The Atmosphere and Climatology

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The climate is not a fixed component in the physical environment. When the reconstructed history of the earth's physical environment is examined, climatic fluctuation is the norm rather than the exception.

Recently, there has been an upsurge of interest in climate change on all scales from local to global. Bryson (1974) argues that the main reasons for this are the increased awareness about the impact of man's activities on the climate, and the concern about the impact of climate on food production. An example of recent climatic change which has caused widespread social dislocation is the persistent drought and the resulting famine in Sahelia for the past seven years. Also, for the past several years western North America has experienced unusually cold winters, and eastern North America unusually mild winters. The increased interest in climatic changes is also evident from the press, and from the marked increase in the number of publications in the scientific literature over the past five years.

Historical Perspective

The history of the climate of the earth extends over several billion years. Fluctuations of the climate have been identified at time scales ranging from 10^9 years, to interdecadal variation and inter-annual variation (Figure 1). The first 90% of the climatic record is very fragmentary. The most recent 10% is much better documented. There are a variety of data sources for reconstructing past climates. Some of these are as follows:

(i) ocean bottom sediment cores
(ii) ice cores from the permanent ice fields
(iii) tree rings
(iv) pollen assemblages from peak bogs
(v) fossilized animal remains
(vi) remains of human cultures
(vii) physical features of the landscape
(viii) instrumental records and written descriptions.

During the last million years continental ice sheets have advanced and contracted at least seven times. The glacial- interglacial sequence extended over a period of 70,000 to 120,000 years, whereas the interglacial periods have been relatively short at about 10,000 years. Since our present interglacial period has lasted about 10,000 years the interesting questions arises, "Are we entering another ice age?"

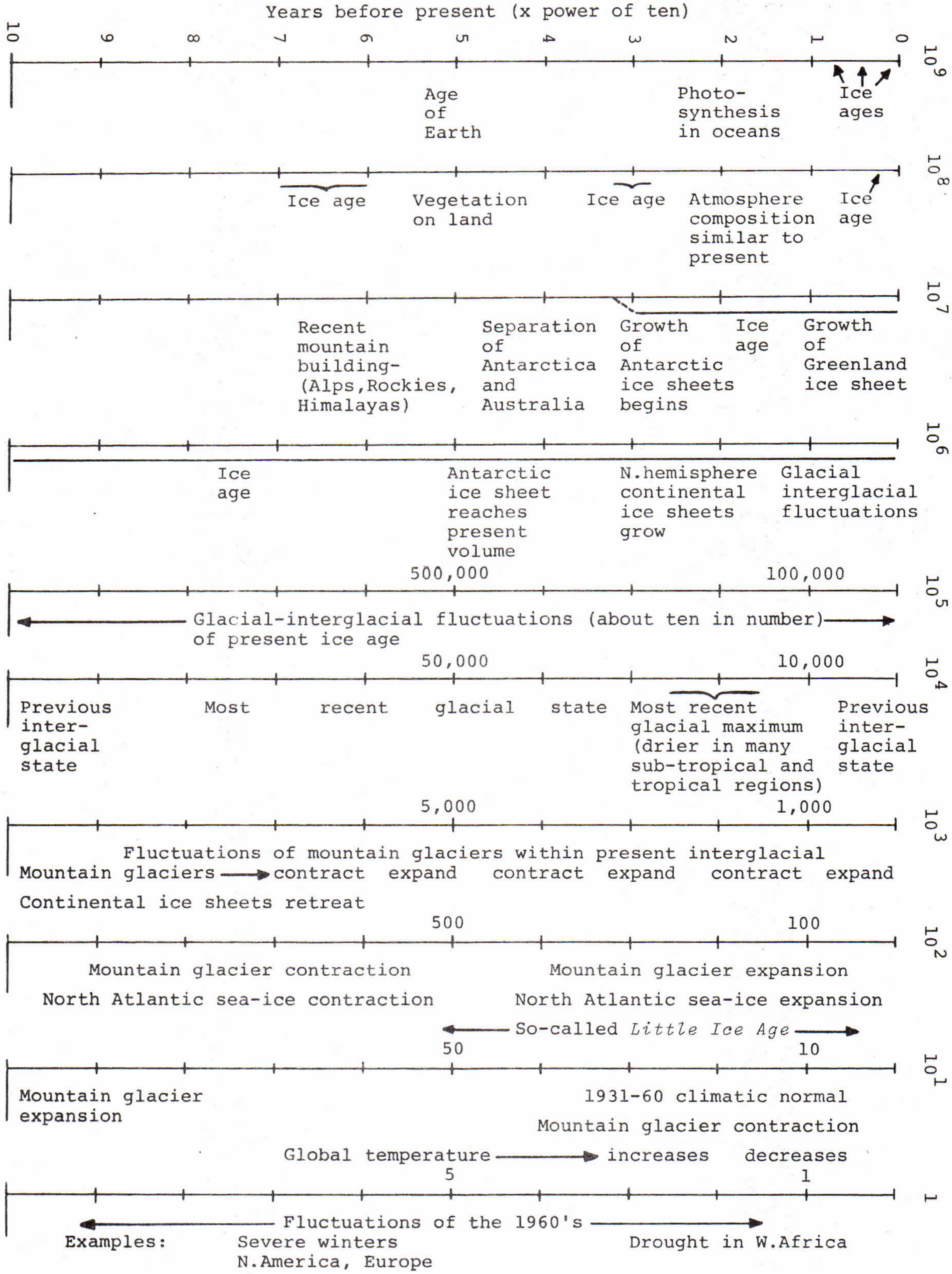
During the last 1000 years there are well documented cycles of climatic fluctuation. From 1000 AD to 1500 AD there was a period of glacier recession, and a general warming in the nothern hemisphere. However, from 1500 AD to 1900 AD was a period of glacier expansion which has been labelled, The Little Ice Age. More recently, the recorded data for the last century clearly show an increase in mean annual world temperature until about 1940 which was then followed by a cooling trend extending to the present day (Mitchell 1963). This pattern is most strongly exhibited in the mid-latitudes of the northern hemisphere.

However, in this period there were many examples of years cooler than the previous one. There was as much variation in the mean annual temperature between decades as there was a change in the average. From 1840 to 1940 the mean annual world temperature rose by 1.7^0C, but the variation from decade to decade was as large.

Causes of Climatic Changes

There are many extra-terrestrial and terrestrial processes hypothesized as causes of the climatic changes (See Figure 2). These processes operate over different time scales and certain of them may act simultaneously, or in various sequences. True equilibrium states may not exist and the climate system may be in a continuous state of adjustment. Unfortunately, such a conclusion must await a complete understanding of the behaviour of the system, and all the possible feedback loops. This emphasizes the urgent need for studies relating to the physical basis of climate and climate variability.

The most recent studies of this nature have attempted to identify and quantify the causes of recent climate change, and the results so far are encouraging. If a constant lithosphere can be assumed the main



<u>FIGURE 1.</u> Examples of climatic fluctuations at time-scales ranging from 10^9 to 1 years. Each successive column, from left to right, is an expanded version (expanded by a factor of ten) of one-tenth of the previous column.

(from Kutzbach, 1974)

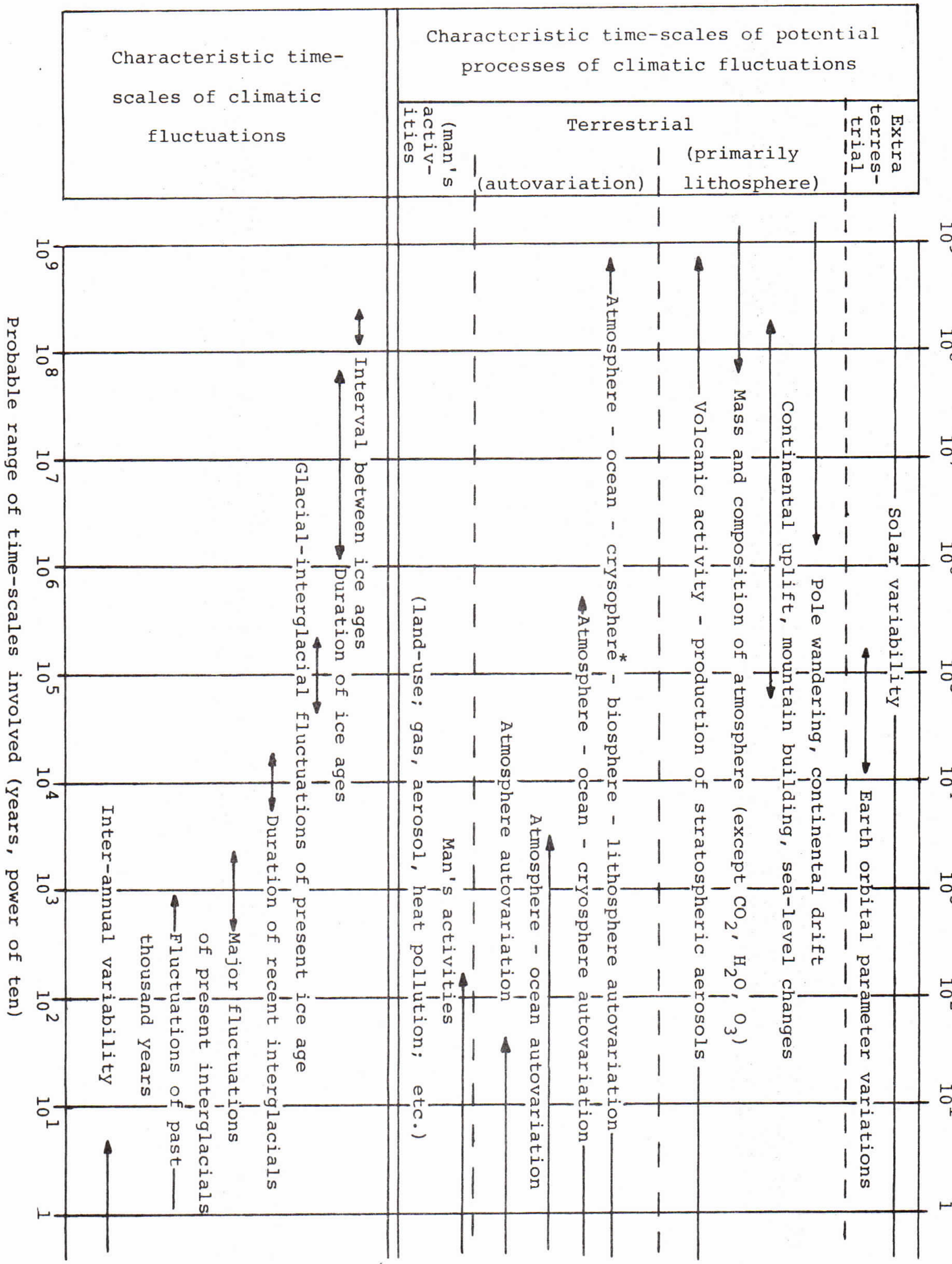


FIGURE 2. Examples of potential processes involved in climatic fluctuations (*top*) and characteristic time-scales of observed climatic fluctuations (*bottom*). Revised and adapted from Mitchell (1965, 1968)

(from Kulzbach, 1974)

* snow cover, sea ice, continental ice sheets.

variables which could affect the climate are:

(i) the intensity of sunlight reaching the earth

(ii) the transmittance of the atmosphere as mofidified by processes extrinsic to the atmosphere

(iii) the atmosphere control of upward terrestrial radiation as modified by gases and particulates extrinsic to the atmosphere, and

(iv) the albedo (reflectivity) of the earth/atmosphere system .

Each of these will be examined but in order to put the discussion in context it is important to know how large a climatic change must be in order to be significant. In terms of temperature, the data suggests there has been a change of about 4°C to 6°C in the mean global surface temperature from full glacial period to the present. In high latitudes a change of 10°C is indicated and in the tropics, a change of a few degrees celsius. Wahl and Lawson (1970) have documented precipitation changes from 1850 to 1870 and compared these to the modern normal period (1930 - 60). They conclude that in the western United States the plains were 20% wetter for the whole year, and 20 to 30% wetter in summer in the earlier period. This area supported vast herds of bison in the earlier period, but it is now semiarid in terms of carrying capacity for cattle. If the carrying capacity of this area for cattle is proportional to that for bison then a return to the previous condition would result in a significant increase in food production. These changes in precipitation are small compared to intermillenial changes of the holocene and it illustrates the fact that a climatic change need not be very large to have a significant effect upon living systems. Further, only small changes in the causal factors are needed to cause significant climatic change. Reitan (1971) estimated that a change of incoming solar radiation of only 2 cal cm^{-2} day^{-1} would explain the temperature changes for the past century. A brief discussion of the factors affecting the solar radiation the earth receives would therefore seem to be appropriate.

<u>Changes in the Solar Constant</u>

There is no conclusive evidence that the solar constant changes on the scale of decades to millenia. Therefore in terms of short term fluctuation in climate the changing solar input hypothesis contributes little to our understanding.

Atmospheric Transmittance

The transmittance of the atmosphere is a critical parameter since the climate is primarily determined by the temporal and spatial energy distribution at the surface. There are several extrinsic sources of particulates and aerosols which can change the transmittance of the atmosphere. These include volcanic eruptions, burning of fossil fuel, increased soil disturbance by man, forest fires and slash and burn agriculture in the tropics. Historically volcanic activity has been the most important source of particulate matter. Hamilton and Seliga (1972) show that the temperature of the Greenland and Antarctic ice sheets, for the last one hundred millenia, have been inversely proportional to the volcanic dust fall on the ice sheets. Measured transmittance in this century show the highest values in the 1920's and 30's when volcanic activity was at a relative minimum level (Budyko 1969). Volcanic activity increased again in the 1950's and 60's but the temperature began to decrease in the 1940's. Some other source of particulates is therefore suggested. Bryson (1974) argues for increased particulates loading in the atmosphere from the activities of man, starting in the 1930's with the dust bowl in the United States, and continuing with increased soil disturbance through the mechanization of agriculture and increased population pressure particularly in the subtropics and middle latitudes. He also shows, through calculations of particulate emission rates and residence times, that both volcanoes and man-related activities are adequate to explain the hemispheric cooling of $0.4^{\circ}C$ since 1940.

Recently it has been pointed out by a spate of articles that the atmospheric transmittance of ultraviolet radiation may be significantly increased due to a deterioration of the ozone layer by Freons. The possible consequences could be severe climatic change due to changes in the thermal structure of the ozonosphere, and biological changes due to the introduction into the biosphere of ultraviolet radiation heretofor totally excluded. In order to assess the importance of the possible destruction of the ozone screen some basic facts must be reviewed regarding the interaction of ultraviolet radiation, ozone and Freon.

At the surface to the earth, ultraviolet radiation is restricted to the span 2870 Å to 4000 Å. This represents about two-thirds the ultraviolet emitted by the sun. The remainder is absorbed by ozone (2000 Å to 3100 Å), and by oxygen (2450 Å downwards). Ozone (O_3) is concentrated in the ozonosphere between 10 and 50 km altitude. It is generated by the dissociation of normal molecular oxygen (O_2), through the absorption of ultraviolet radiation, into two oxygen atoms which in turn combine with O_2 to yield O_3. In the upper atmosphere an equilibrium exists between O_3 and O_2, and an effective ultraviolet screen exists up to about 3100 Å.

Freon is a trade name given to a group of synthetic organic compounds containing the elements chlorine, flourine and carbon. They are chemically and thermally stable with high density, low boiling point, low viscosity and low surface tension. They are used primarily as refrigerants and propellants in aerosol sprays. The two most commmon Freons are trichlorofluoromethane ($CFCl_3$) and dichloro-difluoromethane (CF_2Cl_2), or Freon 11 and Freon 12. These chemicals are not very soluble in water, and therefore, are not removed from the troposphere by rain. The few measurements that have been made indicate that nearly all of the Freons released into the troposphere have remained there. As yet there is no clear evidence of a natural sink for Freons.

Between 1960 and 1972 the production of Freons 11 and 12 increased annually by 22%. In 1972 the total production was 500,000 metric tons of which 400,000 tons were in the U.S.A. A 10% annual growth rate is a reasonable projection for the future.

Freon released at the surface finally diffuses into the stratosphere where they are photo-dissociated by ultraviolet radiation (1750 Å to 2200 Å), and free Cl atoms are released. It is known from laboratory tests that free chlorine breaks down ozone, and therefore, the O_3/O_2 balance in the ozonosphere is upset. The predictions regarding how the free chlorine will upset the ozone balance are ominous, and come from models proposed by Molina and Rowland (1974) and Cicerone et al (1974). The former concluded that there will be a 10% decrease in the O_3 content of the stratosphere within 50 to 80 years, and the latter, a similar decrease by 1985 to 1990. Also, due to the long residence time of Freons in the troposphere, and the delay time required for them to filter into the stratosphere, even if man ceased his production today the destruction of ozone would peak in 1990, and remain significant for several decades.

It must be remembered that the models do not claim to predict exactly what will happen. They are after all only models built on various assumptions. They have pointed out that there are significant gaps in our knowledge regarding the ozone layer. Recently, there has been a significant increase in the research being conducted on the problem. Also, the rather neglected field of atmospheric chemistry will probably expand greatly in the next decade.

Albedo Changes

The changing of the albedo of the earth by extrinsic factors appears to be of minor importance as a cause of climatic change. Man can change the surface albedo by changing the nature of the surface e.g., natural surfaces changed to agricultural crops and cities. Approximately 5% of the albedo of the earth is contributed by the earth's surface, of which 30% is land with 12% of this devoted to agricultural or urban use. A reasonable change in albedo due to changed land use is 15%. Thus, if a rate of change is estimated at 5% per decade then .05 x .30 x .12 x .15 x .05 or 1.35×10^{-5} is the change of albedo per decade. Manabe and Wetherald (1967) show this would change the mean surface temperature $0.001^{o}C$ per decade and this effect appears insignificant. However, snow cover changes can change the albedo and the surface heat balance very significantly but changes in snow cover occur in response to the climatic changes and is not an extrinsic factor for change.

In 1971 the mean annual snow and ice cover in the northern hemisphere increased by about 12% from 32.9×10^6 to 36.9×10^6 km^2 (Kukla and Kukla 1974). It fluctuated around the latter value up to the end of 1973. However, the most recent data indicate that the expansion of the snow and ice cover may have reversed in 1974 (Thompson 1975).

Atmospheric Control of Terrestrial Radiation

A change in the composition of the atmosphere can change the distribution of temperature within the atmosphere. This can lead to changes in the static stability of the atmosphere which in turn can lead to changes in the general circulation and significant shifts in the distribution of rainfall. The most important extrinsic variable in changing the composition of the atmosphere in this respect is carbon dioxide. Manabe and Wetherald (1967) estimate that the global mean surface temperature rises 0.01°C per p.p.m. increases in CO_2. Currently, the atmospheric concentration of CO_2 is 320 p.p.m. and is increasing by 1 p.p.m. per year, and the present figure in the last century has increased from 292 p.p.m. As a single reason this does not explain the behaviour of global mean temperature over this period. However, CO_2 is concentrated in the troposphere and is non-existant above an altitude of 11 Km. The documented change in CO_2 will change the lapse rate about 0.001°C Km^{-1} p.p.m.$^{-1}$

The latitude of the subtropical anticyclone depends upon the vertical lapse rate, and the horizontal temperature gradient. Bryson (1974) shows that, given an increase of 0.1°C in surface temperature due to changing CO_2 between 1957 and 1967, and an increase of 0.05°C per 1000 Km in the north-south temperature gradient would give a decrease of precipitation of 86 mm annually in the Sahel of West Africa. The actual decrease, averaged over five Sahelian stations, was 96 mm in this period

Conclusion

The climate of the earth has changed significantly through geologic times and at present there is an increasing concern about climate change as it relates to food production and other environmental concerns. In terms of change in the causal parameters it does not take drastic changes to cause significant changes in the climate. Climatic patterns appear fragile in many parts of the world, and small changes in climate can lead to disastrous consequences in the existing social and economic structure.

References

Basuk, J., 1975: Freons and ozone in the stratosphere. Bull. Amer. Meteorol. Soc., 56, 6, 589-592.

Bryson, R.A., Science, 184, 4138, 753 (1974).

Budyko, M.I., Tellus, 21, 611 (1969).

Cicerone, R.J., R.S. Stolarski, and S. Walters, 1974: Stratospheric ozone destruction by man made chlorofluoromethanes. Science, 185, 1165-1166.

Hamilton, W.L., and T.A. Seliga, Nature (Land), 235, 320 (1972).

Kukla, G.J., and H.J. Kukla, Science, 183, 4126, 709 (1974).

Kutzbach, J., W.M.O. Bulletin, XXIII, 3, 155 (1974).

Manabe, S., and R.T. Wetherald, J. Atmos. Science, 24, 241 (1967).

Molina, M.J., and R.S. Rowland, 1974: Stratospheric sink for chlorofluoromethanes: Chlorine atom - catalysed destruction of ozone. Nature, 249, 810-812.

Mitchell, J.M., Jr., p.161; in Changes of Climate (Arid Zone Research 20, Unesco Paris, 1963).

Thompson, L.M., 1975: Weather variability, climatic change, and grain production. Science, 188, 535-541.

Wahl, E.W., and T.L. Lawson, Mon. Weather Review, 98, 259 (1970).