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# Environmental Implications of an Increasingly Erratic Climate

**S. Elwynn Taylor**
*Department of Agronomy, Iowa State University Ames, IA 50011, USA*
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# 기후변화에 대한 생태계 적응전략

**에스 엘윈 테일러**
미국 아이오와주립대 농학과
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**ABSTRACT**

**Many aspects of climate have been observed to be increasingly volatile during the past several decades. Episodic climate change is not considered to be uncommon. However, there are substantial environmental, social, and economic impacts associated with climate variability that can be managed if the climate and its impacts are properly understood. Plants and natural communities exhibit several types of adaptive strategy to climate change. There is ample reason to relate increasingly erratic weather with a warming climate. Historic climate extremes, the adaptive mechanisms plants exhibit, and how people have (or have not) responded with strategically sound concepts and policy to facilitate a sustainable environmental ethic are reviewed with a vision of international needs and economic stability.**

*Key words*: **Climate change, Environment, Tree rings, Weather records, Drought cycle, Solar activity, Plant adaptation**

## I. INTRODUCTION

Climate is changing. Climate changes are not permanent. Climate has always changed. Climate will always change. Our concern is with reasons for, rate and range of, and responses (environment and biological) to changing climate.

All people who have experienced concern regarding the production of food have sensed the ubiquitous importance of weather. In Beijing there is a rather unique gateway to a historical structure identified on the tourist map as "Temple of Heaven". The pasterns are topped by what appear to be Lotus buds and thunderstorms. A student guide explained that old Chinese characters identified it as "the place of praying for favorable weather and fine crops." It was said that a major New Year's duty of the emperor was to enter these gates offering prescribed prayers and oblations that the weather in the season to come would be "favorable for a rich and bounteous harvest". The appreciation of this ancient culture for agricultural meteorology is clearly apparent.

Some aspects of the climate are more cyclic or follow trends over several years. The "sudden" recurrence of strong hurricanes impacting the United States in 2004 after a period of some 38 years of scant occurrence (only Hurricane Andrew in 1992), though not unexpected, has resulted in severe environmental, human and economic cost. During the 1933-1965 period (33 years), 11 major hurricanes impacted on the Florida peninsula. The previous 33 years had sparse impacts (5) according to the U.S. Hurricane Center records available on their public internet site. A strong hurricane brings obvious wind and water damage and not-so-obvious transport of

Corresponding Author: S. Elwynn Taylor (setaylor@iastate.edu)

biological threats. The introduction of Asian rust of soybean to North America was apparently facilitated by hurricane activity in 2004.

Anomalous tropical storm activity and distribution are directly associated with the anomalies of sea surface temperature in tropical and sub-tropical oceans. Although some temperature anomalies may persist for only a few days or weeks, others, such as the Pacific Decadal Oscillation (PDO), typically influence weather conditions for several years. An anomaly analysis is published semi-weekly at www.elnino.noaa.gov.

## II. CLIMATE CHANGE

### 2.1. Historical Observations

Consistent records of weather are of relatively recent origin. It is reported that standardized observations of precipitation were initiated in Korea about 1441. A gauge from 1770 is displayed at the Korea National Weather Service lobby labeled as a National Treasure. Long-term weather observations in Europe appear to have followed the invention of the barometer/ thermometer and associated instruments in the early 17$^{th}$ century. Proxy records, largely growth rings of trees, have proved useful in the characterizing of historical climate trends and events. Proxy observations serve to fill gaps between climate stations and to extend the history of weather well beyond the existence of observing instruments. Efforts to derive temperature, sunlight, and precipitation data from proxy data are at best generalizations, and few proxy sources are sensitive to conditions throughout the calendar year.

Tree ring data (Duvick and Blasing, 1983) showed an apparent 20-year periodicity since the late 17$^{th}$ century. During historic times the periods agree with observed epochs of river flow. Between 1926-1980, the corn experienced 5 years of markedly adverse yields, and the observed trees showed substantially lower radial growth for 13 years. Only two of the adverse years for corn were also adverse for trees in the same general locality. Five of the very adverse years for trees were actually excellent corn yield years, and in three cases record high corn yields were recorded (USDA, 2005). It is clear that perennial and annual crops respond differently to climate conditions.

### 2.2. Floods

The climate associated with a concurrent expansion of the US Corn Belt and the increased incidence of flooding is evident in the precipitation record. Much of the southern and central United States experienced an increase of precipitation during the latter half of the 20$^{th}$ Century. This amounted to approximately a 10% increase in average annual precipitation in the state of Iowa (Carlson, 2005). In this locality the average annual evapotranspiration of field crops is about 74% of the average annual precipitation. The precipitation in excess of the evaporative consumption either contributes to the ground water reserve (not substantial in this location) or to stream flow. In this case the stream flow has been essentially doubled, and the incidence of flooding has increased by some 800%. There has been little temperature change during the period, so potential evapotranspiration is changed little during the period. There was a measured decrease in precipitation in the watershed supplying the Panama Canal during the same period. The contrast between the Dust Bowl years of central North America and the conditions 60 years later is dramatic. It appears that local climate changes may be more related to shifting patterns rather than to global or planetary changes.

Lacking comprehensive long-term climate observations, some indication of climate may be gleaned from footnotes in historic documents and from proxy climate indicators. Tree rings are popular proxy records. Although an adverse year for crops is not necessarily adverse for trees (and vice versa), the tree ring record is a usable proxy weather record. A dry/wet year interpretation of the climate of the Eastern seaboard of the USA expresses an apparent 10/19-year occurrence of dry and wet conditions. The record also indicates the possible existence of recurring episodes of generally moist and generally dry intervals of a duration of about 40 years that may be associated with solar activity as discussed below. Drought indicated in the eastern North American proxy record had a major impact on the British colonization of North America in the early 1600s according to popularly reported work by Dennis Blanton of William and Mary College and David Stahle of the University of Arkansas (Stahle *et al.*, 1998).

Several years ago I noted an exhibit at the World's Fair Pavilion in San Antonio, TX (USA) that depicted inundations of a community by the flooding of the Rio Grande River since the 1600s. The display mentioned "the well-known 19-year flood cycle". This caught my attention because of the not-so-well-known 19-year grain production cycle in central North America.

### 2.3. Drought

The great "Dust Bowl" of the mid-1930s in central North America was followed by generally favorable crop production conditions until the droughts of the mid-1950s (severe, but not as severe as the Dust Bowl). There were no serious adverse climate impacts on the crops of central North America from 1956 through 1972, and people began to assume that severe drought was no longer a serious consideration in the central USA. Dr. Louis Thompson (personal communication) and some of his associates cautioned national planners about the nature of the 19-year spacing of seriously adverse crop conditions. A major Midwest drought occurred in 1974. Inspection of crop yields over 150 years revealed that the apparent cycle consists of a 6-year segment of high drought risk and a 12- or 13-year segment of low drought risk. Dr. Thompson (1986, 1988) published an updated crop and weather analysis for corn and for soybean. During a visit to Leningrad (now St. Petersburg), Russia, in the early 1990s I noted that the flooding of the River Neva as recorded on the walls of the Peter-Paul Fortress exhibited a familiar 19-year pattern. Dr. Louis Thompson pointed out (to me) the works of Samuel Benner (1881) and his identification of an apparently periodic flooding of the Ohio River. He showed data for the major 18-year cycle and minor 9- or 10-year cycle (pa 129-31 in 1892 edition) of flooding and of commodity price fluctuations.

### 2.4. Temperature

Temperature is a principal factor in the volatility of weather and of crop yields and market prices. The other major factor is precipitation. The two cannot be separated as the water requirement of plants is controlled by supply (usually precipitation) and demand (usually temperature dependent). As temperature increases, the vapor pressure difference for given dew point depressions increases (approximately doubles for a 10°C increase). Secondary factors (wind, atmospheric moisture, and the nature of the evaporating surface) are of such importance that they too must be evaluated.

## III. CAUSE OF GLOBAL CHANGE

The planetary energy balance has been afforded increasing importance since the early 1950s; perhaps the advent of environmental observations by satellite contributed to an expansion of this aspect of climatology from an interest to a world scientific priority. Observations by satellite sensors have made planetary energy measurements feasible and sufficiently accurate to possibly detect subtle changes affected by human activity.

The major factors influencing planetary balance are the output of the sun, the distance from the sun (geometric), and the albedo and emissivity of the reflecting/radiating planetary surface. The latter factors are complicated by the interest people have in conditions near the surface rather than just at the virtual radiating surface. Accordingly, the planetary factors are divided into atmospheric and terrestrial (surface).

### 3.1. Sun

Consistent records of solar activity began with the works of Galileo in the early 1600s (NASA, 2006). Sunspot size, numbers, and locations change with time in a somewhat regular manner. There is some variability in the size of the solar disk and the apparent radiant temperature of the sun associated with the observed sunspot activity. Extended intervals of wet and dry described under Tree Rings above were notably missing during the Maunder Minimum (observed low sunspot activity). The episodes (including the Maunder Minimum) appear to be connected with the so-called "Gleissberg cycle" (Perry 1995; Damon 2001) of solar activity. The solar activity cycle was considered to be a possible cause of global warming on a short-term (30-90 year) scale by Friis-Christensen and Lassen (1991). Although the possible cause/effect relationship is controversial, the temperature trend of the past 150 years is generally accepted. The relationship of the temperature record to the tree ring record is not controversial, and the relationship to grain yields is likewise clearly demonstrated.

### 3.2. Geometry (Glacial Cycles)

The Newtonian concept of center of mass on a solar system scale gave rise to the understanding of the dynamic orbital configuration of the Earth. When combined with the incidence angle (dependent on the cyclic tilt and wobble of the planet), the energy absorbed and the locations of greatest heating/cooling are influenced. The work of several investigators is generally lumped into the concept known as the Milankovitch cycle. The cycle provides a plausible explanation of the apparently regular cycle (125,000 year) of glaciations.

The impact of planetary temperature on the density of water and the volume of seawater influenced by perched ice has had a significant impact on sea level during the past several million years (Schweitzer and Thompson, 1996). Fossil evidence gives some indication of the temperature experienced at various stages of the glacial episodes (Davis and Taylor, 1980).

### 3.3. Atmosphere

Composition change is historical and is significantly influenced by the modification of carbon sequestering by human activity. The apparent equilibrium level of carbon dioxide at a given temperature is not consistent with current observations. The recent increase of atmospheric carbon is mainly attributed to the consumption of fossil fuels at a rate greater than the deposition of fossil material. The atmospheric impact on planetary temperature and specifically on the temperature at various levels within the planetary boundary layer is of enormous concern and importance, but is not within the scope of this report.

### 3.4. Surface

Climate has warmed in a cyclic manner over the past 150 years of recorded data (Hansen, 2004). Satellite observations indicate that the percentage of permanent ice cover of the Earth has decreased during the period 1970 through 2005, and ice thickness measurements of the north polar ice pack shows that the ice has thinned by about 30% since the 1950s (Meier, 2005). There is a concern about ocean salinity and currents in general as abnormal amounts of fresh water enter the ocean system. The Earth is essentially a water planet, and the planetary energy balance and the terrestrial weather conditions are strongly impacted by the dynamics of the oceans. The ice cover of the earth has been thought to be so tenuous that a retreat of 180 km in the circumpolar snow/ice line would sufficiently impact the albedo to the point of sufficient heating to remove all permanent ice from the surface, a condition last thought to exist about 3 million years before the present (Schweitzer and Thompson, 1996).

## IV. PLANT RESPONSE TO CLIMATE CHANGE

In light of apparent change in planetary heating, it is expected that climate volatility experienced during the coming decades will exceed that of the historic past. The volatility may prove of greater environmental impact than would a general trend of change. The observed plant responses to climate under a wide range of conditions are of potential value to environmental planning and mitigation of the impacts of change. Plants exhibit significant physical and chemical adaptations to even minor climate variations. The extent and time of adaptation under conditions of rapid climate change are not known.

### 4.1. Cork

The cork trees of Europe and trees of less economic value but similar adaptation have developed a cork protective layer that appears significant to survival in an environment that experiences occasional fire. Regeneration of trees following destruction of stems by fire is of ecological significance in many forest localities. A climate change to one favoring range fire in a historically low fire area would encourage vegetation change and perhaps species adaptation. The rate of change/ adaptation is open to speculation.

### 4.2. Leaf

The houseplant fancier has likely encountered defoliation of a plant that is placed in a "new" environment such as moving to a different location in the home or introduction to the home from outdoors or from a nursery. A simple outdoor walk around an open-grown tree will usually provide observation of a range of leaf conformations equipping the plant to optimize for the climate conditions that prevail at the various aspects of the tree (notably southwest to northeast sides).

Orientation is a conspicuous adaptation for some plants. Several members of the legume family(s) express diurnal leaf movement and a few stress- or stimulus-induced movement during the day. The vertical leaves of the North American Redbud (*Cercis canadensis* L.) have been observed to reduce leaf temperature by 5C and transpiration by 50% (Taylor, 1969). On the NE side of the same tree, where stress avoidance was not a factor, the leaves maintained a horizontal position.

### 4.3. Dimension

Understanding of surface slope and aspect (inclination impact on the environment) is the root of local climate and the likely starting point of the entire discipline of Climatology including the major discipline (or perhaps sub-discipline) of Meteorology. Not only is the flora a function of slope and aspect in many natural environments, but also individual species may adapt or hybridize to adapt sufficiently to populate the range of environments. One example is noted in the segregating population of hybrid oaks observed on a small mountain in central California by Benson *et al.* (1967). The data were plotted by Taylor (1975) according to aspect and leaf dimension classification based on Raunkiaer (1934). The leaves of the largest dimension class dominated the northeast-facing slope, and the smallest dimension class was on the southwest slope. There was a regular distribution of intermediate dimension leaves on the intervening aspects. It should be noted that several variable characters in addition to dimension characterize a population.

Studies of leaf thickness (Yun and Taylor, 1986), of leaf dissection, and wind tattering have investigated the extent of the adaptive nature of the leaf. Three cotton leaf forms are recognized as standard, okra form, and super okra form. Taylor (1975) observed that the form of the leaf is related to water use efficiency of photosynthesis. He found that there is an "ideal" leaf dimension for a specific climate. Kerby and Buxton (1978) demonstrated that productivity per unit leaf area can be maintained and water use per unit leaf area greatly reduced at selected (optimized) leaf dimension, although they did not make observations on water use and productivity at constant leaf area index with variable leaf dimension. Computations of optimal leaf dimension (including thickness) show that water use efficiency of production in cultivated crops could be doubled in many cases (that is yield maintained while water use is reduced by 50%). Increasing leaf thickness to the point that any greater thickness reduces the photosynthesis per unit dry weight of leaf has little influence on the diffusion resistance to water vapor but can significantly reduce the resistance to uptake of $CO_2$. In hot and dry environments the leaf of reduced dimension is less susceptible to over-heating (and excessive water loss) when solar energy absorption is extreme. Taylor and Sexton (1972) demonstrated that wind tattering of banana leaves contributes significantly to leaf survival during the dry season in Panama. They also noted that leaf dimension distribution for the vegetation was tightly clustered around the "theoretical" optimum for the dry season climate.

## V. SCALE AND MANAGEMENT OF RISK

It is obvious that a volatile climate will impact yields of annual and perennial crops on a seasonal basis. Perhaps volatility is a more serious impact of weather than is gradual climate change where adaptation of plants or migration of production regions is feasible. The short-term impacts of climate volatility constitute both environmental and economic risk. Risk is by nature manageable.

The El Niño event was not widely known before 1982. It has since then, however, been identified as a major risk factor influencing droughts and floods in numerous agronomically important regions. Knowing the regional risk of drought (of flood) in a given season gives opportunity for damage mitigation measures to be implemented. Anomalous sea surface temperatures (NOAA, 2006) may provide several weeks' to months' warning of a change from average climate conditions. For example, historically there have been no widespread drought events in central North America during El Niño years (although there was a serious yield reduction due to flood in 1993). The atmospheric pressure associated with the El Niño event has a direct impact on the long-range impact and is anticipated by the dynamics of the southern oscillation index (SOI). The Corn Belt of North America has experienced 17 serious drought years during the past century. During the period there were 23 years of record high, or near record high, crop yield. The probability of drought and of plentiful yield was found to be associated with SOI extremes (Carlson *et al.*, 1996). Knowing the risk associated with this aspect of our enigmatic climate enables the producer and the economic analyst to initiate appropriate impact mitigation measures.

## VI. CONCLUSION

The climate is changing. Changes are not permanent but may be long-term. Mitigation studies are essential to the managed sustainability of communities, production, and of ecosystems. Some 40 years ago the noted naturalist and geneticist Edgar A. Anderson told me, " A man who works with nature has a strong ally and a man who works against nature has a formidable foe." There is no question that an understanding of the impacts and biological response to a changing climate is essential. The question is: Will we utilize understanding and our knowledge of natural adaptations to mitigate the adverse environmental, social and economic impacts associated with a changing climate?

## 적 요

최근 수십년간 관측자료에 의하면 기후는 여러 측면에서 눈에 띄게 달라졌다. 이제는 관측이래 최고기온 혹은 최대강수량이란 단어가 그렇게 낯설지않은 시대가 되었고 앞으로의 변화와 그 여파에 더욱 긴장하며 살고 있다. 하지만 기후변화와 그 영향을 조금만 잘 이해하면 생태, 사회, 경제적 영향 가운데 우리가 충분히 받아들일 수 있는 부분도 상당하다. 식물과 자연생태계는 기후변화에 적응할 수 있는 다양한 방법을 이미 우리에게 보여주었다. 지구온난화에 의해 우리의 기후는 더욱 예측불허의 혼란에 빠질 것으로 보인다. 이 논문을 통해 역사적인 기후이변사례와 식물의 적응전략을 찾아보며, 인류가 기후변화를 극복하고 생태계를 유지하기 위해 보여주었거나 혹은 그렇지 못했던 사례에 대해 설명한다.

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