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A Study of Climatological Research as it Pertains to Intelligence Problems

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August 1974

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SUMMARY

The western world's leading climatologists have confirmed recent reports of a detrimental global climatic change. The stability of most nations is based upon a dependable source of food, but this stability will not be possible under the new climatic era. A forecast by the University of Wisconsin projects that the earth's climate is returning to that of the neo-boreal era (1600-1850)—an era of drought, famine, and political unrest in the western world.

A responsibility of the Intelligence Community is to assess a nation's capability and stability under varying internal or external pressures. The assessments normally include an analysis of the country's social, economic, political, and military sectors. The implied economic and political intelligence issues resulting from climatic change range far beyond the traditional concept of intelligence. The analysis of these issues is based upon two key questions:

- Can the Agency depend on climatology as a science to accurately project the future?

- What knowledge and understanding is available about world food production and can the consequences of a large climatic change be assessed?

Climate has not been a prime consideration of intelligence analysis because, until recently, it has not caused any significant perturbations to the status of major nations. This is so because during 50 of the last 60 years the Earth has, on the average, enjoyed the best agricultural climate since the eleventh century. An early twentieth century world food surplus hindered U.S. efforts to maintain and equalize farm production and incomes. Climate and its affect on world food production was considered to be only a minor factor not worth consideration in the complicated equation of country assessment. Food production, to meet the growing demands of a geometrically expanding world population, was always considered to be a question of matching technology and science to the problem.

The world is returning to the type of climate which has existed over the last 400 years. That is, the abnormal climate of agricultural-optimum is being replaced by a normal climate of the neo-boreal era.

The climate change began in 1960, but no one including the climatologists recognized it. Crop failures in the Soviet Union and India during the first part of the sixties

were attributed to the natural fluctuation of the weather. India was supported by massive U.S. grain shipments that fed over 100 million people. To eat, the Soviets slaughtered their livestock, and Premier Nikita Khrushchev was quietly deposed.

Populations and the cost per hectare for technological investment grew exponentially. The world quietly ignored the warning provided by the 1964 crop failure and raced to keep ahead of a growing world population through massive investments in energy, technology, and biology. During the remainder of the 1960s, the climate change remained hidden in those back washes of the world where death through starvation and disease were already a common occurrence. The six West African countries south of the Sahara, known as the Sahel, including Mauretania, Senegal, Mali, Upper Volta, Niger, and Chad, became the first victims of the climate change. The failure of the African monsoon beginning in 1968 has driven these countries to the edge of economic and political ruin. They are now effectively wards of the United Nations and depend upon the United States for a majority of their food supply.

Later, in the 1970s one nation after another experienced the impact of the climatic change. The headlines from around the world told a story still not fully understood or one we don't want to face, such as:

- Burma (March 1973)–little rice for export due to drought
- North Korea (March 1973)–record high grain import reflected poor 1972 harvest
- Costa Rica and Honduras (1973)–worst drought in 50 years
- United States (April 1973)–"flood of the century along the Great Lakes"
- Japan (1973)–cold spell seriously damaged crops
- Pakistan (March 1973)–Islam planned import of U.S. grain to off-set crop failure due to drought
- Pakistan (August 1973)–worst flood in 20 years affected 2.8 million acres
- North Vietnam (September 1973)–important crop damaged by heavy rains
- Manila (March 1974)–millions in Asia face critical rice shortage
- Ecuador (April 1974)–shortage of rice reaching crisis proportion; political repercussions could threaten its stability

- USSR (June 1974)—poor weather threatens to reduce grain yields in the USSR
- China (June 1974)—droughts and floods
- India (June 1974)—monsoons late
- United States (July 1974)—heavy rain and droughts cause record loss to potential bumper crop.

During the last year every prominent country has launched a major new climatic forecasting program.

- USSR reorganized their climatic forecasting groups and replaced the head of the Hydrometeorological Service.
- Japan is planning to launch a major earth synchronous (U.S. manufactured) meterological satellite and has secured complete collection, processing, and analysis systems from the U.S.
- China has made m; ,or purchases of meteorological collection and analysis equipment from western industrial sources.
- India is studying the application of climatic modification to secure a more homogeneous distribution of moisture from an erratic drought/flood monsoon.
- The U.S. National Academy of Sciences is preparing its recommendation for a National Climatic Research Program.
- The National Science Foundation (NSF) and the National Oceanographic and Atmospheric Agency (NOAA) have developed a National Climate Plan which will be presented to the Office of Mangement and Budget (OMB) for funding in FY 76.

Climate is now a critical factor. The politics of food will become the central issue of every government. On July 19, 1974, the Kiev Domestic Service reported massive rains and quoted an old proverb from Lvov Oblast, "The rains come not on the day for which we pray but only when we are making hay." The climate of the neo-boreal time period has arrived.

WHAT ARE THE INTELLIGENCE ISSUES?

In 1972 the Intelligence Community was faced with two issues concerning climatology:

- No methodologies available to alert policymakers of adverse climatic change
- No tools to assess the economic and political impact of such a change.

In that year the Soviet Union lost a significant portion of its winter wheat crop when the snows failed to provide adequate cover and a sharp freeze destroyed the exposed vegetation. The summer moisture that normally is carried by the westerlies did not arrive in the Ukraine or the northern Oblasts (politcial-economic districts) of the Soviet Union. Hence, the wheat harvest was delayed, and a significant portion of the ripened crop found itself blanketed by the winter snow. The rest is economic history.

Since 1972, the grain crisis has intensified. Each year the world consumes approximately 1.2 billion metric tons. Since 1969 the storage of grain has decreased from 600 million metric tons to less than 100 million metric tons–a 30-day world supply.

With global climatic-induced agricultural failures of the early 1970s, the stability of many governments has been seriously threatened. Many governments have gone to great lengths to hide their agricultural predicaments from other countries as well as from their own people. It has become increasingly imperative to determine whether 1972 was an isolated event or–as the climatologists predicted–a major shift in the world's climate.

The economic and political impact of a major climatic shift is almost beyond comprehension. Any nation with scientific knowledge of the atmospheric sciences will challenge this natural climatic change. The potential for international conflict due to controlled climate modification can be a reality in the 1970s. History has demonstrated that people and governments with nothing to lose have traditionally shown little regard for treaties and international conventions. Thus, any country could pursue a climate modification course highly detrimental to adjacent nations in order to ensure its own economic, political, or social survival.

In November of 1974 the United States will be participating in the World Food Conference in Rome, Italy. Some major issues of this conference will be the ability of the world to feed itself; how shortages will be met; and who will provide the needed food.

Timely forecasting of climate and its impact on any nation is vital to the planning and execution of U.S. policy on social, economic, and political issues. The new climatic era brings a promise of famine and starvation to many areas of the world. The resultant unrest caused by the mass movement of peoples across borders as well as the attendant intelligence questions cannot be met with existing analytical tools. In addition, the Agency will be faced with tracing and anticipating climate modification undertaken by a country to relieve its own situation at the detriment of the United States. The implication of such a modification must be carefully assessed.

CLIMATIC PHENOMENA AND THE STATE OF THE ART

Since the late 1960s, a number of foreboding climatic predictions has appeared in various climatic, meterological, and geological periodicals, consistently following one of two themes.

- A global climatic change was underway
- This climatic change would create worldwide agriculture failures in the 1970s.

Most meteorologists argued that they could not find any justification for these predictions. The climatologists who argued for the proposition could not provide definitive causal explanations for their hypothesis.

Early in the 1970s a series of adverse climatic anomalies occurred:

- The world's snow and ice cover had increased by at least 10 to 15 percent.
- In the eastern Canadian area of the Arctic Greenland, below normal temperatures were recorded for 19 consecutive months. Nothing like this had happened in the last 100 years.
- The Moscow region suffered its worst drought in three to five hundred years.
- Drought occurred in Central America, the sub-Sahara, South Asia, China, and Australia.
- Massive floods took place in the midwestern United States.

Within a single year, adversity had visited almost every nation on the globe.

The archaeologists and the climatologists document a rather grim history of the cultural pressures instigated by changes in climatic regime. Recently, some archaeologists and historians have been revising old theories about the fall of numerous elaborate and powerful civilizations of the past, such as the Indus, the Hittites, the Mycenaean, and the Mali empire of Africa. There is considerable evidence that these empires may have been undone not by barbarian invaders but by climatic change. Bryn Mawr archaeologist, Rhys Carpenter, has tied several of these declines to specific global cool periods, major and minor, that affected the global atmospheric circulation and brought wave upon wave of drought to formerly rich agricultural lands.

Refugees from these collapsing civilizations were often able to migrate to better lands. Reid Bryson, of the University of Wisconsin's Institute for Environmental Studies, speculates that a new rainfall pattern might actually revive agriculture in some once-flourishing regions such as the northern Sahara and the Iranian plateau where Darius' armies fed. This would be of little comfort, however, to people afflicted by the southward encroachment of the Sahara. The world is too densely populated and politically divided to accommodate mass migrations.

Yet to understand the results of climatic change, we must know something of the basics of climatology and the people associated with this science.

The State of the Art of Climatology

The climate of a region on the Earth is said to be represented by a statistical collection of its weather conditions during a specified time interval. This interval is usually at least two or three decades; for the Agency's purposes, we will be dealing with months and years. Climatology, as derived from the Greek word *clima* meaning inclination of the sun's rays, reflects the importance attributed by the early students of climatology to the influence of the sun. For some unknown reason, this importance was virtually ignored by climatologists until a decade ago.

The keys to understanding climatology are:

- The acceptance of the principal that nature abhors a heterogeneous *distribution of energy*.
- *Energy reaching the Earth* is modulated by variations in the Earth's orbit, the inclination of the Earth's axis while in orbit, the materials in the Earth's atmosphere (dust, moisture, etc.), and energy fluctuations in the sun itself.
- The *Earth's atmosphere* absorbs only a small percentage of the energy coming directly from the sun.

Thermal Distribution of Energy

Parameters such as temperature, rainfall, and wind velocity can be directly related to the heterogeneous distribution of thermal energy on the surface of the Earth. They are the physical manifestations of a global system which attempts to attain a thermal equilibrium through the interchange of potential and kinetic energy between the atmosphere and the oceans.

Energy Reaching the Earth

There are two major reasons for the heterogeneous distribution of energy on the surface of the Earth:

- Cloud formations
- Surface albedo–ratio of energy reflected to energy received from the sun.

Each affects the amount of solar energy absorbed by the Earth.

The energy required for the physical processes taking place in the Earth-atmosphere-ocean system is almost totally provided by the sun. Each minute the sun radiates approximately 56 x 10^{26} calories of energy of which 2 x 10^3 calories per square centimeter per minute are incident upon our outer atmosphere. The exact amount of solar radiation that actually is incident depends upon the time of year, the time of day, and the latitude. Bare Earth absorbs and transforms approximately 75 percent of all visible light impinging upon it. The remainder of the energy is reflected back into space.

Figure 1 depicts the atmospheric energy as it is received from the sun. The surface of the Earth, heated by the absorption of visible or short-wave solar radiation, converts this energy to thermal or long-wave radiation which, in turn, convectively and conductively heats the atmosphere.

In a typical region of scattered clouds 2 percent of the incident visible solar energy is absorbed in the stratosphere. Fifteen percent of the remaining energy is typically absorbed in the troposphere and converted to thermal energy.

Forty-seven percent of the visual radiation eventually reaches the surface–31 percent directly and 16 percent through atmospheric diffusion. Note that 36 percent of the original energy is reflected back into space–23 percent from the tops of clouds, 6 percent through diffusion in the troposphere, and 7 percent from the surface.

It is not obvious how the Earth maintains its energy balance. The Earth's surface absorbs about 124 kilo-langleys of solar radiation each year. Energy per unit area is expressed in langleys (ly) or kilo-langleys (kly). One langley is equivalent to 1 calorie per square centimeter. The Earth effectively radiates 52 kly of long-wave energy to the atmosphere. The difference between incoming and outgoing radiation is 72 kly which is the net energy balance. The global radiation balance is zero averaged (approximately) over the year, but it will not equal zero either seasonally or annually in a given latitude zone.

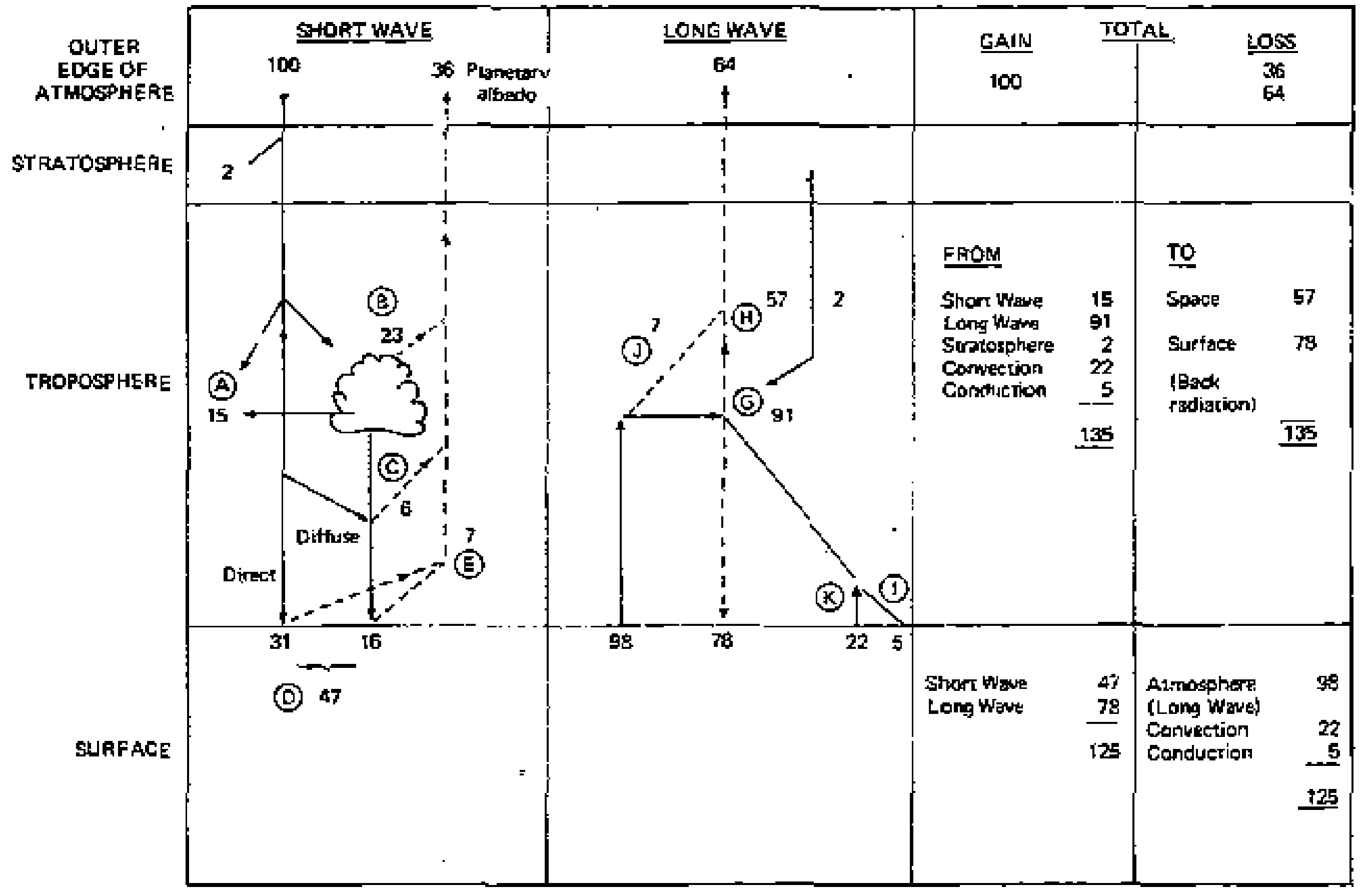


Figure 1. Atmospheric Energy
(in percent)

The atmosphere is uniformly a radiative heat sink at all latitudes, while the Earth's surface—except near the poles--is a heat source. Energy must therefore be transferred from the surface to the atmosphere to keep the surface from warming and the atmosphere from cooling. The vertical heat exchange occurs mainly by evaporation of water from the surface (heat loss) and condensation in the atmosphere (heat gain) and by conduction of sensible heat from the surface and turbulent diffusion into the atmosphere (convection).

An example of energy balance is represented in Figure 1. The atmosphere can gain energy from a variety of sources. The troposphere gains 15 percent of its thermal energy through direct conversion of visual energy to thermal energy. Of the black body (thermal) radiation from the Earth's surface (98 percent), 91 percent is partially absorbed in the atmosphere, and the remaining 7 percent is radiated into space. The stratosphere provides an additional 2 percent to the troposphere; convection (22 percent) and conduction (5 percent) account for about 27 percent.

The surface, then, has two sources of energy. It gains 47 percent in visual-to-thermal energy transformation and 78 percent in back radiation. The surface loses 98 percent to the atmosphere through long (infrared) waves, and 22 percent through convection and 5 percent through conduction. The gains and losses in the atmosphere-surface system are time dependent.

A layer of clouds, snow and ice can reflect 80 to 90 percent of the visible light back into space. Because climate depends primarily upon the amount of solar radiation that is absorbed by the Earth and atmosphere, albedo becomes important. Albedo is the ratio of the energy received from the sun and reflected by the Earth. The greater the albedo, the colder the Earth.

Clouds can serve to moderate whatever climate trend is under way: if the Earth's surface temperature climbs for whatever reason, more water evaporates and may rise to form more cloud cover. This increases the albedo and lowers the rate of heating. Ice and snow, on the other hand, provide positive feedback; if the average year-round temperature decreases, the extent of ice and snow coverage increases and reflects more of the incoming sunlight back to space. The result is to lower the rate of heating still more, particularly in the regions closest to the poles.

There is yet another contributor to the planet's albedo--airborne particles, particularly the extremely fine dust particles that have been carried too high in the atmosphere to be washed out by precipitation. Many of these particles remain aloft for months or years. Thus, a heterogeneous distribution of clouds may eventually cause a heterogeneous distribution of thermal energy around the Earth.

Earth's Atmosphere

Many mechanisms are employed by the Earth to bring itself into thermal equilibrium. When thermal radiation from land surfaces heats the air directly above it, the rising air causes a change in the local atmospheric pressure. The spinning of the Earth and the resultant pressure differentials are physically manifested by the gaseous currents known as "wind." Thermal radiation from the Earth also causes the evaporation-condensation cycle that forces moisture from land and ocean sources to enter the atmosphere (Figure 2). Thus, the atmosphere becomes one of the major means of equalizing the thermal energy distribution around the world.

For evaporation to occur, both a driving force and a source of energy in the transformation phase are required. Radiation is the main energy source. In the presence of an adequate supply of energy, most precipitation evaporates before it has a chance to run off. The oceans lose more water by evaporation (84 percent) than they gain by precipitation (77 percent). The deficit is made up by run off from the continents (7 percent) over which precipitation exceeds evaporation.

The oceans provide about 84 percent of global evaporation, while the continents provide the remaining 16 percent. The change of phase from a liquid state to a vapor requires that energy be provided to overcome the intermolecular attractions between water molecules. The latent heat required to evaporate one gram of water at $0^{o}C$. is 600 calories. Condensation is responsible for releasing this energy. Thus the 7 percent horizontal advection of water vapor to the land mass contributes significantly to the transfer of energy to the continents. The normal dynamic movement of air and vapor masses is continuously directed at the equalization of energy in the oceans as well as land masses.

Since 80 percent of the Earth's surface is water, principally the oceans, it would seem reasonable that mechanisms had to exist in the oceans to offset the heterogeneous distribution of thermal energy. Throughout all the major oceans, great currents of water flow between energy sinks and sumps. The winds created by the ocean's radiated energy form atmospheric tides. As an example, the greatest mass of water on the Earth–the Pacific Ocean is constantly depressed one meter on the east side as compared with the west due to an atmospheric pressure anomaly

Figure 3 shows that the most dangerous effect of the global cooling trend has been a change in atmospheric circulation and rainfall. The change centers on the behavior of the circumpolar vortex, the great cap of high-altitude winds revolving about the poles from west to east. The broad band across the Northern Hemisphere marks the approximate southern edge of the wind system as it was during the summertime in the early 1960s. Its southern edge determines the location of the prominent high-pressure regions, indicated here by narrow clockwise-spiraling arrows representing winds flowing outward. The highs

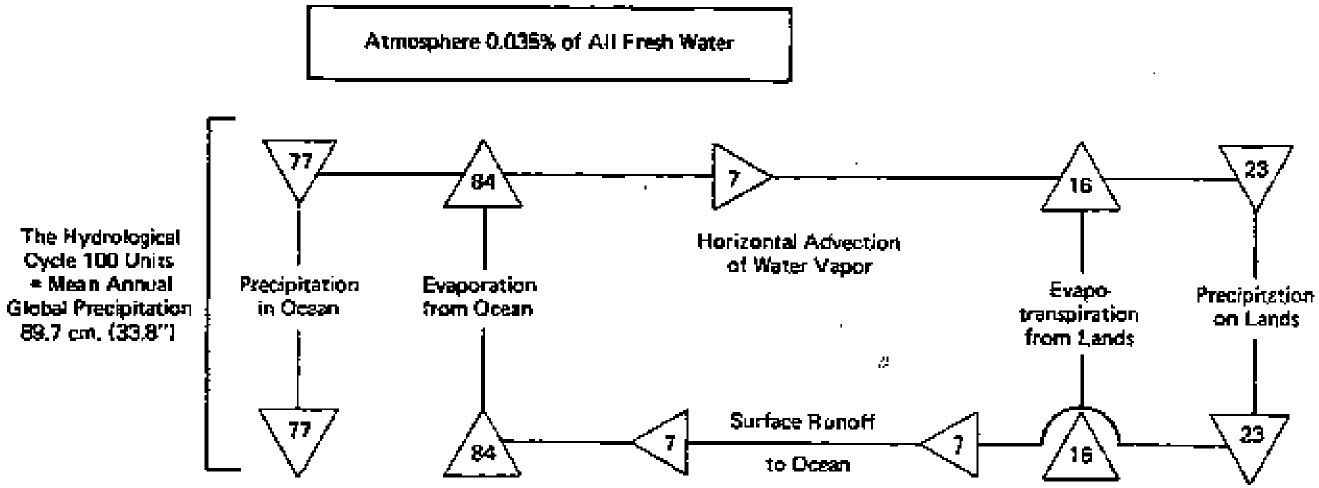


Figure 2. Atmospheric Moisture
(in percent)

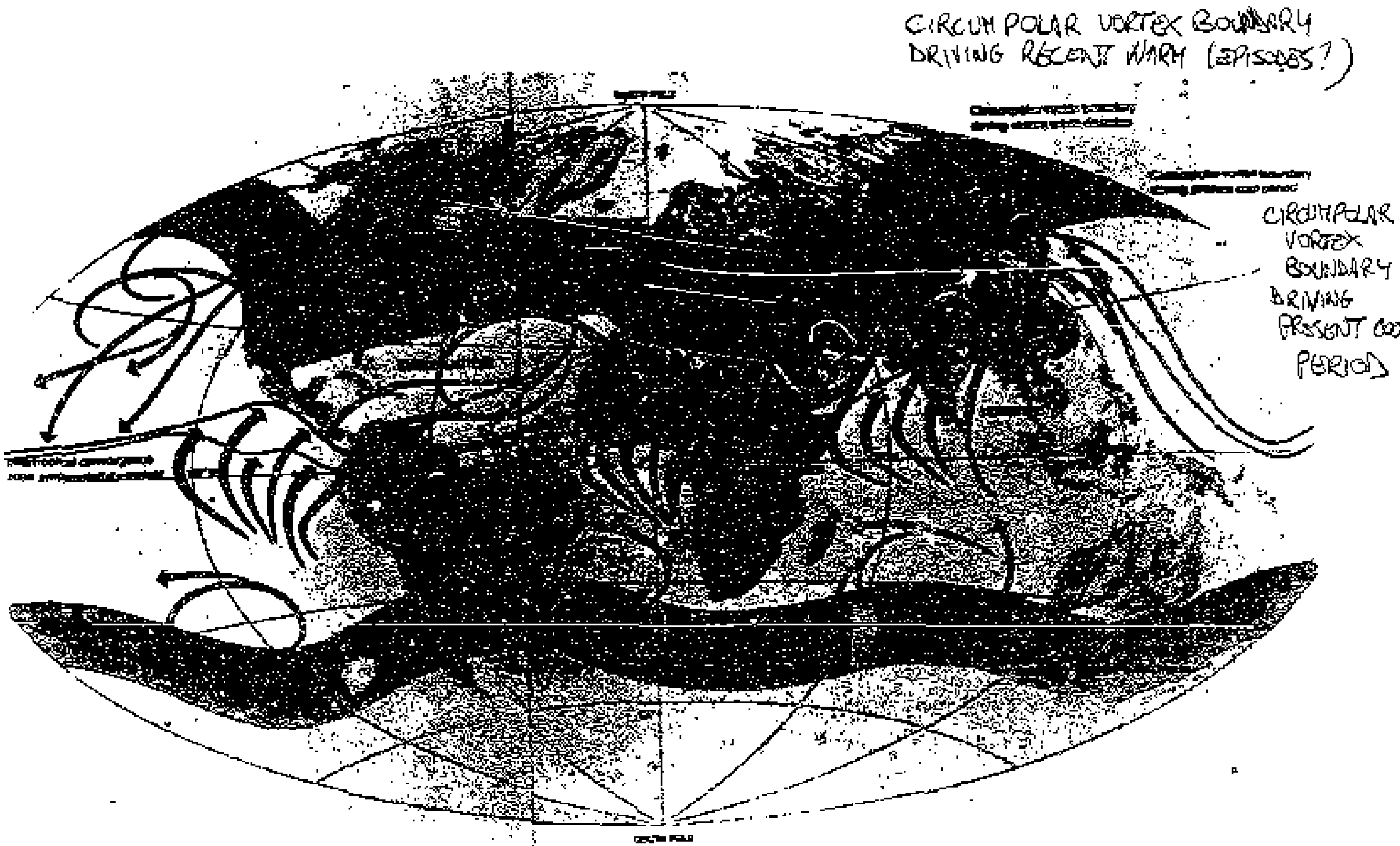


Figure 3. Globel Weather Variations

result from dry winds that descend after traveling at high altitudes from the equator. They created the world's great deserts and determine the northern limit of penetration by rain-bearing summer monsoons (indicated by heavy, northward-trending arrows). The limit is known as the "intertropical convergence zone."

Because of the global cooling trend, the lower edge of the circumpolar vortex has in recent years stayed farther south during the summer, in the position shown by the smaller band near the equator. It has kept the high pressure zones farther south too, blocking the monsoons out of regions where they are vital to the survival of hundreds of millions of people. At the same time, the vortex's semistationary wave patterns have altered, affecting rainfall patterns in temperate regions and making the climate more variable. The deeper wave over the U.S., for example, is believed responsible for recent cold winters in the West and mild ones in the East. The West has been subjected to north winds; the East, the return flow. Although some evidence exists that the cooling trend has affected wind patterns in the Southern Hemisphere as well, weather statistics are scanty.

Current Approaches to Climatology

There are three basic schools or philosophies of climatology. The first is centered around Professor H. H. Lamb, who is currently the Director of the Climatic Research Unit at the University of East Anglia in the United Kingdom. This school contends that if a climatologist is to project future climates, he must understand what has occurred in the past. The second is characterized by Dr. Joseph Smagorinsky, who is the Director of the Geophysical Fluid Dynamics Laboratory at Princeton University. This center believes that a complete understanding of atmospheric circulation is sufficient for climatic forecasting. The third is best represented by Dr. M. I. Budyko, an eminent Soviet climatological theoretician. He pursues the hypothesis that an understanding of the total distribution of thermal energy is necessary for climatic forecasting.

The Lambian school is based on the establishment of climatic statistical trends. A great deal of effort has been expended by the followers of this philosophy in quantifying the qualitative descriptions provided by historical sources (ancient court scribes, ship's logs, and scholars). Their reconstruction of climatic conditions has reached back 5,000 years. This particular approach was almost totally dependent upon man-made records. In recent years, the use of geophysical indicators such as tree rings, sedimentary deposits, and Arctic ice layering has added substantially to the global data pool.

Unique scientific methods have been developed which allow the climatologist to determine the historical intensity and distribution of solar radiation and precipitation on a worldwide bases. Before these developments, it was necessary for the scientist to infer climatic variability based on many indirect factors. Though this work is still quite incomplete, preliminary reports by Dr. John Imbrie (Brown University) have provided a fascinating portrayal of the Earth's climatology over the last 50 million years.

Current evidence indicates that the continental areas which were once in the tropical climatic regions of this planet, for some reason, underwent a rapid climatic change. Beginning approximately 20 million years ago (miocene period), large climatic variations characterized by what is known as the Ice Ages began to make appearances. Dr Imbrie's group has been able to establish that these Ice Ages are cyclic in nature and consist of approximately a 90,000-year glacial period followed by a relatively brief warming peak for 10,000 to 12,500 years, called the interglacial periods. Thus, as we see in Figure 4 based upon a sample space of 20 million years, this rather narrow period of the interglacial span is a consistent feature.

Investigations indicate interglacial periods never extended beyond 12,500 years nor has the period ever been less than 10,000 years (Figure 5). The glacial periods may be characterized by large continental ice sheets that extended across vast regions of Europe, North America, and Asia. This phenomena is well documented on the North American continent and came to an end approximately 10,000 years ago. The present interglacial era is characterized by a thermal maximum which occurred about 5,000 to 3,000 B.C. During this time, many major deserts in the world – as we know them – were formed, such as the Sahara, the Arabian, and great Mongolian deserts.

Climate change at the end of these interglacial time periods is rather sharp and dramatic. Excellent historical evidence exists from areas on the European plains which once were oak forests and were later transformed into poplar, then into birch, and finally into tundra within a 100-year span. Thus, the researchers of the CLIMAP group (CLImatic MAPing) hypothesize that the change from an interglacial to glacial time period could take place in less than 200 years. An example of rapid climatic changes are the remains of frozen mastodons completely preserved in Siberian and North American ice packs.

Scientists are confident that unless man is able to effectively modify the climate, the northern regions, such as Canada, the European part of the Soviet Union, and major areas in northern China, will again be covered with 100 to 200 feet of ice and snow. That this will occur within the next 2,500 years they are quite positive; that it may occur sooner is open to speculation.

The Smagorinsky-ian school of climatology is based upon the meteorologist's attempts to extend the predictive capabilities of the equations of fluid motion. Meteorology deals principally with the forecasting of atmospheric pressure differentials and the propensity for given patterns to result in rain, snow, ice, high winds, etc. It does not take into account solar or Earth radiation nor hydrological (i.e., evaporation) variables.

Since the availability of serial, numerical computers in the latter half of the 1940s, the meteorologist has developed a system of models to predict near-term atmospheric variations. The basic tool employed by this group is the General Circulation Model. These

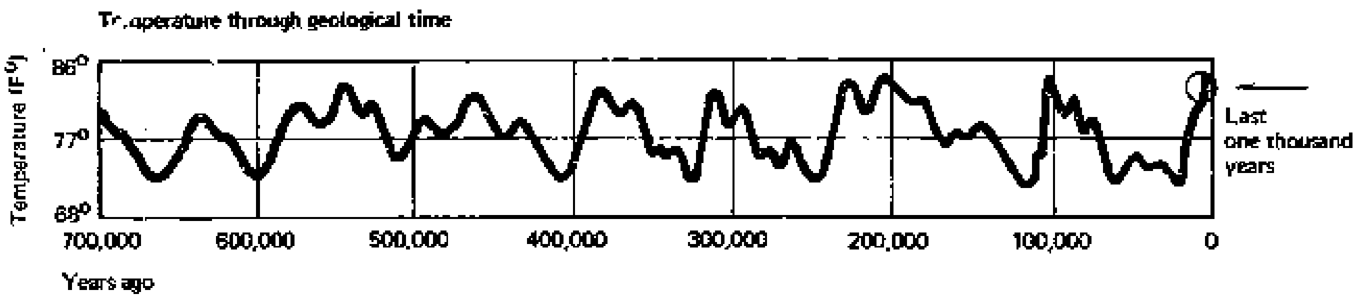
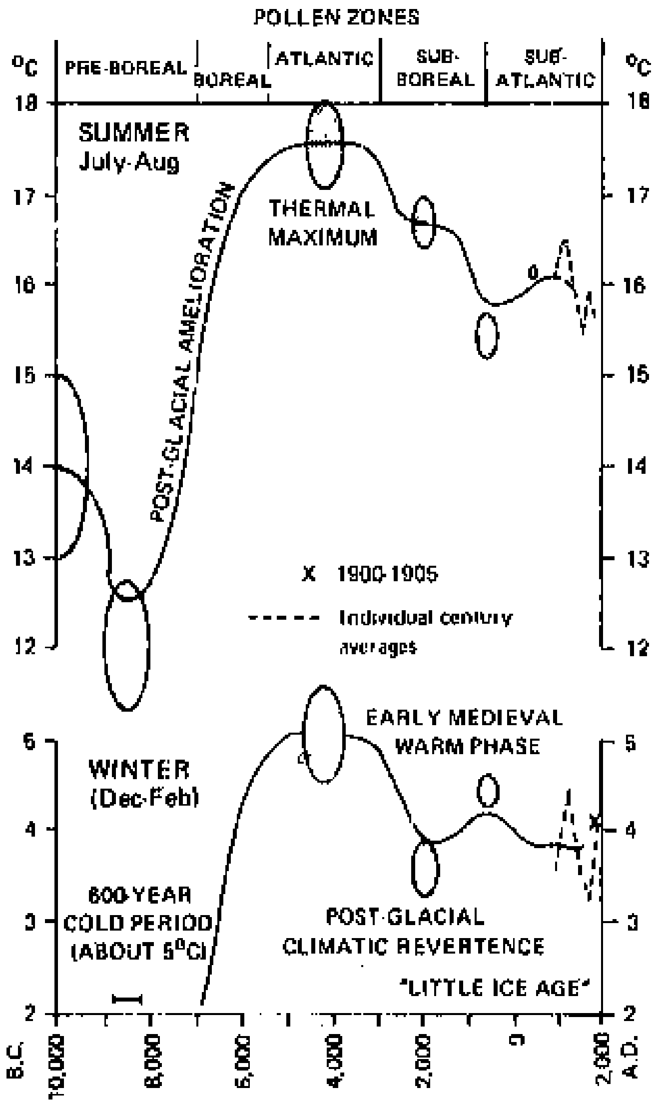


Figure 4. Temperature History
Through Geological Time



Air temperatures in the lowlands of central England. Trends of the supposed 1000-year and 100-year averages since 10,000 B.C. (the latter calculated for the last millennium) (*after Lamb, 1966*). Shaded ovals indicate the approximate ranges within which the temperature estimates lie and error margins of the radiocarbon dates. Note that the pre-boreal phase begins about 8300 B.C. following the end of the Glacial Period.

Figure 5. Climate Variation in Central England

models describe the effects of large-scale atmospheric motion and are treated explicitly by numerical integration. For almost 30 years the meteorologist has tried unsuccessfully to extend his predictive capability past a 24-hour forecast. The Smagorinsky-ian approach, however, is the currently accepted methodology within the United States Government and receives more than 90 percent of all the research and development funding available therein.

The Budyko-ian school is based upon the theoretical work of Dr. M. I. Budyko, who is associated with the Global Meterological Institute in Leningrad. The basis of this approach to the climatological problem is Dr. Budyko's 1955 paper entitled, "The Heat Balance of the Earth's Surface." This paper advances the hypothesis that all atmospheric motions are dependent upon the thermodynamic effect of a nonhomogeneous distribution of energy on the Earth's surface. Though this work originally met with opposition from the world's meteorologists, it is now accepted as a more reasonable basis for developing a successful climatic prediction model. The earlier, simplistic explanation of climate was basically Budyko-ian.

RECENT MILESTONES

Explanation of the scientific phenomena and elaboration of the three methodological schools provide a background for more recent developments–developments which have more relevancy to requirements as they might emerge in the Intelligence Community. The University of Wisconsin's work appears to be providing the cohesion for continuing research in this area.

The Wisconsin Study

The University of Wisconsin was the first accredited academic center to forecast that a major global climatic change was underway. Their analysis of the Icelandic temperature data, which they contend has historically been a bellwether for northern hemisphere climatic conditions, indicated that the world was returning to the type of climate which prevailed during the first part of the last century (Figure 6). This climatic change could have far-reaching economic and social impact. They observed that the climate we have enjoyed in recent decades was extremely favorable for agriculture. During this period, from 1930 to 1960, the world population doubled, national boundaries were redrawn, the industrial revolution became a worldwide phenomenon, marginal lands began to be used in an effort to feed a vastly increased population, and special crop strains optimally suited to prevailing weather conditions were developed and became part of what was called the "green revolution."

The climate of the 1800s was far less favorable for agriculture in most areas of the world. In the United States during that century, the midwest grain-producing areas were cooler and wetter, and snow lines of the Russian steppes lasted for longer periods of time. More extended periods of drought were noted in the areas of the Soviet Union now known as the new lands. Moreover, extensive monsoon failures were common around the world, affecting in particular China, the Philippines, and the Indian subcontinent.

The Wisconsin analysis questioned whether a return to these climatic conditions could support a population that has grown from 1.1 billion in 1850 to 3.75 billion in 1970. The Wisconsin group predicted that the climate could not support the world's population since technology offers no immediate solution. Further, world grain reserves

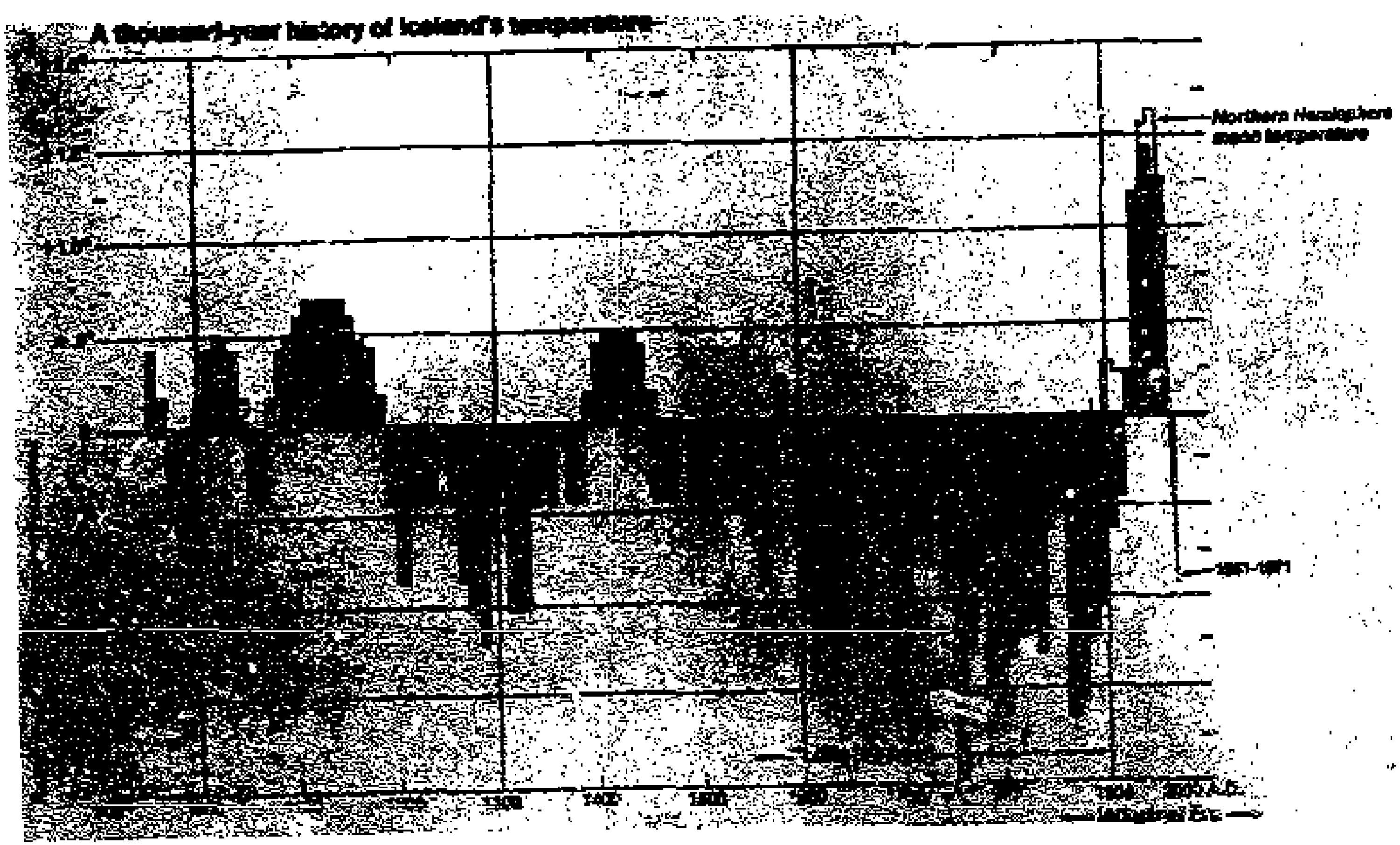


Figure 6. Historical Temperature Trend

currently amount to less than one month; thus, any delay in availability of supplies implies mass starvations. They also contended that new crop strains could not be developed overnight, and marginal lands would be less suited or perhaps unsuited to agricultural production. Moreover, they observed that agriculture would become even more energy dependent in a world of declining resources. Their "Food for Thought" chart (Figure 7) conveys some idea of the enormity of the problem and the precarious state in which most of the world's nations could find themselves *if the Wisconsin forecast is correct.*

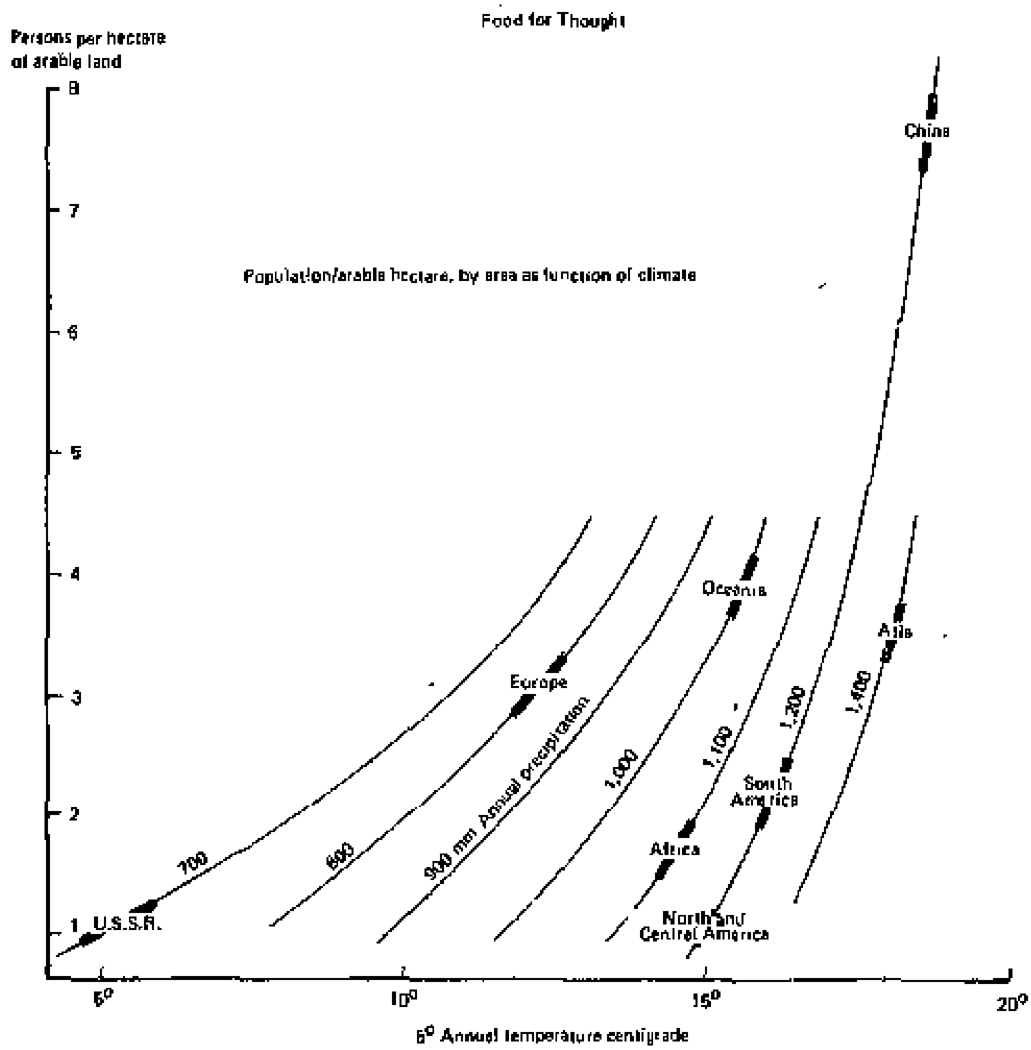


Figure 7. Food for Thought

As an example, Europe presently, with an annual mean temperature of 12°C. (about 53°F.), supports three persons per arable hectare. If, however, the temperature declines 1°C. only a little over two persons per hectare could be supported and more than 20 percent of the population could not be fed from domestic sources. China now supports over seven persons per arable hectare; a shift of 1°C. would mean it could only support four persons per hectare - a drop of over 43 percent.

A unique aspect of the Wisconsin analysis was their estimate of the duration of this climatic change. An analysis by Dr. J. E. Kutzbach (Wisconsin) on the rate of climatic changes during the preceding 1600 years indicates an ominous consistency in the rate of which the change takes place. The maximum temperature drop normally occurred within 40 years of inception. The earliest return occurred within 70 years. (Figure 8). The longest period noted was 180 years.

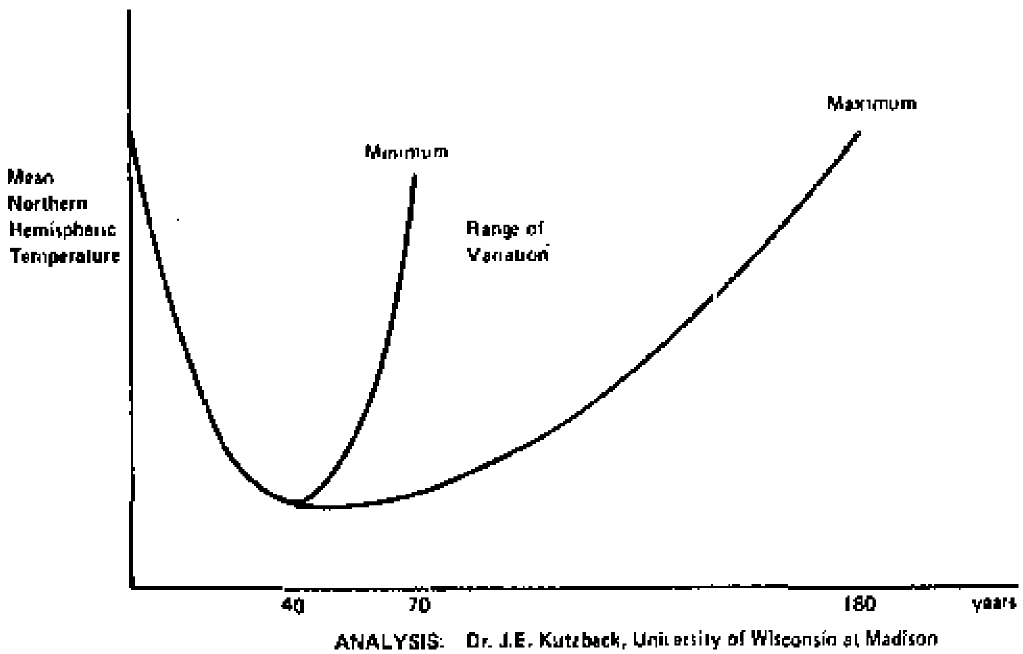


Figure 8. Mean Temperature Variation During a New Climatic Era

The study of the impact of climatic change on past and present cultures has been a cooperative venture between the social scientist, the historian, and the climatologist. It has been shown (Figure 6) that over the last 10,000 years there have been many climatic changes of regional and global significance. Detailed descriptions exist showing how these climatic changes affected the people of these regions. The Wisconsin forecast suggests that the world is returning to the climatic regime that existed from the 1600s to the 1850s, normally, called the neo-boreal or "Little Ice Age." (This climate was physically characterized by broad strips of excess and deficit rainfall in the middle latitudes and extensive failure of the monsoons.) The political, historical, and economic consequences of this climatic era have heretofore been masked by the historian's preoccupation with the technical progress. We have recent evidence of this type of faulty analysis which has persuaded the modern agroeconomist that man's agricultural growth during the last 40 years was only due to technology and not the agro-climatic optimum of that period.

During the last neo-boreal era great segments of the world population were decimated. The great plagues of Europe, India, Africa, and Russia that occurred during this period could have been the direct result of starvation and malnutrition. In the past year data from the Sahel, Ethiopia, and India indicate that for each death caused by starvation, ten people died of epidemic diseases such as smallpox and cholera. Bodies weak from hunger are easy prey to the normal pathogenic enemies of man.

The governments and people of northern Europe once struggled to survive in an environment of persistent crop failure and declining population. On the other hand, Spain, Portugal, and Italy enjoyed a golden age. Their climate assured them of a reliable base for food production. The German states, Russia, the other Slavic nations, and to a certain extent even England and France, lived in the twilight of permanent winter.

For 250 years most of the world suffered major economic and political unrest which could be directly or indirectly attributed to the climate of the neo-boreal era. The great potato famine of 1845 in Ireland was the last gasp of the "little ice age." Yet for every death in Ireland there were ten in the Asian countries.

What would a return to this climate mean today? Based on the Wisconsin study, it would mean that India will have a major drought every four years and could only support three-fourths of her present population. The world reserve would have to supply 30 to 50 million metric tons of grain each year to prevent the deaths of 150 million Indians. China, with a major famine every five years, would require a supply of 50 million metric tons of grain. The Soviet Union would lose Kazakhstan for grain production thereby showing a yearly loss of 48 million metric tons of grain. Canada, a major exporter, would lose over 50 percent in production capability and 75 percent in exporting. Northern Europe would lose 25 to 30 percent of its present product capability while the Common Market countries would zero their exports.

People, Places and Approaches

A limited number of people within the United States are involved in climatological research. On the West Coast there are two significant groups. The first is under Dr. Larry Gates at the RAND Corporation in Santa Monica. Dr. Gates' work has been supported by ARPA and is theoretically Smagorinsky-ian. He has worked for three years under an ARPA grant utilizing basically the UCLA two-level General Circulation Model. Though the work has been theoretically interesting and has developed many new software capabilities, they have still not arrived at an operational system. Dr. Gates has been strongly impressed by developments in the Budyko-ian school and is in the process of modifying their simulation programs to incorporate some of the more recent thermodynamic developments.

The Scripps Institution group at La Jolla, under the direction of Dr. John Isaacs, and more recently with the inclusion of Dr. Jerome Namais, has followed both the Lambian and Budyko-ian approaches to climatological problems. Their main capabilities have been in the development of climatological observables. Dr. Isaacs' early work, which has been continued by Namais' research, was directed at the thermodynamic influence of the oceans on world atmospheric circulation. At present, no pragmatic climatological forecasting is being pursued at Scripps.

The atmospheric sciences group at the University of Arizona is solidly Budyko-ian Dr. William Sellers who heads this group is one of the country's leading technicians in Budyko-ian methodology. His first published climatic model in 1968 was not well received by the Smagorinsky-ians or by the Budyko-ians within the world community. They did acknowledge, however, that it was the first pragmatic systematizing of this approach. His latest model, developed in 1972, has had a significant effect in crystalizing this whole philosophy and demonstrating a pragmatic climatological model.

There are two climate groups in the midwest one being NCAR (National Center for Atmospheric Research) at Boulder, Colorado. Their efforts have been to explore highly disaggregated atmospheric models. The second group, at the University of Wisconsin, is under Reid Bryson and John Kutzbach, both mentioned earlier. Their work at Wisconsin represents the focal point for climatological research in the United States. They are the only people within the academic community in the United States that have a seasonal climatological forecasting system.

The eastern establishment, consisting of Princeton and the Massachusetts Institute of Technology, is primarily Smagorinsky-ian. They are basically NOAA-funded and, though primarily engaged in increasing the accuracy of meteorological forecasts, have attempted without success to provide climatological forecasting capabilities.

In summation, the eastern schools have employed basically the Smagorinsky-ian principles in one way or another. The limitation of this approach, although not yet apparent to the establishment, is rapidly being abandoned by the academic community. The pragmatic capabilities of the Budyko-ians and the methodologies therein are quickly being absorbed by both the East and West Coast establishments. The Lambians and their primarily statistical approach are beginning to lose favor, but their development of historical climatological records has provided a vital service within the climatological community.

San Diego Conference

By the fall of 1973 the Office of Research and Development (ORD) had obtained sufficient evidence to alert the Agency analysts that forecasts of an ongoing global climate change were reasonable and worthy of attention. ORD also determined that it was feasible to begin the development of forecasting techniques and impact assessment. However, Agency analysts remained skeptical, noting that the mix of approaches (Wisconsin, Scripps, RAND, NCAR) and the scientific personalities pursuing them prevented a clear expression of what the recognized authorities were agreeing on.

To resolve these issues, the principal investigators representing the various research approaches convened in San Diego in April 1974 to discuss these three specific topics:

- The state of climatological forecasting: identification of elements of the methodology wherein there is some consensus, current trends in development, and new approaches.

- Prospects for developing near-term applications of climatology to Agency interests.

- Recommendations for high- and low-risk approaches for long-range climatological models development.

For two days they argued, discussed, and defended their approaches to climatic forecasting and the impact of climatic change. By the second day a consensus was reached on the following fundamental issues:

- A global climatic change is taking place.

- We will not soon return to the climate patterns of the recent past.

- For the future, there is a high probability of increased variability in a number of features of climate that are of importance to crop growth.

- The most promising long-range (1-5 years) approach to climate forecasting appears to be the statistical synoptic approach. The consensus expressed caution in using these projections without an attempt to develop some physical understanding of the underlying weather-forcing mechanisms.

In general, the conference participants were skeptical of the prospects of making a one- to five-year forecast at this time, stating that only season-to-season forecasts were within the state of the art.

The conference participants unanimously recommended that the clear need for a long-range prediction dictated the establishment of an Operational Diagnostic Center charged with developing global forecasting techniques and for servicing the Government's needs for one-to-five year forecasts.

National Climate Plan

In the summer of 1973 the Wisconsin Plan for Climatic Research was presented to the National Security Council. NOAA and the National Science Foundation were requested to review this plan and to suggest how it should be implemented. The Wisconsin Plan stimulated activity in many agencies.

In the fall of 1973 three agencies in the government became active in the development of climatic research plans: NSF, NOAA, and the National Academy of Sciences. The National Academy of Sciences established the Committee on Climatic Variation, chaired by Dr. Larry Gates. The committee members completed their recommendations for a National Climatic Research Plan in June of 1974. This plan is presently under assessment by the National Academy of Sciences. Its final approval is expected late this year. Early in 1974, NOAA began developing a plan which would include a Center for Climatic and Environmental Assessment as suggested by preliminary recommendations from the National Academy of Sciences Committee. This plan would allow NOAA to respond rapidly to the needs of government agencies that are concerned with the impact of climatic factors on both a national and global scale.

In the spring of 1974, the Director of the Polar Studies Division of NSF developed a plan to establish a Center for Climatic Research as well as to provide funding to appropriate academic centers.

Both of these plans have been incorporated into what is now called the National Climate Plan. NOAA would be responsible for developing methods for practical climate forecasting as well as developing techniques applicable for the assessment of national and international food production. NSF would provide support to responsible academic centers and establish a Center for Climatic Research. This Center would operate in a similar manner as the present National Center for Atmospheric Research (NCAR) at Boulder, Colorado. The National Climatic Plan is presently under review by NOAA and the NSF. They expect to seek approval from the Office of Management and Budget in the fall of 1974 for FY 76 program funding.

CONCLUSIONS

Leaders in climatology and economics are in agreement that a climatic change is taking place and that it has already caused major economic problems throughout the world. As it becomes more apparent to the nations around the world that the current trend is indeed a long-term reality, new alignments will be made among nations to insure a secure supply of food resources. Assessing the impact of climatic change on major nations will, in the future, occupy a major portion of the Intelligence Community's assets.

Climatology is a budding science that has only recently given promise of fruition. Classical climatology was occupied with the archiving of evidence. Until 1968 very little was accomplished in this science toward defining casual relationships. During the last two years climatologists have made substantial progress in the development of methodologies and techniques in forecasting climatic changes. Recent developments in climatology have shown extensive promise toward providing seasonal forecasting. In the near future it may be possible to provide forecasts in the realm of one to five years.

The function of research within the Agency has been directed at defining the relationship of climatology to the intelligence problems. It is increasingly evident that the Intelligence Community must understand the magnitude of international threats which occur as a function of climatic change. These methodologies are necessary to forewarn us of the economic and political collapse of nations caused by a worldwide failure in food production. In addition, methodologies are also necessary to project and assess a nation's propensity to initiate militarily large-scale migrations of their people as has been the case for the last 4,000 years.

Though the issues are important, the United States has a limited capability in climatic forecasting. The government expends over $150 million annually on short-range weather forecasting, but only a minimum of direct dollars on climatic forecasting. Only a few academic centers in the United States are engaged in training personnel in this field, which suggests we have a limited chance of solving the Intelligence Community's problem unless decisive action is taken.

BIBLIOGRAPHY

Adem, J., 1964: "On the Physical Basis for the Numerical Prediction of Monthly and Seasonal Temperatures in the Troposphere-Ocean-Continent System," *Mon. Wea. Rev.* 92: 91-103.

Alexander, Tom, 1974: "Ominous Changes in the World's Weather," *Fortune*, p. 90.

Asakura, Tadashi, 1974: "Unusual Weather and Environmental Pollution," U.S. Joint Publications Research Service, JPRS L/4913, 22 May.

Bauer, K. G., 1971: "Linear Prediction of a Multivariate Time Series Applied to Atmospheric Scale Field," Ph.D. Thesis, University of Wisconsin-Madison (Unpublished), 180 pp.

Bryson, R. A. and J. A. Dutton, 1961: "Some Aspects of the Variance Spectra of Tree Rings and Varves," *Annal N. Y. Acad. Sci.* 95(1): 580-604.

Bryson, R. A., 1972: Climatic Modification by Air Pollution in *The Environmental Future*, N. Polunin (ed.). London: Macmillan, xiv + 660 (pp. 134-174).

Bryson, R. A. and J. E. Kutzbach, 1973: "On the Analysis of Pollen-Climatic Canonical Transfer Functions" (in preparation).

Bryson, R. A. and W. P. Lowry, 1955: "Synoptic Climatology of the Arizona Summer Precipitation Singularity," *Bull. Ameri. Met. Soc.* 36: 329-399.

Budyko, M. I., 1969: "The Effect of Solar Radiation Variation on the Climate of the Earth," *Tellus* 21: 611-619.

Chang, Jen-Hu, 1970: "Potential Photosynthesis and Crop Productivity," *Ann. Assoc. Am. Geogr.* 70: 92-101.

Cottam, G., E. Howell, F. Stearns, and N. Korbiger, 1972: "Productivity Profile of Wisconsin, Part II," *Eastern Deciduous Forest Memo Report* #72-142.

Davis, N. E., 1972: "The Variability of the Onset of Spring in Britain," *Quart. J. Roy. Met. Soc.* 98: 763-777.

Davitaya, F. F., 1965: "The Possible Influence of Atmospheric Dustiness on the Recession of Glaciers and Warming of the Climate," *Izvestiya Akad. Nauk SSSR Geogr. Ser.* No. 2, Mar-Apr.: 3-33.

Dwyer, H. A. and T. Pet rson, 1973: "Time-dependent Global Energy Modeling," *Jour. Appl. Meteor.* 12(1): 36-42.

Fritts, H. C., T. J. Blasing, B. P. Hayden, and J. E. Kutzbach, 1971: "Multivariate Techniques for Specifying Tree-Growth and Climate Relationships and for Reconstructing Anomalies of Paleoclimate," *Jour. Appl. Meteor.* 10(5): 845-864.

Fultz, D., 1961: "Developments in Controlled Experiments on Larger Scale Geophysical Problems," *Adv. Geophys.* 7: 1-103.

Ilesanmi, O. O., 1971: "An Empirical Formulation of an ITD Rainfall Model for the Tropics: A Case Study for Nigeria," *Jour. Appl. Met.* 10(5): 882-891.

Kukla, George J., and J. Helena, 1974: "Increased Surface Albedo in the Northern Hemisphere," *Science* 183(4126): 709.

Kutzbach, J. E., 1970: "Large-Scale Features of Monthly Mean Northern Hemisphere Anomaly Maps of Sea Level Pressure," *Mon. Wea. Rev.* 98(9): 708-716.

Lamb, H. H., 1966: "Climate in the 1960's," *Geographic Journal* 132: 183-212.

Lamb, H. H., 1970: "Volcanic Dust in the Atmosphere," *Phil. Trans. Roy. Soc. London* 266(1178): 425-533.

Landsberg, H., 1967: "Climate, Man, and Some World Problems," *Scientia* May-June.

Lettau, H. H. and K. Lettau, 1969: "Shortwave Radiation Climatonomy," *Tellus* 21: 208-222.

Lettau, K., 1973: "Modeling of the Annual Cycle of Soil Moisture," *Proc. of the Symposium of Phenology and Seasonality Modeling*. Springer-Verlag: New York (accepted for publication in 1973).

Leith, H., 1972: "Modeling and Primary Productivity of the World," *Nature and Resources* 8: 2-10.

Lorenz, E. N., 1970: "Climatic Change as a Mathematical Problem," *J. Appl. Met.*, 9.

Machta, Lester, 1972: "Mauna Loa and Global Trends in Air Quality," *Bull. Am. Met. Soc.* 53(5): 402-421.

McQuigg, J., S. Johnson, and J. Tudor, 1972: "Meteorological Diversity-Load Diversity, A Fresh Look at an Old Problem," *J. Appl. Met.* (11)4: 561-566.

Miller, P. C., 1971: "Bioclimate, Leaf Temperature, and Primary Production in Red Mangrove Canopies in South Florida," *Ecol. 53: 22-45.*

Mitchell, J. M. Jr., 1961: "Recent Secular Changes of Global Temperature," *Annals of New York Academy of Sciences*, Article 1. 95: 235-250.

Monteith, J. L., 1965: "Light Distribution and Photosynthesis in Field Crops," *Ann. Bot.* 29: 17-37.

Paddock, W. and P. Paddock, 1967: *Famine--1975!* Boston: Little, Brown, & Co., x + 276 pp.

Reitan, C. H., 197.: "An Assessment of the Role of Volcanic Dust in Determining Modern Changes in the Temperature of the Northern Hemisphere," Ph.D. Thesis, University of Wisconsin-Madison (unpublished), 147 pp.

Sellers, W. D., 1969: "A Global Climatic Model Based on the Energy Balance of the Earth-Atmosphere System," *J. App. Met.* 8: 392-400.

Smagorinsky, J., 1963: "General Circulation Experiments with the Primitive Equations. I: The Basic Experiment," *Mon. Wea. Rev.* 91(3): 99-164.

Thompson, L. M., 1968: "Impact of World Food Needs on American Agriculture," *Jour. Soil and Water Res.* 23.

Thompson, L. M., 1969: "Weather and Technology in the Production of Wheat in the United States," *Jour. Soil and Water Res.* 24: 219-224.

Thompson, L. M., 1970: "Weather and Technology in the Production of Soybeans in the Central United States," *Agr. Journ.* 62: 232-236.

Thompson, L. M., 1966: "Weather Variability and the Need for a Food Reserve," Iowa State University, Center for Agriculture and Economic Development, Report #26, 101 pp.

Webb, Thompson, III and R. A. Bryson, 1972: "Late- and Post-Glacial Climatic Change in the Northern Midwest, U. S. A.: Quantitative Estimates Derived from Fossil Pollen Spectra by Multivariate Statistical Analysis," *Quaternary Res.* 2(1): 70-115.

Wick, Gerald, 1973: "Where Poseidon Courts Aeolus," *New Scientist*, January 18, p. 123.

Wigham, D., and H. Leith, 1971: "Eastern Deciduous Forest Biome Memo Report," #71-9.

Winstanley, Derek, 1973: "Recent Rainfall Trends in Africa, the Middle East, and India," *Nature* 243: 464-465.

Yamamoto, G., and M. Tanaka, 1972: "Increase of Global Albedo Due to Air Pollution," *J. Atmos. Sci.* 29(8): 1405-1412.

Yin, M. T., 1949: "A Synoptic-Aerologic Study of the Onset of the Summer Monsoon over India and Burma," *Jour. Meteor.* 6: 393-400.

Figure 3. Global Weather Variations

Figure 6. Historical Temperature Trend