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The Significance of the Mediterranean Sea to Global Climatology*

Arthur R. Miller

ABSTRACT

Food production is affected by climate and by climate change. The indices for climate change may be recognized in long-term systematic observations of oceanic water columns at selected referential sites. The Mediterranean Sea, as part of the global oceanic circulation system, may be sensitive to climatic variation and may have an influence upon climate. The establishment of international reference stations for the Mediterranean area is suggested.

INTRODUCTION

This paper combines material from three climatological reports of recent origin (Newman and Pickett, 1974; Nierenberg, 1974; A.R. Miller, unpublished) in order to define the probable impact of climatological change upon the Mediterranean environment and the possible influence of the Mediterranean upon climate itself. For this purpose one can draw upon the lead-off statements in the first of these, the Third Annual Report to the President and Congress of the National Advisory Committee on Oceans and Atmosphere (W.A. Nierenberg, Chairman, 1974). The first statement is extremely terse, "Climate changes".

In a closed cycle one can say that "Climate affects Food Production — Food Production affects People — People affect Energy Use — Energy Use affects Climate," Further, emphasis is stressed upon the importance of this cycle by the alarming statement, "We neglect any link in this chain at our peril". This Annual Report goes on to say that "The possibility of inducing global climate

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change is not out of the question". The growing consumption of energy and the absorption of that energy into the upper layers of the oceans is all the more reason why the "ocean-atmosphere link is so important for climate".

Briefly, paraphrasing some elements of the article, the sea's surface receives most of the solar energy because of the vast extent of oceans and seas. The fly-wheel capacity of the ocean to store and give off heat consists of initial absorption in the upper layers where, by transport and convective activity, the effects are carried downward into the deeper layers of the ocean. As a huge reservoir, the ocean can be ignored in the short-term variations of

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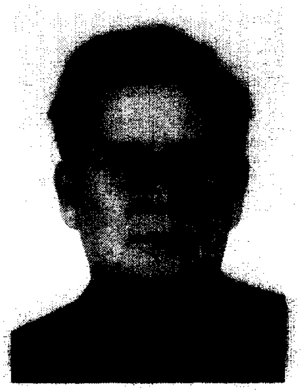

Mr. Arthur R. Miller is Associate Scientist at the Woods Hole Oceanographic Institution, Mass., U.S.A., having begun his career there shortly after World War II. Having no formal training, as a few others at Woods Hole, oceanographic expertise has been gained through long and varied exposures to sea life and research. As a physical oceanographer these exposures have consisted of planning, organizing, fund-seeking, directing, and carrying-out many research cruises, the longest of which was the round-the-world cruise of ATLANTIS II during the International Indian Ocean Expedition and the Cooperative Kuroshio Investigations in 1965. An active participant in the IGY Program and in Mediterranean investigations, he is a firm believer in international collaboration in the Marine Sciences. He has been United States Delegate to many international conferences and workshops and is the ICSEM nominee as Expert for Cooperative Investigations of the Mediterranean Sea. He has participated in Law-of-the-Sea discussions and has acted as consultant to research organizations and industry. Mr. Miller is author and co-author of more than 40 scientific articles. He, along with Dr. A.C. Redfield, was the discoverer of forerunners and resurgences associated with east coast hurricanes. He was instrumental in the discovery of the hot metallurgical brines in the Red Sea and the deep sinking of surface water in the Mediterranean, and is the principal author of a physical oceanographic atlas of the Mediterranean Sea.

weather but cannot be ruled out in year-to-year change where the surface layers are important. The deeper one considers the ocean structure the slower should be the change until time-periods of centuries or longer may be commensurate with very deep water variations. It has been estimated that the heat released through man-made uses of energy amounts to about 0.02% of net solar radiation. Projection of the rate of growth in energy use would increase this proportion to 2% in one century corresponding to a temperature rise of 2.5°F. Climatic change, if not already present, is in the offing. Clearly, the oceans should reflect that change.

CLIMATIC CHANGE AND FOOD PRODUCTION

In a recent issue of *Science*, Newman and Pickett (1974) have compared food supply variations with climates of the world. They have looked into the climatic requirements of staple crop production. In regions with alternate wet and dry seasons, one finds much of the production of staple food grains. These areas have climates where seasonal precipitation and highest solar radiation and temperatures are *in phase*. Marginal areas for cultivation have climatic variations which include drought and short growing seasons. In Mediterranean climates maximum rainfall is in the winter with occasional frosts while maximum radiation and temperatures occur in the summer. This out-of-phase relationship is not conducive to great crop production although there are cool season crops adaptable to Mediterranean climates. Areas well-suited for extensive cultivation have a soil formation rich in plant nutrients with beneficial topographic features produced by a long-term balance between precipitation and temperature. The mid-latitude grassland climates permit extensive staple grain production because of in-phase relationships of solar radiation, temperature, and precipitation. Figure 1, from the Newman and Pickett article, shows the climates of North America, Africa, and Europe in terms of annual precipitations and temperatures.

Newman and Pickett go on to explain that, when more arable land is utilized for extensive crop production, more transitional zones become involved. These are zones where the in-phase relationship is *marginal* and where the ideal balance for extensive staple production is apt to be upset by extreme drought or excessive precipitation. In places where the gradient conditions from humid to arid are steep, as in the case of the northern half of Africa, there is vulnerability to crop failures. This is a situation where annual isotherms and annual isohyets (rainfall) are parallel to each other. The possibility of migration of isopleths sets up a precarious in-phase relationship. On a continental scale, they suggest that, if world climate is changing, a tension zone such as the Sahel area south of the Sahara would give early evidences of change with a shift in the mean isotherm—isohyet pattern.

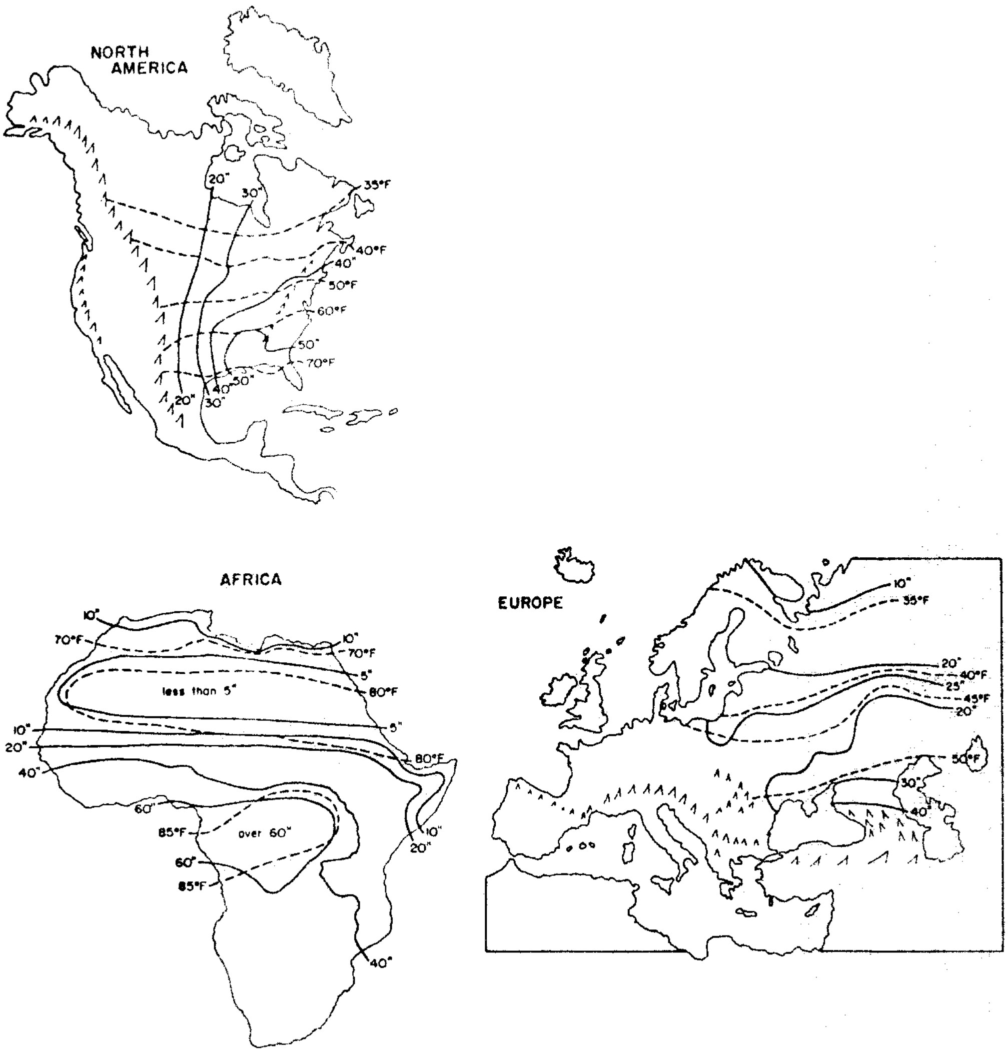

Fig. 1. Climates of North America, Africa, and Europe. Annual precipitation in inches; annual temperature in degrees Fahrenheit. (From Newman and Pickett, 1974)

North Africa has steep latitudinal gradients of humidity to arid conditions associated with the parallelism of the isopleths of temperature and precipitation, but it is not unique in this respect. Annual isotherms and isohyets are more or less parallel in most of continental Europe and northern Asia, though the areal gradients may not be as steep or as well-defined as those of North Africa. In contrast, the isotherms and isohyets of North and South America are normal to each other, particularly in the grassland regions of the mid-continents. (Note: Various climatic charts depicting temperature and rainfall

TABLE I

Date compilation for world wheat exchange (million metric tons)

Region	1934—38	1948—52	1960	1966	1973 (prel.) (fiscal yr.)
North America	+5	+23	+39	+59	+88
Latin America	+9	+1	0	+5	-4
Western Europe	-24	-22	-25	-27	-21
Eastern Europe and U.S.S.R.	+5	—	0	-4	-27
Africa	+1	0	-2	-7	-4
Asia	+2	-6	-17	-34	-39
Australia	+3	+3	+6	+8	+7
Cumulative exports	+24	+27	+45	+72	+95

Note: +, net exports; —, net imports.
Source: Lester Brown (March, 1974).

conditions or other associated material appear to substantiate the continental differences as stressed by Newman and Pickett.) The authors point out that the wind systems, influenced in part by the major mountain ranges, transport moist tropical air deep into mid-continental regions. Orientations of mountain ranges in Eur-Asia do not provide the great barrier to normal westerly airflow as in the Americas and, consequently, the annual isotherms and isohyets remain parallel through the vast interior of the Eur-Asian continental mass. Climatic risk is great in the Old World continents because of the north-south transitional gradients. Because the annual isotherms and isohyets are *not* parallel in the New World, a favorable water balance extends over very broad areas in the north-south direction giving a distinct climatic advantage to the New World in terms of agricultural production. Table I, from a draft statement of the IFIAS Workshop on Impact of Climate Change Bonn, 1974, gives an estimate of world grain trade. Only North America and Australia are net grain exporters as of 1973. However, grain exports from North America in the mid-30's were minimal, possibly relating to the "dust-bowl" conditions of those times.

ATMOSPHERIC EXCHANGE PROCESSES IN CLIMATIC CHANGE

In the consideration of the climatological factors affecting the general disposition of isothems and isohyets, the exchange processes over oceans and seas loom very large among the causes for climatic change, particularly mediterranean seas. The Mediterranean Sea, together with the Black Sea and the Red Sea, lies between the major continental masses of the Old World. As a broad area with considerable importance with respect to the transfer or storage of moisture and heat, it deserves to be taken into account in terms of climatic risk to the north—south transitional temperature—moisture gradients of the continents. The third paper, by the present author, was prepared for the IFIAS Workshop Conference in Bonn, West Germany on the Impact of Climate Change. It was not published and, therefore, is not cited but its content follows in the succeeding remarks.

THE OCEANS AS A NATURAL REACTOR TO CLIMATE

If one defines climatology as the science pertaining to the study of average conditions of weather over long periods of time, the recognition of climatological change requires intentional systematic observation over long periods and the detection and identification of natural reactors to climate. One reactor is the ocean, with prime examples in the heat-storage sinks of the polar seas in which the process of storage and integration of temperatures are carried out. Although less familiar as a storage phenomenon, the Mediterranean Sea is also a heat sink, lying in a temperate location astride familiar general circulation patterns. The storage of heat is brought about through westward flow, into the Atlantic Ocean, over the Gibraltar Sill, where Mediterranean water with greater than normal heat and salt content sinks to great depths (Wüst, 1950). The westward flow is comparable in volume transport to the eastward flow immediately above, carrying surface Atlantic water into the Mediterranean area. Temperature and moisture balances are maintained by way of influence over the Eurasian and African climate (Bunker, 1972).

In a neighboring pattern of oceanic influence the Indian Ocean takes part in the monsoon system of the Indian sub-continent with a great transfer of moisture (Bunker and Chaffee, 1969) induced by dry winds passing over a stirred-up sea surface (Düing, 1970). Hurricanes, further to the south and east, dramatically transfer heat, moisture, and energy from one place to another. Oceanic influence on climate has many forms. The Mediterranean Sea is an area of cyclogenesis and serves as a weather breeder. It is an evaporating basin. It also serves as a collecting area for the land drainage of the European continent and part of Africa. The latitudinal extent of this drainage is vast, extending from the Equator to about 60° North. Yet, none of the *fresh* water draining into the Black Sea or Mediterranean Sea basins is carried westward into the Atlantic Ocean. It is removed by evaporation and carried aloft to be re-cycled or transported away from the drainage area. In-flowing North Atlantic water gives evidence of additional evaporation in the increase of salt concentration from 36.45% to 38.45% (Miller, 1975). Perhaps climatic stability can be assumed for the present as long as the salt concentration of the Mediterranean remains constant. However, that assumption has a temporary connotation. The geological history of Mediterranean sea water demonstrates a gamut of past conditions from the complete drying up forming salt

Fig. 2. Annual salinity maxima in Middle Adriatic — full line. Dashed line represents superposition of ice quantity about Iceland and pressure differences between Athens and Trieste. (From Zore-Armanda, 1972)

beds (Nesteroff et al., 1972) to fresh-water concentrations (Huang and Stanley, 1972).

There is the possibility that the Mediterranean Sea is an integrator of climatological changes affecting the North Atlantic Ocean. Since its supply of sea water comes exclusively from the surface waters of the Atlantic, the entire Mediterranean water column should be responsive to changes within those surface waters. With a turnover rate of 80—100 years (Lacombe and Tchernia, 1972), change on a climatological scale may be amenable to observation and detection if the seasonal noise of the local environment can be screened out (Miller, 1972). As an example, Fig. 2 shows that over twenty years of systematic sampling in the Adriatic Sea have demonstrated a good correlation between the salinity variations of the Adriatic and the size of the sea-ice population about Greenland (Zore-Armanda, 1972).

EFFECTS OF THE MEDITERRANEAN ON DEEP NORTH ATLANTIC WATER

The Mediterranean Sea, in turn, affects the deep North Atlantic Ocean. Counterbalancing the inflow of surface Atlantic water, the high salinity product of the Mediterranean pours westward over the Gibraltar Sill and spreads deeply across the Atlantic towards the North American continent (Worthington and Wright, 1970). The mixing process, taking place when salty warm Mediterranean water meets cold Atlantic water, is so sensitive that the effects of the rise and fall of tide in the Bay of Cadiz can be detected in the products of mixing. This has been the interpretation for the two deep salinity maxima found in the water column off Cadiz (Siedler, 1968). A bi-modal high-salinity distribution associated with Mediterranean water has been detected by sensitive instruments and has been observed recently in the MODE experiments off southeastern United States (Zenk, 1973).

While deep water of the Mediterranean Sea might be affected by recent climatological events, the deep water of the Atlantic itself may not be completely isolated from those same recent events, whatever they may be. A long-term series of deep observations has been conducted off Bermuda for over a period of eighteen years. An example of these are shown as anomalies from the mean in Fig. 3. These observations have been critically analyzed by Miss Elizabeth Schroeder of Woods Hole Oceanographic Institution who has noted that, at 1000 meters and above, the water has become cooler and fresher (pers. comm.). These changes, while not smooth, culminate with 1970 as a turning-point year. Other standard properties such as dissolved oxygen content have corresponding turning-points. The ocean's effect on climate has been demonstrated by Namias (1969, 1972), who has shown that cooling of the ocean surface forecasts short-term changes in barometric pressures. Meteorological changes noted in 1972 and 1973, for example, and the increase in reported surface ice reflection (Kukla and Kukla, 1974) for which see Fig. 4, may have been presaged by the Bermuda observations of 1970.

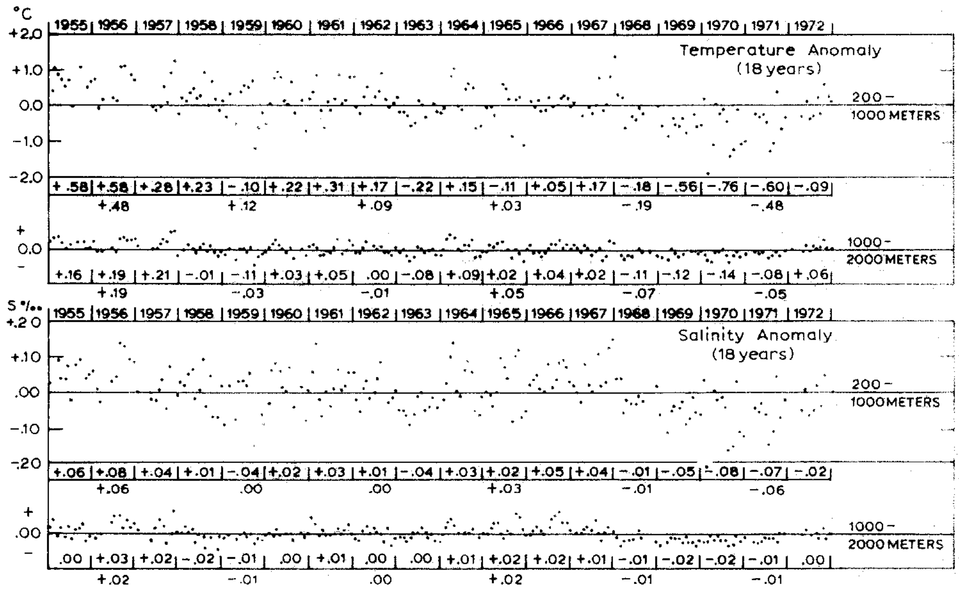

Fig. 3. Eighteen-year temperature and salinity anomalies from data taken off Bermuda, 1955–1972. (Courtesy of E. Schroeder, WHOI). Numbers refer to yearly and three-yearly departures from the mean.

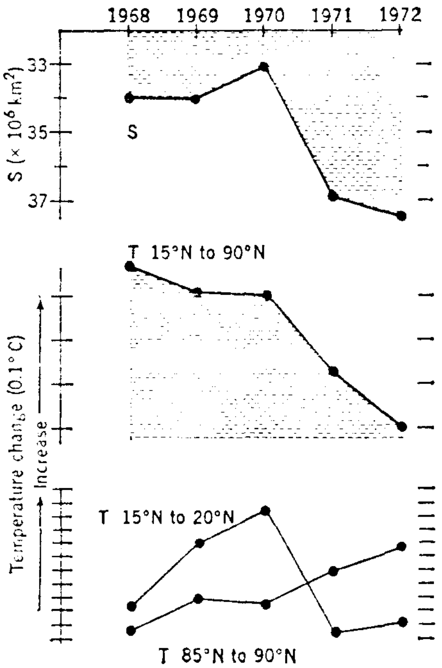

Fig. 4. Annual mean snow and ice cover, (S); relative mean atmospheric temperature, (T); 500—1000 mbars. (From Kukla and Kukla, 1974).

A PLEA FOR LONG-TERM SERIES OF OBSERVATIONS

A system of long-term series of observations deserves to be set up and maintained in the Mediterranean Sea. The systematic collection of material at selected reference stations could be aided by the inclusion of these referential points within research programs of various vessels and institutions. More long-term programs, similar to the Bermuda series, need to be carried out if the identification of climatic changes by such means is attainable. There are practical difficulties, however. The nature of a long-term observational program requires dogged faith and persistence. It is vulnerable to boredom and expense. However, if established reference stations are recognized as indices for manifold purposes their justifications need not be difficult.

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