Climate Changes during the Holocene and their Impact on Hydrological Systems

It is now widely accepted that increasing concentrations of greenhouse gases in the atmosphere are affecting the Earth's radiation balance, resulting in higher global atmospheric temperatures. However, there is still a great deal of uncertainty about the likely effects of such a temperature rise on climate, and even more about the impacts of climate change and variability on the world's hydrological regimes and socio-economic systems. Studying the effects of climate variability in the past can give clues regarding possible future effects.

This volume provides a comprehensive review of the effects of climate variability on hydrological and human systems in the Holocene (approximately the last 10,000 years of pre-history and history), in various parts of the world. The book concentrates on the regions bordering the Mediterranean Sea to the east and north, the western and central parts of Europe, China, Japan, west and south Africa and the southwestern USA. The main conclusion is that global warming will bring about a decrease in precipitation in the regions dominated by the westerlies (Mediterranean climates) and an increase in precipitation in the monsoon (sub-tropical and tropical climates) regions.

Climate Changes during the Holocene and their Impact on Hydrological Systems will be of value to researchers and professionals in hydrology, climatology, geology and historical geography.

ARIE S. ISSAR received his M.Sc. and Ph.D. in geology at The Hebrew University of Jerusalem. From 1961 to 1964, he was an advisor to the Government of Iran in the field of groundwater, research and development, under the auspices of the UN Food and Agriculture Organization (FAO). From 1965 to 1974 he was Head of the Hydrogeological Division of the Geological Survey of Israel. In 1975, he founded and later led the Water Resources Research Center of the Jacob Blaustein Institute for Desert Research, and became a Professor of Ben-Gurion University of the Negev, where he was holder of the Alain Poher Chair in the Hydrogeology of Arid Zones. Professor Issar has published over a hundred papers in scientific journals concerning hydrogeology and hydrochemistry of arid zones, the water problems of the Middle East, as well as the impact of climate change on hydrology and socio-economic systems. He has authored or co-authored several books, including:

Groundwater Recharge: A Guide to Understanding and Estimating Natural Recharge (1990; Lerner, D. N., Issar, A. S., Simmers, I. IAH & Verlag Heinz Heise).
Water Shall Flow from the Rock: Hydrogeology and Climate in the Lands of the Bible (1990; Springer-Verlag)
Runoff, Infiltration and Subsurface Flow of Water in Arid and Semi-arid Regions (1996; Edited by A. S. Issar and S. D. Resnick; Kluwer Academic Publishers).
Diachronic Climatic Impacts on Water Resources (1996; edited by A. N. Angelakis and A. S. Issar, NATO ASI Series, Springer-Verlag)
Water, Environment and Society in Times of Climate Change (1998; edited by A. S. Issar and N. Brown; Kluwer Academic Publishers).

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Arie S. Issar

The Hebrew University of Jerusalem

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To Margalit with love

Contents

Figures and tables

FIGURES

TABLES

Preface

There is a general agreement among scientists that the surface temperatures of both oceans and continents are rising. It is also agreed that greenhouse gases like carbon dioxide and methane are increasing in the atmosphere and that this increase is a result of the continuous rise in human industrial and transportation activity, depending on the fossil fuels, i.e., coal and petroleum. There is still an ongoing debate whether all three phenomena are interconnected and whether part of the blame for the warming should be apportioned to natural processes, such as those that caused climate changes before the industrial revolution. The majority of scientists will not contest natural processes as a possible additional factor but will put the main blame on the emission of greenhouse gases, while admitting that there are some questions which still remain to be solved: such as what is the cooling effect of other products of industry emitted into the atmosphere (e.g., smoke and sulfurous particles, which may cause a shading layer with a cooling effect).

One of the most important tools for investigating the reasons for the global change, as well as for predicting future developments, is computerized general climatological models (GCM), which simulate the physical processes taking place in the atmosphere and beyond, and their impact on the temperatures of sea and land. However, as with all computer models, the correct output is a function of correct input, when input in this case involves data as well as procedures. Simulation–calibration runs are essential for testing procedures. The enormous complexity of the climatic events and their scale requires as many simulation runs as possible, all on the basis of enormous amounts of observations. Meteorological observations are limited in both space and time, especially those based on reliable instruments and observers. This is an obstacle in the use of GCMs to simulate already observed scenarios, not to speak of forecasting future ones. Consequently, when one is considering processes that go back into the past beyond the periods for which data exists or over regions where direct past meteorological data are not available, simulation has to rely on proxy-data. These include measurements that provide clues of past impacts of climate changes on the environment, such as deposits of glaciers, imprints of ancient shores of oceans and lakes and the nature of the deposits in aquatic environments. A major advance in reconstructing ancient climates was achieved by the understanding of the impact of atmospheric and oceanic temperatures on the distribution of environmentally stable isotopes such as oxygen-18, hydrogen-2 (deuterium) and carbon-13. This achievement added an additional dimension to the investigation of ice and sea bottom cores as well as to that of tree rings and cave stalagmites.

While the reliability of the predictions of the GCMs is of general global importance, for certain regions it is crucial; these regions are mainly the low-lying coastal plains bordering the oceans and seas because warming will most probably induce the melting of glaciers and cause the rise of sea levels, flooding these regions. Other regions that will be seriously affected occur along the margins of the desert belts of the globe, where climate change may spell the advance or retreat of the desert, with devastating floods or droughts. The latter problem stimulated me, a hydro-geologist involved in the investigation of water resources in arid zones, to extend my field of investigations into the past. While the basic principle of geology, as determined by the founders of this science during the nineteenth century, is that present processes of erosion and deposition are the key for understanding the past, the maxim of the present study was that past climatological and environmental scenarios are the key for forecasting future events. For this purpose, I searched for paleo-hydrological clues to determine whether processes of flooding and desertification in the past were a function of climate changes or human activity. A good example is the desertion of the cities and the agricultural farms that flourished during Nabatean, Roman and Byzantine times in the arid part of the Levant. Most contemporary archaeologists, historians and ecologists maintain that this desertion was for anthropogenic reasons. When this investigation was progressing and the natural cause became more and more convincing, I was invited by the Division of Water Sciences of UNESCO to join the working group set up by this organization in the framework of the International Hydrologic Program (IHP) to evaluate the impact of climate change on the hydrological cycle. The question was whether data on climate changes in the Middle East, and the impact of such changes in the past on the availability of water resources, could be used to assess the impact of future global change. This invitation was accepted, and indeed study of the data available showed that conclusions from the past could be drawn, as will be discussed later on.

The major climate changes during the Holocene that influenced the history of the eastern Mediterranean region were later correlated to proxy-data time series suggested by different investigators for different regions of the globe. Conformities and non-conformities with the Levant base section were investigated in order to find out whether differences result from variations in the interpretation of data or whether they reflect differences in the nature of the impact of climate change. While trying to do this correlation, one had to take into consideration not only the differences in climate between the various regions but also the vulnerability of the ecological and socio-economical systems in the different areas. Systems along the margins of climate belts were more vulnerable to changes than those in the center of such regions. This difference influenced not only the intensity of the change, if it occurred at all, but also the duration of the impact. For example, regions along the margins of deserts, like the Levant, were first to show the impact of climate change, followed by more humid regions, like Europe, and then by the tropical zones. On top of these differences, one had to take into consideration limitations dictated by the nature of the proxy-data. For example, sea-level changes could be interpreted as either tectonic or eustatic, and changes in the palynological assemblages could be interpreted as either anthropogenic or natural. Yet, notwithstanding these limitations, a rather detailed paleo-climatic columnar section for the Holocene developed, which was able to withstand many tests of prediction. One such test was the forcing of monsoons during warm periods, which was found later to be in agreement with the forecasts derived from the GCMs.

When it comes to the impact of human societies on the environment, it appeared in most cases that it was a severe climate change which decided the history of the environment, rather than human faults. Even so, enough blame for destruction of natural bio-systems and environment still rested on human shoulders. On this basis, I cannot advocate the rejuvenation of the classical geographical “deterministic paradigm”, which put all blame on nature and which was endorsed by the geographer Elsworth Huntington and his school during the first few decades of the twentieth century. Rather, I would suggest a neo-deterministic approach, which considers the human socio-economic and the natural systems as interdependent parts in a general system sensitive to climate changes (Issar and Zohar, 2003). These changes and their impacts can be traced using paleo-environmental proxy-data, such as isotopes, sediments and sea and lake levels. Historical records on changes pertaining to the human socio-economic systems can then be correlated and help to draw more objective conclusions regarding the past. This improves our ability to use the events of the past as a tool for predicting the future of the hydrological systems in periods of global change.

In the following chapters, proxy-data of time series are presented using before present (BP) as the age parameter even though for many of the ages the conventional BCE (or BC) and ACE (or AD) would have been more appropriate for correlation with historical periods and events. However, the historical timetable is in the first place confined to a country or a culture, and the accuracy required is in the order of magnitude of decades if not a few years. For achieving this, the historical timetable is based mainly on archaeological data, which in some cases is based on carbon-14 dates, while in others it is based on pottery stratigraphy as well as historical documentation. By comparison, the dates of the various time series presented in the following chapters are based on several different methods, which differ one from the other in their precision. The levels of precision demanded are that of more than a few centuries during the lower half of the Holocene and a century to a few decades during its upper half. Moreover, as this book is attempting to correlate between events that occurred “simultaneously” in different regions placed in different climate belts, the effect of the climate changes on the environmental time series may be different in its initiation, its duration and its impact. Consequently, the time boundaries of “simultaneous” event climate changes are rather blurred and the level of precision provided by the various dating methods used in the numerous investigations cited in this book were found to be sufficient for inter-regional correlation. The reader should thus regard the term BP, unless the method of dating and precision is defined, as indicating “years ago” and rather flexible according to the range on the time dimension: a few centuries either way during the first half of the Holocene, and a few decades during the second half.

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