do about it. Analogies can provide clues, generate ideas, spark reactions that lead to different searches for new analogies. Each analogy provides us with additional information about the target problem, thus fulfilling one of the many functions that an analogy can perform. Even if one does not accept particular analogies to future global warming, critical assessments of them can improve our understanding of the potential regional impacts of global warming. This has especially been the case with regard to the search for historical and geologic climate analogs. If an analog is rejected by some researchers, they will often search for other ways to identify regional impacts. The search for analogs should go on. BUT their outputs should be used with extreme care and should not be viewed as predictions of the future. In addition, scientists must take care in how they present, explain and use their analogs, in order to avoid what Martin (1979) termed "the bias of science."

*Does History Have a Future?*

Whether the global or regional climate ultimately gets warmer, colder or stays within the range of recent historical variability, societies, nations, regions, organizations, and individuals will still have to cope with the impacts of this interannual and interdecadal variability. The use of historical analogies to forecast societal responses to environmental change provides
climate impacts researchers and political and corporate decisionmakers, among others, with a win/win situation. Such studies can, at the least, yield useful information about the coping mechanisms that come into play when societies at the regional level are confronted by climate-related environmental change. The value of such information is not directly dependent on the direction, degree or rate of a climate change. Thus, the use of historical analogies has a future in scientific discourse in general, and more specifically in attempts to gain a glimpse of societies' abilities to cope with yet-unidentifiable environmental changes of the future.

In sum, analogies are an integral part of both physical and social science research with regard to the global warming issue. Almost every aspect of the global warming dialog, from the projection of future production of radiatively active trace gases to the effects of global warming on society, must be explicitly recognized as having been based on analogy. Analogies are useful heuristic devices that can enhance our understanding. Given the current state of uncertainty surrounding the implications for atmospheric processes, the environment, and society of an increased loading of the atmosphere with radiatively active trace gases, it is essential that we examine the analogies we use and favor those that are explicit, formal, and first-order analogies, rather than implicit, casual, second- and third-order analogies.

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