Little Ice Age Theory

James A. Marusek

I. Introduction

General Discussion

The sun is undergoing a state change. It is possible that we may be at the cusp of the next Little Ice Age. For several centuries the relationship between periods of quiet sun and a prolonged brutal cold climate on Earth (referred to as Little Ice Ages) have been recognized. But the exact mechanisms behind this relationship have remained a mystery. We exist in an age of scientific enlightenment, equipped with modern tools to measure subtle changes with great precision. Therefore it is important to try and come to grips with these natural climatic drivers and mold the evolution of theories that describe the mechanisms behind Little Ice Ages.

The sun changes over time. There are decadal periods when the sun is very active magnetically, producing many sunspots. These periods are referred to as Solar Grand Maxima. And then there are periods when the sun is very weak producing few sunspot. These periods are called Solar Grand Minima. Solar Grand Minima correspond to dark cold glooming periods called Little Ice Ages. And there are states in-between. During most of the 20th century, the sun was in a Solar Grand Maxima. But that came to an abrupt end beginning in July 2000. The sun produced 6 massive explosions in rapid succession. Each of these explosions produced solar proton events with a proton flux greater than 10,000 pfu @ >10 MeV. These occurred in July 2000, November 2000, September 2001, two in November 2001, and a final one in October 2003. And there hasn't been any of this magnitude since. Then the sun produced one of the weakest solar minimums since the Ap Index was first recorded (beginning in 1932). The current solar cycle (Solar Cycle 24) is very weak. Not quite weak enough to be called a Solar Grand Minima but very close. It is analogous to a period referred to as a 'Dalton Minimum'.

As we transitioned from a Grand Solar Maxima, which typified the 20th century to a magnetically quiet solar period similar to a Dalton Minimum (~1798-1823 A.D.), it gave us the opportunity to observe the changes in solar parameters across this transition.

I propose two mechanisms primarily responsible for Little Ice Age climatic conditions. These two components are Cloud Theory and Wind Theory. At the core of Cloud Theory are galactic cosmic rays (GCRs) and at the core of Wind Theory are diamond dust ice crystals. During Little Ice Ages, there is an increase of low level clouds that cause a general global cooling and an alteration of the jet streams that drives cold air from upper latitudes deep into the mid latitude regions.

Little Ice Age conditions are defined not only by colder temperatures but also by a shift in the patterns of wind streams. They produce long-lasting locked wind stream patterns responsible for great floods and great droughts. They also affect the cycle of seasons producing great irregularity and crop failures. Altered wind streams impacts the development of massive storms and hurricanes. These Little Ice Age conditions in the past caused poor crop yields, famines, major epidemics, mass migration, war, and major political upheavals.

Solar Cycle

Sunspots are dark spots that appear on the surface of the sun. They are the location of intense magnetic activity and they are the sites of very violent explosions that produce solar storms.

The sun goes through a cycle lasting approximately 11 years. It starts at a solar minimum when there are very few sunspots and builds to a solar maximum when hundreds of sunspots are present on the surface of the sun and then returns back to a solar quiet minimum. This cycle is called a solar cycle. We are currently within Solar Cycle 24, so named because it is the 24th consecutive cycle that astronomers have observed. The first documented cycle began in March 1755.

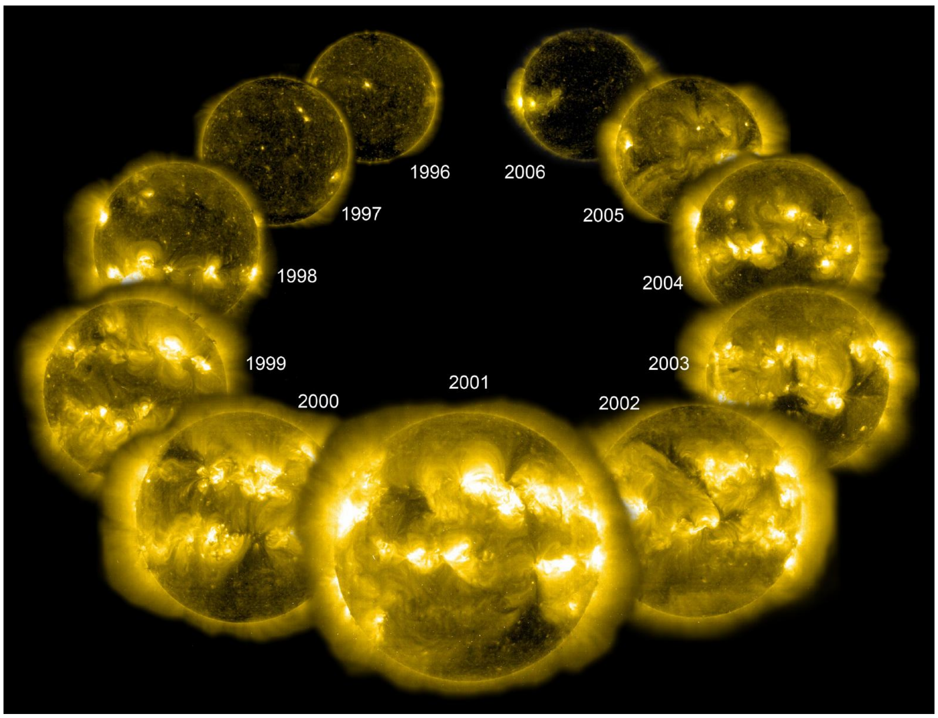

Figure 1. Image of Solar Cycle 23 from the Solar and Heliospheric Observatory (SOHO) by Steele Hill (NASA GSFC)

The sun exhibits great variability in the strength of each solar cycle. Some solar cycles produce a high number of sunspots. Other solar cycles produce low numbers. When a group of cycles occur together with high number of sunspots, this is referred to as a solar *Grand Maxima*. When a group of cycles occur with minimal sunspots, this is referred to as a solar *Grand Minima*. Usoskin details the reconstruction of solar activity during the Holocene period from 10,000 B.C. to the present.[1] Refer to Figure 2. The red areas on the graph denote energetic solar *Grand Maxima* states. The blue areas denote quiet solar *Grand Minima* states.

The reconstructions indicate that the overall level of solar activity since the middle of the 20th century stands amongst the highest of the past 10,000 years. This time period was a very strong *Grand Maxima*. Typically these *Grand Maxima's* are short-lived lasting in the order of 50 years. The reconstruction also reveals *Grand Minima* epochs of suppressed activity, of varying durations have occurred repeatedly over that time span. A solar *Grand Minima* is defined as a period when the (smoothed) sunspot number is less than 15 during at least two consecutive decades. The sun spends about 17 percent of the time in a *Grand Minima* state. Examples of recent extremely quiet solar *Grand Minima* are the Maunder Minimum (about 1645-1715 A.D.) and Spörer Minimum (about 1420-1570 A.D.)

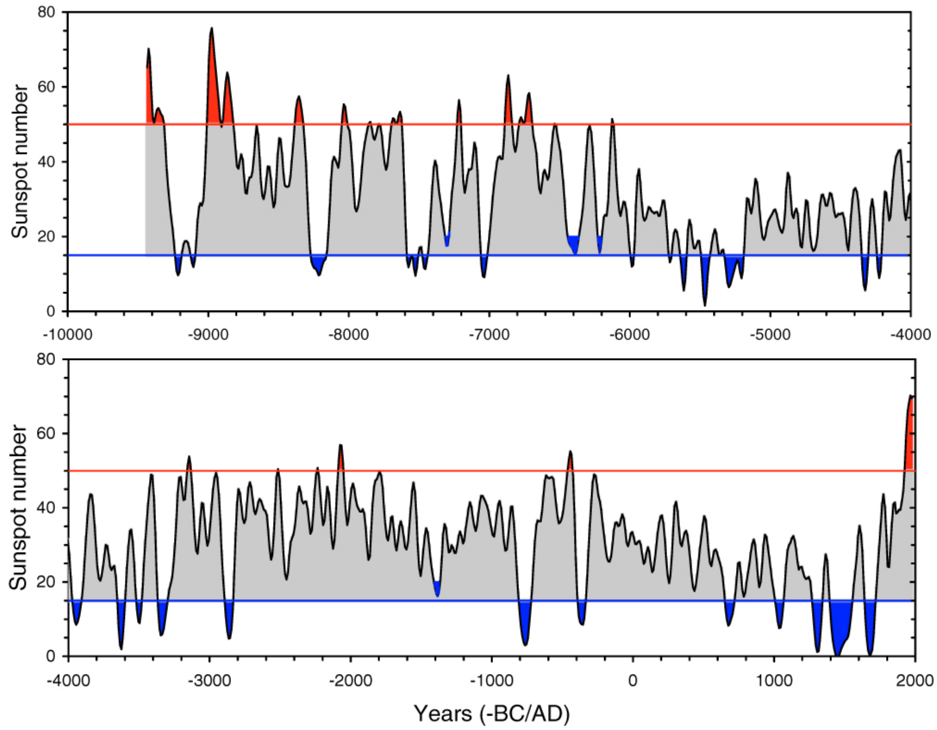

Figure 2. Sunspot activity throughout the Holocene. Blue and red areas denote *grand minima and maxima*, respectively. The entire series is spread out over two panels for better visibility.[1]

Little Ice Age

Several centuries ago, the Earth underwent a very dramatic shift in climate. This period was known as the Little Ice Age. This period coincided with periods of minimal sunspot activity called the Maunder Minimum from 1645 to 1715 A.D. *But how did the climate change during the Little Ice Age and why was it so dreaded?*

Average temperatures dropped approximately 1.5º C below current levels. Many rivers froze and during the spring thaw created massive ice dams generally along the bends in rivers. These caused major floods and when the ice dams burst caused general destruction of river towns. The cold and extreme weather caused a reduction of the growing season. This caused disastrous harvest failure. Hunger became the heart of this crisis. Plagues, smallpox, typhus, measles and fever belong to a cluster of deadly diseases that correlate closely with harvest yields. Little Ice Age conditions that produced famines increased the frequency and intensity of these diseases. Flooding created swamplands that became mosquito breeding grounds and introduced tropical diseases such as malaria throughout Europe.[31] During the Little Ice Age, glaciers expanded rapidly in Greenland, Iceland, Scandinavia and North America. Glaciers expansion destroyed alpine settlements. It also caused vast tracts of land to become uninhabitable. The Arctic ice pack expanded into the far south. Several reports describe Eskimos landing their kayaks in Scotland. The Viking colonies in Greenland were abandoned altogether, as were many Inuit communities.[32] And into this mix entered almost continuous warfare, rebellions and revolutions. In a short timeframe, when it was all done, a third of the world's population perished. Extreme weather events were common during the Little Ice Age and frankly terrifying. They included great storms, deep and long lasting droughts and massive floods. The Nile River Inundations, the India Monsoons and China Loess were all affected.

The exact scale of demographic contraction is hard to document. In 1654 the abbess of the convent of Port-Royal near Paris lamented that a 'a third of the world had died', while, a generation later, the Chinese emperor asserted that during the transition from the Ming to the Qing dynasties 'over half of China's population perished'. Many surviving statistical data support such claims. Thus parish registers from Île-de-France, where Port Royal stood, show that 'almost one quarter of the population vanished in a single year'. In China, tentative reconstruction of population levels in Tangcheng county in Jiangnan between 1631 and 1645 shows that some areas suffered almost 60 per cent losses. The number of taxable households in western Poland also fell by more than 50 percent between the census of 1629 and that of 1661 while, further east, tax registers in what is now Belarus showed falls of between 40 and 95 per cent in urban populations between 1648 and 1667. In Germany, parts of Pomerania and Mecklenburg in the north, like parts of Hessen and the Palatinate in the center, apparently lost two-thirds of their population between 1618 and 1648. Württemberg, in the southwest, boasted a population of 450,000 in 1618 but only 100,000 in 1639.[2]

The climate during the last Little Ice Age was typified by unusually cold winters, great storms and unusual long lasting periods of rainfall in some regions that produced great floods and unusual long lasting periods of no rainfall that produced great droughts. These were driven by a global change in wind patterns. Although the written record is somewhat limited, the following weather events are delineated in Appendix A for the Maunder Minimum.

In his book *Global Crisis*, Geoffrey Parker describes the catastrophic effect of climate change during the last Little Ice Age in the 17th century.[2] He describes three regions that were greatly affected. These were marginal lands, cities, and macro regions. I have included Appendix B as a sidebar to discuss the vulnerabilities of cities for a return of Little Ice Age climate.

Quiet Sun

The sun is currently undergoing a state change. It is transitioning from a Grand Solar Maxima, which typified the 20th century to a magnetically quiet solar period similar to a Dalton Minimum. As a result, it would be beneficial to observe how the sun has changed and the effect of these solar changes on Earth.

The following is observed:

1. The number of sunspots have decreased significantly by 50% or greater.
2. There have been fewer solar flares and coronal mass ejections (CME's), which produces Solar Proton Events (SPE's) and geomagnetic storms on Earth. During the transition, beginning in July 2000, the sun produced 6 massive explosions in rapid succession. Each of these explosions produced solar proton events with a proton flux greater than 10,000 pfu @ >10 MeV. These occurred in July 2000, November 2000, September 2001, two in November 2001, and a final one in October 2003. *And there hasn't been any of this magnitude since.*[3]
3. The magnetic field exerted by the sun has significantly weakened. The Average Magnetic Planetary Index (Ap index) is a proxy measurement for the intensity of solar magnetic activity as it alters the geomagnetic field on Earth. It has been referred to as the common yardstick for solar magnetic activity. Ap index measurements began in January 1932. The quieter the sun is magnetically, the smaller the Ap index. During the 822 months between January 1932 and June 2000, only one month had an average Ap index that dropped down to 4. But during the 186 months between July 2000 and December 2015, the monthly Ap index fell to 4 or lower on 15 occasions.[4]
4. The number of Galactic Cosmic Rays (GCRs) striking Earth has increased. GCRs are high-energy charged particles that originate outside our solar system. They are produced when a star exhausts its nuclear fuel and explodes into a supernova. The Sun's magnetic field modulates the GCR flux rate on Earth. Cosmic rays are deflected by the interplanetary magnetic field embedded in the solar wind, and therefore have difficulty reaching the inner solar system. The effects from the solar winds are felt at distance approximately 200 AU from the sun, in a region

of space known as the Heliosphere. As the sun goes quiet magnetically, the Heliosphere shrinks, and a greater number of these particles are able to penetrate into the Earth's atmosphere. Currently the sun's interplanetary magnetic field has fallen to around 4 nano-Tesla (nT) from a typical value of 6 to 8 nT. The solar wind pressure is down to a 50-year low. The heliospheric current sheet is flattening. In 2009, cosmic ray intensities increased 19% beyond anything we've seen since satellite measurements began 50 years ago.[33]

5. In general, the sun's total irradiance varies about 0.1 percent over normal solar cycles. But this variation is not linear across the entire radiation spectrum. Between 2004 and 2007, it was observed that the decrease in ultraviolet radiation (with wavelengths of 400 nanometers) was 4 to 6 times larger than expected, whereas the visible light (400-700 nanometers) showed a slight increase.[5] This is significant because Solar UV flux is a major driver of stratospheric chemistry.
6. The upper atmosphere of Earth collapsed. The thermosphere ranges in altitude from 90 km to 600+ km above the Earth's surface. During the depth of last solar minimum in 2008-2009, the thermosphere contracted by the largest amount observed in at least the last 43 years. The magnitude of the collapse was two to three times greater than low solar activity could explain.[6]
7. Solar radio flux during the peak of the solar cycle has diminished significantly. The F10.7 index is a measure of the solar radio flux per unit frequency at a wavelength of 10.7 cm, near the peak of the observed solar radio emission. The current solar cycle has the lowest F10.7 flux since recordings began in February 1947.[7]
8. Sightings of noctilucent clouds (or night clouds) are appearing at lower latitudes. These clouds are formed from ice crystals in the extreme upper atmosphere, called the mesosphere and are thought to be seeded from comets/meteors. Noctilucent clouds (NLCs) were first reported by Europeans in the late 1800s. In those days, you had to travel to latitudes well above 50º to see them. Now, however, NLCs are spreading. In recent years they have been sighted as far south as Colorado and Utah in the United States.

The last solar Grand Minima was the Maunder Minimum (1645-1715 AD). During the 30-year period from 1672-1699 AD, there were less than 50 sunspots detected, whereas during the past century over the same period between 40,000-50,000 sunspots normally would appear.

II. Cloud Theory

The sun is a major force controlling natural climate change on Earth. Our Milky Way galaxy is awash with cosmic rays, high-speed charged particles (protons, ions). Because the particles are charged, their travel is strongly influenced by magnetic fields. Our sun produces a magnetic field that extends to the edges of our solar system. This field deflects many of the cosmic rays away from Earth. But when the sun goes quiet (minimal sunspots), this field collapses inward allowing cosmic rays to penetrate deeper into our solar system. As a result, far greater numbers collide with Earth and penetrate down into the lower atmosphere where they ionize small particles of moisture (humidity) forming them into water droplets that become clouds. Charged raindrops are ten to a hundred times more efficient in capturing aerosols than uncharged drops. Low clouds tend to be optically thick and are efficient at reflecting sunlight back into space. A large increase in Earth's cloud cover produces a global drop in temperature.

Galactic Cosmic Rays (GCRs) are high-energy charged particles that originate outside our solar system. About 85 percent are protons (nuclei of hydrogen atoms), 12 percent alpha particles (helium nuclei) and the remainder are electrons and the nuclei of heavier atoms. The energy levels of GCRs observed in deep space generally lie in the 100 MeV (million electron volts) to 10 GeV (billion electron volts) range. Above 1 GeV, the particle flux rate decreases significantly according to a power law with an exponent of approximately 2.5. The ability of particles to penetrate deep into our lower atmosphere is a function of the speed, a function of their energy levels. Many of these particles are traveling at near the speed of light. Cosmic rays are produced when a star exhausts its nuclear fuel and explodes into a supernova. These stars are generally new short-lived blue stars of the spectral type O (20-100 solar masses) or blue-white stars of spectral type B (3-20 solar masses).

Galactic cosmic rays are a very effective amplifying mechanism for climate forcing because the energy needed to change cloudiness is small compared with the resulting changes in solar radiation received at the Earth’s surface.

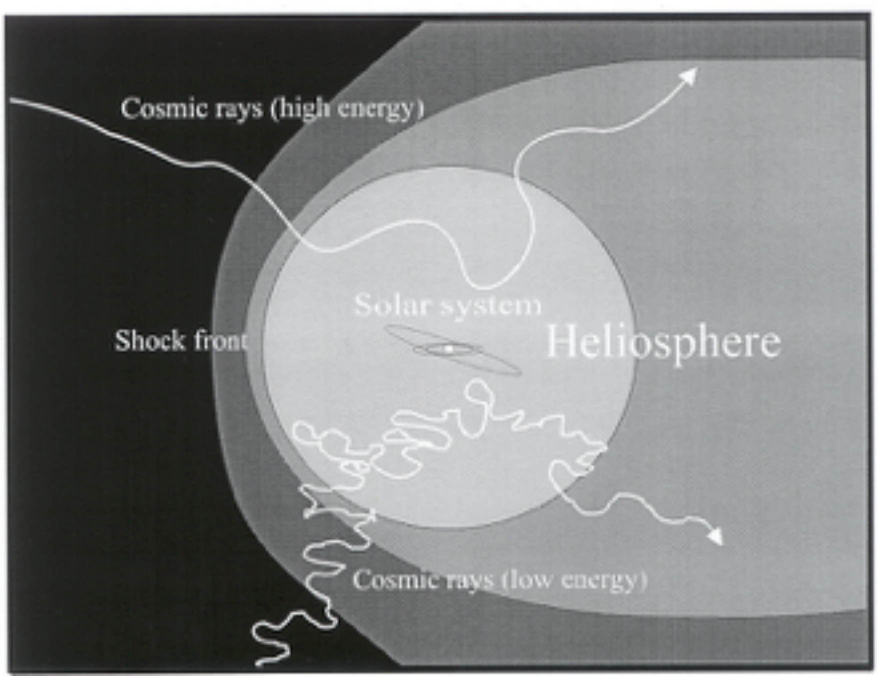

Figure 3. Pictorial of GCR interaction with the Sun’s Heliosphere.

The Sun's magnetic field modulates the GCR flux rate on Earth. Just as cosmic rays are deflected by the magnetic fields in interstellar space, they are also affected by the interplanetary magnetic field embedded in the solar wind (the plasma of ions and electrons blowing from the solar corona at about 400 km/sec), and therefore have difficulty reaching the inner solar system. The effects from the solar winds are felt at distance approximately 200 AU from the sun, in a region of space known as the Heliosphere. Refer to Figure 3.

The relationship between solar cycles and GCR flux rate at the Earth's surface is shown in Figure 4. R_z is the Sunspot Number. J is the cosmic ray flux. This flux rate measured energetic galactic cosmic rays in the energy range of 145-440 MeV using ground based neutron monitors. During solar maximum the GCR flux rate is at its minimum. During solar minimums, the GCR flux rate increases significantly. The graph covers the period from 1974-2001.

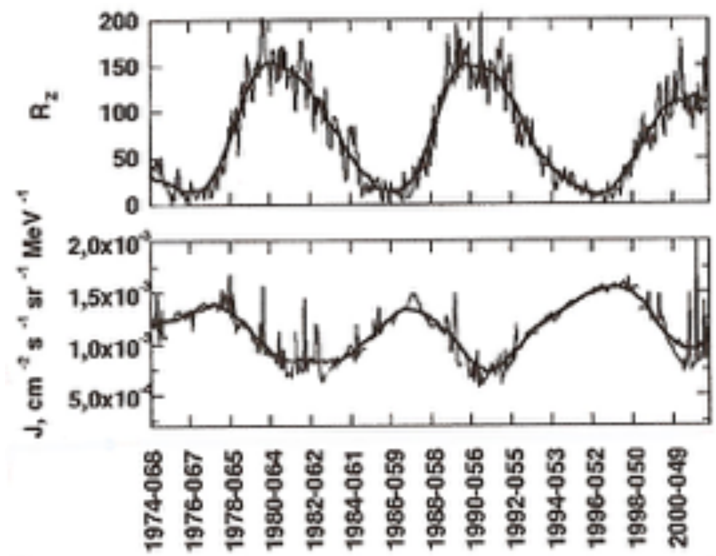

Figure 4. Sunspot Cycle vs. GCR flux rate.[8]

When GCRs collide with the Earth's atmosphere, they release in nuclear collision a cascade of secondary particles (protons, neutrons and muons), which continue to penetrate deeper and deeper into the atmosphere. This cascading effect continues until the particle's energy falls too low to undergo further collisions. This generally ends around 16 kilometers above the Earth's surface in the lower atmosphere. The ions produced within the troposphere by cosmic rays are important element of aerosol production. In the troposphere, ionization contributes to gas-particle formation of ultra fine (<20nm) aerosols that build into cloud condensation nuclei (CCN). Charged raindrops are ten to a hundred times more efficient in capturing aerosols than uncharged drops. In slightly supersaturated water vapor, when aerosol is dissolved in the tiny haze particles the droplets' vapor pressure lowers, which increases droplet growth. The water vapor condenses into larger water droplets that form clouds.

Earth's ocean cloud cover is strongly correlated with GCR flux modulated by solar cycle variations. Refer to Figure 5.

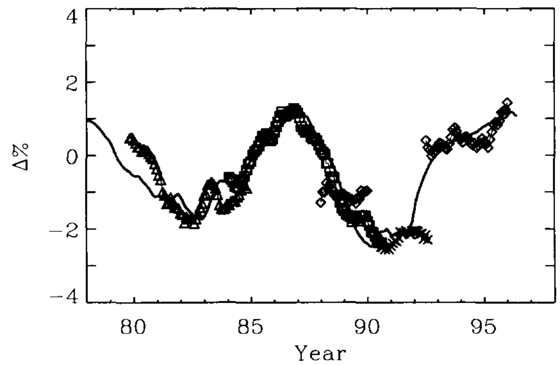

Figure 5. A strong correlation between Galactic Cosmic Rays (GCRs) and Earth's cloud cover over the oceans. This figure shows cosmic rays fluxes from Climax (thick curve) plotted against four satellite cloud data sets. Triangles are the Nimbus-7 satellite data, squares are the ISCCP-C2 data, diamonds are the DMSP data, and crosses are the ISCCP-D2 data.[9]

In 2006, the Danish National Space Science Center in Copenhagen, Denmark conducted experimental studies of aerosol nucleation in air, containing trace amounts of ozone, sulfur dioxide and water vapor at concentrations representative of Earth's atmosphere over the oceans. Their SKY experiments confirmed the causal mechanism by which cosmic rays facilitate the production of clouds in Earth's atmosphere.[10] Specifically the experiments showed that (1) stable cloud aerosol clusters were formed in the presence of ions, (2) the nucleation rate was proportional to the ion density, (3) the characteristic time for producing stable clusters was very short (2 seconds or less).

Experiments at CERN (Conseil Européen pour la Recherche Nucléaire, or European Council for Nuclear Research) in Geneva, Switzerland, titled CLOUD (Cosmics Leaving OUtdoor Droplets), verified that ionization from cosmic rays significantly enhances aerosol formation.[11]

Further experiments by Svensmark and collaborators at the Danish National Space Science Center published in 2013, showed that aerosols with diameter larger than 50 nm are produced by ultraviolet light (from trace amounts of ozone, sulfur dioxide, and water vapor), and these are large enough to serve as cloud condensation nuclei.[12]

The foundation of this theory has made major inroads over the past few years. I felt that it would be worthwhile to interject my thoughts into the Cloud Theory. They are provided in Appendix C.

In summary, as the sun slides into the next Solar Grand Minima and sun's magnetic field strength collapses inward. This allows a greater number of galactic cosmic rays to reach the inner solar system. Some of these particles traveling near the speed of light impact Earth and drive deep into Earth's lower atmosphere releasing a cascade of ions. These ions provide electric charge to the microscopic water droplets in the air. Charged water droplets are ten to a hundred times more efficient in capturing aerosols than uncharged droplets. Thus these microscopic water droplets clump together to form the small water droplets that make up clouds. Low clouds tend to be optically thick and are efficient at reflecting sunlight back into space. A Solar Grand Minima produces a large increase in Earth's cloud cover over the oceans and as a result, a global drop in temperature.

III. Wind Theory

Summary

As the sun goes quiet, the level of UV radiation emitted by the sun drops significantly. This reduction alters the heating in the upper atmospheric region called the stratopause. This alters the reaction zone where diamond dust ice crystals form. Diamond dust reflects sunlight at the top of the atmosphere. It is a force multiplier because of the minute amounts of water needed to produce diamond dust ice crystals. These microscopic ice crystals can stay aloft for weeks and months creating pockets of cold air beneath. As normal diamond dust production in Polar Regions drop, temperature rises and the polar vortex weakens. Diamond dust falling in the stratosphere outside the polar vortex creates blocking highs that change the wind pattern of the jet stream from a zonal to a meridional flow. The meridional flow pattern also allows the jet stream to penetrate and move colder air from regions of high latitude into mid latitude.

Wind Streams

There are two primary wind streams that affect Earth's weather and climate. These are the polar and subtropical jet streams. One set of each of these wind streams exists in the Northern hemisphere and another set in the Southern hemisphere.

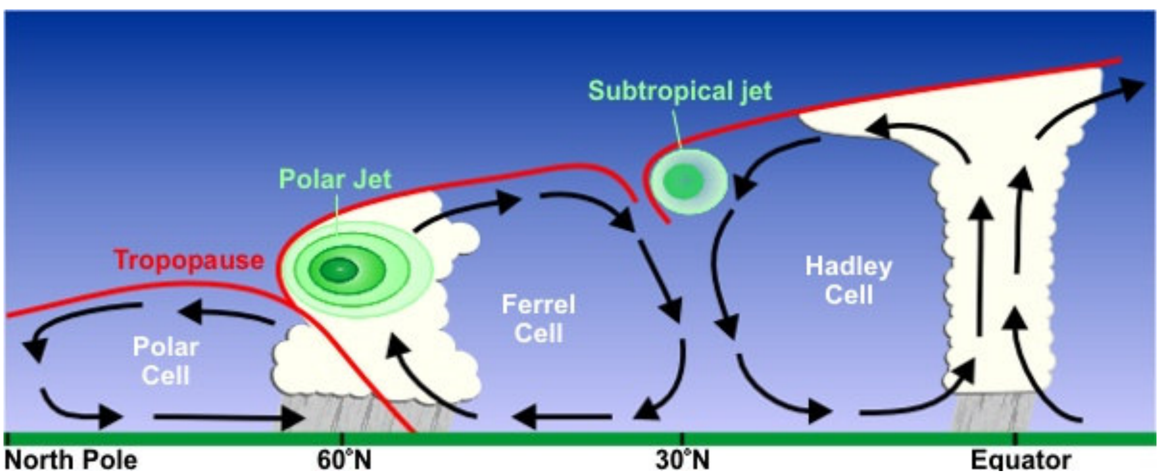

Figure 6. Jet Streams

There are two polar vortices, one around the North Pole, and one around the South Pole. The polar vortex (also called the circumpolar vortex, polar low, or polar cyclone) is a persistent, large-scale cyclone, circling the planet's geographical poles. A Polar Vortex is created when an area of low pressure sits at the rotation pole of a planet. This causes air to spiral down from higher in the atmosphere, like water going down a drain. The bases of the two polar vortices are located in the middle and upper troposphere and extend into the stratosphere. These cold-core low-pressure areas strengthen in the winter and weaken in the summer due to their dependence upon the temperature differential between the equator and the poles. They usually span less than 1,000 kilometers (620 miles) in diameter within which the air circulates in a counter-clockwise fashion in the Northern Hemisphere, and in a clockwise fashion in the Southern Hemisphere. As with other cyclones, their rotation is caused by the Coriolis effect.

The major jet streams on Earth are westerly winds (flowing west to east). Their paths typically have a meandering shape; jet streams may start, stop, split into two or more parts, combine into one stream, or flow in various directions including the opposite direction of most of the jet. The strongest jet streams are the polar jets (also called the polar night jet), at around 9–12 km (30,000–39,000 ft) above sea level, and the higher and somewhat weaker subtropical jets at around 10–16 km (33,000–52,000 ft). The Northern Hemisphere and the Southern Hemisphere each have a polar jet and a subtropical jet.

The polar jet is the boundary layer that surrounds the polar vortex. In the Northern Hemisphere in winter it is generally located between 30° and 60° N latitude. In the Southern Hemisphere it is generally located between 50° and 65° S latitude. It is a barrier because it effectively blocks any mixing between air inside and outside the vortex during the winter. Wind speeds in the polar jet wind speeds varying between 193 and 402 km (120 and 250 miles) per hour. When the polar vortex is strong it constrains the extremely cold air to the Polar Regions, but when it is weak, the vortex can be penetrated and the frigid Arctic/Antarctic air pushed thousands of miles in the direction of the equator. The northern hemisphere polar jet flows over the middle to northern latitudes of North America, Europe, and Asia and their intervening oceans. While the southern hemisphere polar jet mostly circles Antarctica all year round. The Antarctic polar vortex is more pronounced and persistent than the Arctic vortex. This is primarily due to the distribution of land masses at high latitudes in the northern hemisphere which produce Rossby waves which contribute to the breakdown of the vortex, whereas in the southern hemisphere the vortex remains less disturbed. Almost all big storms develop, mature, and dissipate in the vicinity of this main jet stream.

When the upper level winds are parallel or nearly parallel to the lines of latitude the wind pattern is termed zonal. When the winds cross the latitude lines at a sharp angle, the wind pattern is termed meridional. In a meridional pattern the jet stream will have highly amplified troughs and ridges. Low-pressure systems tend to move faster (west to east) when associated with a zonal flow. A highly meridional flow can cause atmospheric blocking and spells of much below and much above normal temperatures. A meridional pattern, which its highly curved flow, generates more vorticity than that associated with a zonal flow.

Figure 7. An example of a meridional jet stream.

Diamond Dust

Diamond dust is a very unusual form of ice crystal. These ice crystals have a hexagonal molecular structure. They are microscopic in size, approximately the width of a human hair. The majority of these crystals are either solid column or plates. The solid columns can range from (50-1000 μm) in length and from (2-7 μm) in width. The plates can range from (3-100 μm) in thickness. As a result, they are incredibly light. Diamond dust generally forms under otherwise clear or nearly clear skies, so it is sometimes referred to as clear-sky precipitation. Because diamond dust does not always reduce visibility it is often first noticed by the brief flashes caused when the tiny crystals, tumbling through the air, reflect sunlight to your eye. This glittering effect gave the ice crystals their name "diamond dust" because they appear to be diamonds flashing in the sky. So unlike normal snow clouds, clouds of diamond dust can be nearly invisible.

In very clean areas, where there are no particles (ice nuclei) to help the droplets freeze, they can remain liquid to −39 °C (−38 °F), at which point even very tiny, pure water droplets will freeze and form diamond dust. It is most commonly observed in Antarctica and the Arctic, but it can occur anywhere with a temperature well below freezing. In the interior of Antarctica, it is fairly common to observe diamond dust at temperatures below about −25 °C (−13 °F).

When these ice crystals align together, they can produce atmospheric phenomena such as halos, sundogs and moondogs and light pillars [sun pillars and moon pillars], along with parhelic circles. There are two main forms of diamond dust ice crystals. These are microscopic hexagon solid plates, and hexagon columns. But other forms exist including hollow hexagon columns and pyramids. Thin hexagon plates can act like miniature mirrors that can reflect sunlight. They can produce atmospheric optical effects like light pillars. Hexagon columns can refract sunlight like a prism and can produce atmospheric optical phenomena including (22º and 46º) halos, sundogs, moondogs, and parhelion.

These ice crystals are incredibly light. Individual crystals appear to float in the air. While diamond dust can be seen in any area of the world that has cold winters, it is most frequent in the interior of Antarctica, where it is common year-round. The Plateau Station was in operation from 1966-69. Diamond dust was observed on average 316 days a year at Plateau Station in Antarctica.[13] It is estimated that over 70% of the precipitation that fell at Plateau Station in 1967, fell in the form of diamond dust.[14] Once melted, the total precipitation for the year was only 25 mm (0.98 in).

Diamond dust ice crystals can form in the stratopause and upper stratosphere where solar heating from UV radiation can melt and evaporate the frozen moisture within the ozone layer. The stratopause is the boundary between the stratosphere and the mesosphere. The atmospheric pressure in this region is 1/1000th of the atmospheric pressure at sea level. As this liquid moisture reaches the edge of the reaction zone, the water is super cooled in this rarified atmosphere and then frozen in the form of diamond dust.

Diamond dust generated in the stratopause and upper stratosphere act as miniature mirrors which reflect the sunlight back into deep space from the top of the atmosphere. As a result the sunlight is reflected before it can heat any of the atmosphere. Plate shaped crystals float in the air horizontally like a leaf. On the other hand, column shaped ice crystals tend to float in the air vertically. But when these aerodynamic hexagon columns encounter wind streams, they will reorient to a horizontal orientation. Because diamond dust is incredibly light, it can float aloft for weeks or months before it reaches the earth's surface. Diamond dust is like a force multiplier. Water in the form of diamond dust ice crystals is very efficient per unit weight as a planetary cooling mechanism. (Clouds of diamond dust can filter light similar to a camera lens filter.)

Because of the reflective/refractive characteristics of these ice crystals, they cool the atmosphere beneath. When there are diamond dust ice falls, temperature drops of 10º C are commonly observed. "Pockets of cold" form beneath diamond dust clouds that ever so slowly drift down through the atmosphere. These molecules of air are constricted and become denser. In meteorological terms, high-pressure masses are formed. If these cold dense regions become large enough they can deflect or block jet stream winds.

Ozone Layer

The Earth is surrounded by a thin layer of ozone in the middle atmosphere. Ozone is a minor constituent of the stratosphere (1-10 parts per million). Ozone and oxygen molecules in the stratosphere absorb ultraviolet light from the Sun, providing a filter that prevents this radiation from passing to the Earth's surface. While both oxygen and ozone together absorb 95 to 99.9% of the Sun's ultraviolet radiation, only ozone effectively absorbs the most energetic ultraviolet light (UV), known as UV-C (220-290 nm) and UV-B (290-320 nm).

Ozone levels in the atmosphere are in a natural state of quasi-equilibrium. There is a delicate balance associated with the very upper part of the ozone layer. This balance is driven by the sun. One solar reaction is a destroyer and the other a restorer. Ozone is destroyed by solar proton events, a component of solar storms but slowly restored by UV radiation, a component of sunlight.

Earth's atmosphere is composed of approximately 21% molecular oxygen (O_2) and 78% molecular nitrogen (N_2). These two molecules are the principal constituents in the Stratosphere. A number of minor constituents are present which includes nitric oxide (NO), atomic oxygen (O), ozone (O_3) and water vapor. Ozone is produced in the stratosphere through a natural process of photo dissociation of O_2 by ultraviolet light (UV).

$$3O_2 + UV \rightarrow 2O_3$$

Nitric oxide is produced through a natural process when solar and galactic cosmic rays (high-energy protons), collide with nitrogen and oxygen molecules unbinding the atoms allowing them to freely recombine to form nitric oxide. Nitric oxide is a natural ozone-depleting chemical.

$$NO + O_3 \rightarrow NO_2 + O_2$$

$$O + NO_2 \rightarrow NO + O_2$$

The sun routinely generates violent explosions that produce burst of high-energy protons. These events are known as Solar Proton Events (SPE's). Ozone layer density on Earth can be dramatically affected by SPE's, which can locally decrease ozone content in the stratosphere 10-15%. [15]

A solar storm of 28 October 2003 produced a massive Solar Proton Event with a proton flux of 29,500 (pfu @ 10 MeV). As a consequence, there was a very large increase in the production of NO_X ($NO + NO_2$) over a range of altitudes and latitudes. Over the next several months, these particles transported downward through the mesosphere and upper stratosphere.[16] This caused a record level loss of ozone in the upper atmosphere. Measured ozone levels were reduced up to 60 percent about 40 kilometers above Earth's high northern latitudes.[17] In the southern polar cap region, ozone losses of 75% were measured in the mesosphere and upper stratosphere from this solar storm.[18]

Annually ozone holes appear in the Polar Regions each year. Ozone holes are areas where the reduction of ozone is dramatic; leaving voids in the ozone layer. UV radiation creates ozone through the process of photo disassociation when it strikes oxygen in the atmosphere. During the perpetual darkness in the Polar Regions during winter, UV radiation is blocked by the tilt axis of Earth relative to the sun. Therefore ozone losses cannot be restored in this region until the sunlight returns and as a result ozone holes naturally form. The ozone losses occur annually each spring in the Polar Regions but recover by the summer.

The next question that needs to be asked is *"What effect does the sun going quiet, have on the ozone layer?"*

> Beginning in July 2000 as the sun began to go quiet, the sun produced 6 massive explosions in rapid succession. Each of these explosions produced solar proton events with a proton flux greater than 10,000 (pfu @ >10 MeV). These occurred in July 2000, November 2000, September 2001, two in November 2001, and a final one in October 2003. And there hasn't been any of this magnitude since. So after October 2003, the *destruction* of the ozone layer by natural forces was minimized significantly because of an absence of massive solar storms.
>
> Spectral Irradiance Monitor (SIM) which is part of the Solar Radiation and Climate Experiment (Sorce) satellite suggests that ultraviolet irradiance fell far more than expected between 2004 and 2007 — by ten times as much as the total solar irradiance (TSI) did. This means that the *restorative properties* of UV radiation on the ozone layer has diminished.

These two effects appear to counter-balance each other and the ozone layer still remains in a state of quasi-equilibrium.

Reaction Zone

The reaction zone is the region of the upper atmosphere where diamond dust ice crystals are formed.

Temperature in the lower stratosphere is isothermal and averages around -60°C, but increases markedly in the upper part, to reach a maximum of about 0°C at the stratopause. Solar energy is converted to kinetic energy when ozone molecules absorb ultraviolet radiation, resulting in heating of the stratosphere. Temperature increases with ozone concentration. Ozone is not uniformly distributed. Ozone is present in higher concentration in higher latitudes and it is in higher latitudes, rather than at the equator, that the stratosphere is warmest. Due to the very low air density, even the small amount of ozone concentrated in the upper stratosphere is extremely effective in absorbing radiation, thus giving the 'high' temperatures at 50 kilometers.

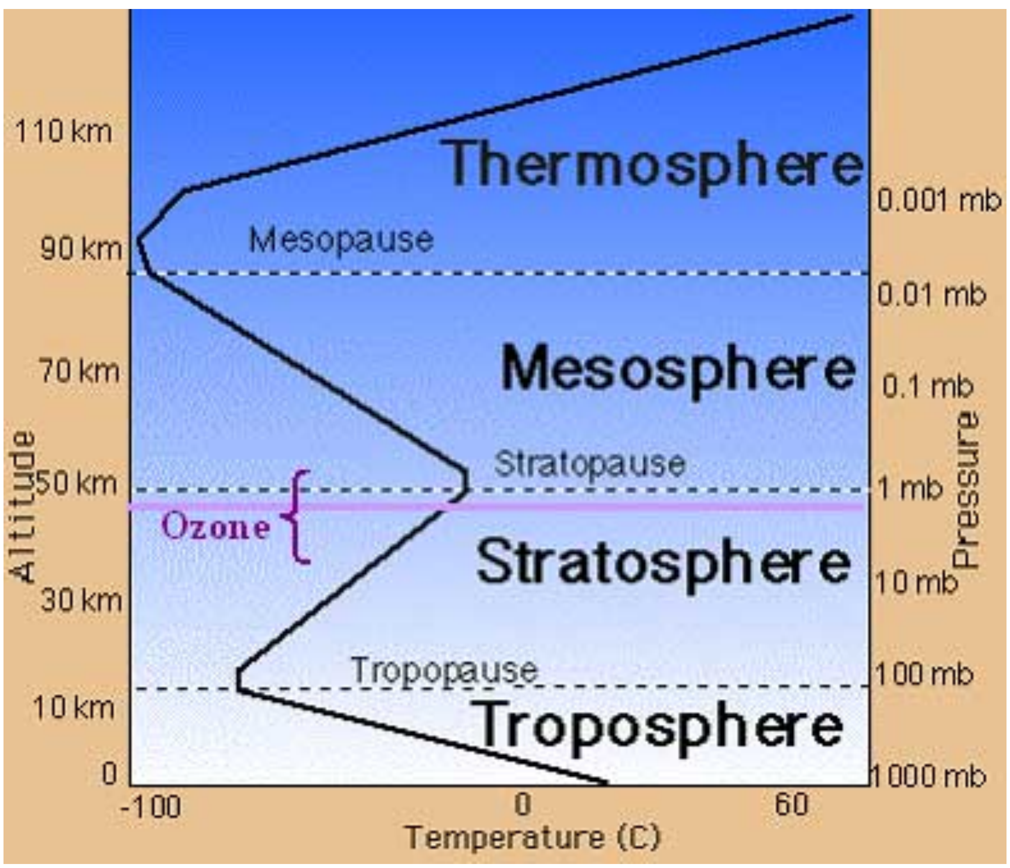

Figure 8. Ozone heating between Mesosphere and Stratosphere.

At the center of the reaction zone, the temperatures reach at or above freezing, the moisture within this zone (normally in the form of ice particles) melts and evaporates by the heating from UV radiation as it reacts with the top layer of ozone. As this liquid moisture falls to the edges of the reaction zone, it is super cooled down to -35 to -40 degrees and transforms into diamond dust ice crystals in the rarefied air (with pressures around 1 millibar) within this reaction zone.

The source of the moisture in the reaction zone is described in Appendix D.

The diamond dust ice crystals slowly drift over weeks and months towards the planets surface reflecting sunlight and forming pooled cold pockets of air beneath. Diamond dust and the cold pockets of air are sucked into the polar vortex into the Polar Regions locking the extreme cold at the poles.

> Diamond dust is frequently observed in the interior of Antarctica, where it is common year-round. The Plateau Station was in operation from 1966-69. Diamond dust was observed on average 316 days a year at Plateau Station in Antarctica.[13] It is estimated that over 70% of the precipitation that fell at Plateau Station in 1967, fell in the form of diamond dust.[14]

The next question that needs to be asked is *"What effect does the sun going quiet, have on this reaction zone?"*

> Spectral Irradiance Monitor (SIM) which is part of the Solar Radiation and Climate Experiment (Sorce) satellite suggests that ultraviolet irradiance fell far more than expected between 2004 and 2007 — by ten times as much as the total solar irradiance (TSI) did. This means that atmospheric heating cause as UV radiation interacting with the ozone layer decreases significantly.

This effect will shrink the reaction zone, especially the sub region where temperatures are at or above 0º C. As a result less diamond dust will be formed and sucked into the polar vortex and as a result the Polar Regions will begin to warm slightly.

This temperature trend can be observed using very accurate satellite data. When the monthly Arctic (60º N to 85º North latitude) lower troposphere temperature data is compared for the period (from when the satellite temperature recordings first began in) December 1978 to July 2000 with the data (when the sun began to go quiet) from August 2000 to February 2016, the temperature in this region increased 0.94º C. In comparison during the same time periods the global temperature (85 S. to 85 N.) only increased by 0.30º C.[19]

Although it is counter intuitive, as the sun goes quiet, there is a significant reduction in the light it emits in the ultraviolet range, this affects the production and distribution of diamond dust ice falls. Less diamond dust being swept into the Polar Regions means these regions will warm slightly and the polar vortex will weaken. Diamond dust not swept up by the Polar Vortex tends to collect into clumps that produce dense cold regions that fall into the jet stream creating high pressure blocking systems. That in turn, alters wind patterns and drive the jet stream winds from a zonal flow to a meridional flow pattern.

Closing Summary

As the sun transitions into a Solar Grand Minima producing a radical decrease in sunspots, the ultra violet (UV) radiation emitted by the sun drops significantly. This drop alters the heating produced by the UV radiation in the upper atmospheric region known as the stratopause. Within this region of rarified air, the temperatures rise above freezing, frozen moisture evaporates, and later as it falls outside the reactions zone, the liquid moisture is super cooled down to the point where microscopic ice crystals form known as diamond dust. Diamond dust is highly reflective and ultra light, allowing the crystals to stay aloft for weeks and months. Pockets of cold dense air forms beneath these ice crystals. Diamond dust is a force multiplier because only a minute amount of water is needed to alter climate. Diamond dust produces the large temperature gradients that power the polar vortex which lock and isolate the extreme cold air to the Polar Regions. But as the UV radiation drops, the region where diamond dust forms in the stratopause shrinks. The diamond dust and the pockets of cold air flowing into the polar vortex diminish, the Polar Region warm slightly, and the polar vortex weakens and deforms. This alters the main Polar jet stream from a zonal to a meridional flow. The meridional flow pattern produces higher wind speeds, blocking ridges that can bring cold weather and heavy snowfalls, a vehicle for moving colder air from high latitude to mid-latitude. It is a driver of severe weather and violent storms.

Although the solar minimum leading up to Solar Cycle 24 produced very few sunspots, it is pale in comparison to a solar Grand Minima event lasting several decades.

Was the pattern of changing wind streams observed during the last Little Ice Age? During the last Grand Minima events, early explorers made significant progress in probing and surveying the New World. They described North America as

> *"In the New World, cold predominates. The rigor of the frigid zone extends over half of those regions which should be temperate by their position [latitude]. Countries where the grape and the fig should ripen, are buried under snow one half of the year; and lands situated in the same parallel with the most fertile and best cultivated provinces in Europe, are chilled with perpetual frosts, which almost destroy the power of vegetation." "The wind, in passing over such an extent of high and frozen land, becomes so impregnated with cold, that it acquires a piercing keenness, which it retains in its progress through warmer climates, and it is not entirely mitigated until it reach[es] the Gulf of Mexico. Over all the continent of North America, a north-westerly wind and excessive cold are synonymous terms. Even in the most sultry weather, the moment that the wind veers to that quarter, its penetrating influence is felt in a transition from heat to cold no less violent than sudden. To this powerful cause we may ascribe the extraordinary domination of cold, and its violent inroads into the southern provinces in that part of the globe."* [20]

The observations of these early explorers indicate that not only was this large amplitude atmospheric circulation pattern present during the last Little Ice Age in North America, it was actually stronger and the jet stream reached all the way down into the Gulf of Mexico pulling with it very frigid air.

Diamond dust drives a global change in wind patterns. A quiet sun not only weakens the polar vortex and drives the main polar jet stream towards a meridional flow but also plays a similar role in altering the subtropical jet stream that pulls moisture from the equator and weakens the trade winds. It affects the major flood cycles such as the Nile River inundation, and the India monsoons.

Appendix A

Extreme Weather during the Maunder Minimum (1645-1715 A.D.)

(Unless otherwise noted, all references are sourced to Reference 21)

The region around the eastern Mediterranean (the Ottoman Empire) was severely affected by adverse climate during the Maunder Minimum. Most areas suffered drought and plague in the 1640's, the 1650's and again in the 1670's, while the winter of 1684 was the wettest recorded in the eastern Mediterranean during the past five centuries, and the winters of the later 1680's were at least 3° C cooler than today. In 1687 a chronicler in Istanbul, Turkey reported 'This winter was severe to a degree that had not been seen in a very long time. For fifty days the roads were closed and people could not go outside. In cities and villages, the snow buried many houses.' In the Golden Horn [major urban waterway and the primary inlet of the Bosphorus in Istanbul], the snow 'came up higher than one's face.' The following year, floods destroyed crops around Edirne [close to Turkey's borders with Greece and Bulgaria], ruining the estates that normally supplied the imperial capital with food.[2]

In the 1640's and 1650's, a civil war griped the British Empire. This war combined with the effects of a series of failed harvest that led to famines, and plague epidemics killed approximately a quarter of a million people in England, Scotland and Wales or 7% of the population. The population in Ireland alone fell by 20%. In 1655, it was recorded that 'a man might travel twenty or thirty miles [in Ireland] and not see a living creature' except for 'very aged men with women and children' whose skin was 'black like an oven because of the terrible famine.' It produced in Scotland a famine of which 'the lyke had never beine seine in this kingdome heretofor, since it was a natione.' [2]

From Newfoundland [Canada] to Patagonia [the southern end of South America], the Americas experienced notably colder winter and cooler summers in the 1640s and 1660s. In 1675 a 'year without summer', remains the second coldest recorded in North America during the last six centuries. All surviving harvest records show dearth in the 1640s and 1650s.[2]

The Canadian Rockies experienced a severe and prolonged drought from 1641 to 1653.[2]

Between 1643 and 1671, Indonesia experienced the longest drought recorded during the past four centuries with intense episodes between 1659 and 1664.[2]

In 1645 A.D. in England, the summer was excessively hot and dry. 'The air very warm and so infectious that dogs, cats, mice, and rats died, and several birds in their flight over the town dropped dead.' The plague was very violent.

In 1645 and 1646 in Russia, there was a drought and plague of locust; and early frosts and poor harvests in the south in 1647 and 1648, creating widespread food shortages.[2]

In 1645, a great storm struck Shanghai, China, which caused the sea to break the dikes, spread saltwater over the land and destroyed the rice crop.

In 1645, rains in Crete more intense than anything recorded in the twentieth century destroyed crops and buildings.[2]

Starting in September 1645, rain fell almost continuously on Sicily for a year, destroying first the winter crops and then drastically reducing the yield of the summer harvest. In August 1646, the wheat prices rose higher than ever previously recorded. Then in the autumn of 1646, a great drought occurred that lasted through the winter and into the succeeding spring of 1647, which seemed to threaten a universal catastrophe.[2]

In 1646, a great storm struck Holland and Denmark and the floods drowned 110,000 people. The sea broke in at Dordrecht, the Netherlands, and thereabout, and drowned 10,000 people. Around Dullar in Friesland and Zealand, it drowned 100,000 people, and 300 villages.

In the Ukraine, the cruel winter of 1645-46 produced heavy snow and frosts. These gave way to daily rains so torrential that the roads became impassable. This destroyed the harvest and made it impossible for the Cossack communities along the lower Dnieper to feed themselves.[2]

Torrential rains in 1646 and a drought in 1647 destroyed the harvest surpluses on which Istanbul (the capital of the Ottoman Empire) depended, creating a food shortage.[2]

The imperial Mughal army [of India] invaded Afghanistan but the winter of 1646-47 brought such intense cold that the Mughal garrisons 'burned themselves in the fires they lit for warmth, and no one left their houses for fear of being frozen.' [2]

In 1646, a plague of locust destroyed the crops in Moldavia. 'No leaf, no blade of grass, no hay, no crop, nothing remained.' The same disaster destroyed the next two harvests.[2]

In Crimea in 1647, people were starving. According to a chronicle 'last year there was no harvest, and now the cattle, sheep and cows are dying.' [2]

In England, 'bad weather ruined the harvest of corn [grain] and hay for five years from the autumn of 1646 onward.' [2] In 1647 and 1648 in England, the weather was very cold, damp and rainy over most of these years. Cattle died everywhere of a murrain. The price of wheat hit its highest mark in 1648 and 1649 (over the 100 year period from 1646-1745) denoting a scarcity.[21]

In the Iberian Peninsula, 1646 produced a disastrous harvest. In May 1647, just when the new grain harvest seemed safe, all over Andalusia, in southern Spain 'the weather turned cold, even worse than the coldest January day'. Freak frosts killed the ears of grain and produced the worst harvest of the century.[2]

In 1647, the harvest failed in France, leaving both the capital and the court short of food.[2]

In some regions of the Dutch Republic, it rained every day between April and November 1648, so that the hay and grain rotted in the fields. Then came 6 months of frost and snow during which the canals froze over, stopping all barge traffic in the Netherlands. Many complained the winter lasted six months. The summer of 1649 was also unusually wet, and the summer of 1650 unusually cold. Between 1648 and 1651, grain prices in the Republic stood at their highest level for a century.[2]

The French kingdom suffered from several years of extreme climate, which led to crop failures and famines. These problems were compounded by excessive taxation, which led to the Fronde revolution in France in the years 1648 to 1653. About one million French men and women died, either directly or indirectly, because of the Fronde. As dawn broke on 27 August 1648, 'one saw children five and six years old with daggers in their hands, and mothers arming them themselves.' [2]

Adverse weather ruined the harvest of 1648, throughout southern Italy. The price of grain in Naples quadrupled. Officials reported murmurs among the people saying, 'It was always better to die by the sword than to die of hunger.' [2]

In the Yucatán in Mexico, beginning in 1648 heavy rains brought a plague of yellow fever into the region. The rains were followed by 'such a hard and extraordinary drought that it rendered the land sterile and produced such intense heat' that wildfires raged throughout the Yucatán, destroying all crops left by the drought. The local chronicler Diego López Cogolludo claimed that 'Almost half the Indians perished with the mortality caused by the plague, famine and smallpox' from 1648 to 1656.[2]

During the winter of 1648-49, the River Thames froze in London, England.

In 1649, there were great floods in England and France. In 1649 and 1650, there was a famine in Scotland and the North of England from rains and wars. This was followed by a plague in Ireland and England. In 1650 and 1651, there was a famine throughout the country of Ireland.

Since 1636, Scotland had experienced the worst sustained drought in a millennium. This culminated in heavy snow followed by a cereal harvest of 'small bulke' in the summer of 1649, so that the prices of food 'of all sortes were higher than ever heirtofoe aney[one] living could remember.' [2]

The plague epidemic that spread through southern Europe in the decade after 1649 killed one half of the inhabitants of Seville, Barcelona, Naples and other similar cities.[2]

In 1649, there was 226 days of rain or snow in Germany followed by a winter that lasted 6 months.[2]

The winter of 1649-50 was the coldest on record in both northern and eastern China.[2]

In Russia, tree-ring, pollen and peat-bed data show that the springs, autumns and winters between 1650 and 1680 were some of the coldest on record during the past 500 years. Repeatedly, crops either failed or produced little food.[2]

Reconstructed tree-ring sequences from the island of Tasmania [island state of Australia] showed a succession of poor growing seasons in the mid and late seventeenth century, a period that saw the 'most prolonged cool period in the past 700 years.' [2]

In Sweden, a prolonged period of cold weather had reduced crop yields and trade, and the harvest of 1650 'was the worst Sweden had known for fifty years, or was to know for near fifty more', and in March, the Stockholm bakers fought each other at the city gates to secure some of the scarce flour.[2]

In China the winters between 1650 and 1680 formed the coldest spell recorded in the Yangzi and Yellow river valleys over the last two millennia.[2]

In southern China in the 1650's, seventeen counties in Guangdong province reported frost or snow. This was the highest number in two centuries.[2]

In 1650, there were excessive heat and drought in Italy. After the harvest, the scorching heat was succeeded by very great rains and these were followed by a most rigorous cold. In France, this year was noted for a great scarcity of grain; the price was three times higher than in the previous five years.

In 1650 in Egypt, the Nile River during its annual flood reached its lowest level of the century. According to Alan Mikhail, 'Egypt is a desert with a river running through it'; a poor Nile flood drastically reduced the crop yields of the entire province. During this period of time, Egypt was the breadbasket of the Ottoman Empire.[2]

The thunderstorms of the year 1651 produced a great flood year in France. All the rivers overflowed their banks. In Provence, France on September 8th, the Durance River ascended to the gates of Avignon. In November at Grenoble, the Isère River overflowed bridge and fifty houses, drowned fifteen hundred beasts in the country and three hundred in the city. The flood left three or four feet of sand in the streets. The waters rose, they say, more than twenty feet above their usual height.

In 1651 in the Netherlands, so much snow fell that the state funeral of Stadholder William II had to be postponed because numerous mourners could not reach The Hague.[2]

The year 1651 saw the longest recorded drought in Languedoc and Roussillon, the Mediterranean borderlands between France and Spain, which lasted 360 days.[2]

In 1652, there was a drought in Scotland. The warmth was very great, the summer being the driest ever known in Scotland. It was also very hot and dry in England and Denmark.

In England, the years 1651-54 produced scorching hot dry summers and dry years. In July 1653, it was so furiously hot in Poland, that in the regiment of foot soldiers, which was the King's Guard, marching most of them barefooted upon sand, more than 100 fell down altogether disabled [heat stroke], whereof a dozen died outright, without any other sickness.

In 1653, a drought near Shanghai, China caused a famine.

During 1654-57, an epidemic of the bubonic plague caused widespread depopulation in Russia.[2]

There was a great drought in southern France in 1654-56. Rains were very rare.

During the winter of 1654-55, it was so cold in Belarus in the Balkans that the provisions of wines and beer froze on the sledges in one night even though they were insulated with straw. The soldiers had to break the vessels and put the pieces of ice wine into kettles to thaw them over a fire in order to drink them.

In 1655 during the winter, Mau and Tien lakes in China were frozen over. For several days, people could walk over them.

This winter of 1655-56 in France and Germany was very severe. In France, the Seine River froze. In Germany, the cold was so great that one could get in Wismar (Mecklenburg-Schwerin) onto the frozen Baltic Sea with a loaded four-horse wagon and travel a distance of 5-6 German miles, which has not been the case for many years. On the land, the wells were frozen to the bottom. On the roads in Bohemia [now western Czech Republic], several people were found frozen to death. It was very cold in Scotland.

In 1656 and 1657 in Rome, Italy, there were floods and a famine. In July, there was a great rainstorm, which caused the Danube River in Europe to flood over its banks, tearing down bridges and mills, drowning many people and cattle. Sixteen towns and villages were swept away.

Between 1657 and 1661, England experienced 5 bad harvests in a row.[2]

The winter of 1657-58 was very severe in Europe. The bays and inlets of Northern Europe froze over. Charles X of Sweden crossed the strait to Denmark with his whole army, including the artillery, baggage and provision trains. In January his army crossed the frozen Small Belt on foot and invaded and conquered the island of Funen. He then traveled on the frozen Great Belt and leapfrogged through the islands of Langeland, Lolland, Falster, and finally his army reached Zealand on 11 February. There was great snow in Rome, Italy on 27 February 1658. The rivers of Italy froze deep enough to bear the heaviest carts. The cold winter in France destroyed the olive trees and it was accompanied by deep snows. The Seine River in France was completely frozen from the first days of January.

After the landmark winter of 1657-58, the snowmelt in France was augmented by torrential rains and many rivers burst their banks, including the Seine, which flooded Paris for the third time in a decade. Since farmers could not sow their crops, the following harvest was very poor.[2]

The winter of 1657-58 was also severe along the U.S. Atlantic coast. Massachusetts Bay froze over while the Delaware River froze so hard that deer ran across it. The winter was severe in England. 'The crow's feet were frozen to their prey; islands of ice enclosed both fish and fowl frozen, and some persons in their boats.' In Europe, people rode their horses on the ice across the Danube River at Vienna, Austria; across the Main River at Frankfurt, Germany; and across the Rhine River at Strasbourg, France; while barge traffic along the rivers and canals of the Netherlands gave way to sledges. The canal between Haarlem and Leiden in the Netherlands remained frozen for 63 days. The Baltic froze so hard that a horse and cart could pass easily from the mouth of the Vistula River at Gdańsk, Poland to the Hel Peninsula.[2]

In England during the spring of 1658, the north wind and cold continued so rigorous and long that farmers lost hope of their grain either growing or ripening. In Modena in northern Italy, there was excessive heat and drought. In Abdera in Greece, there was an excessively hot summer. In Denmark and Copenhagen, there was drought and excessive heat. In September, England was struck by a strong gale that caused much destruction on land and eight frigates and ships of the line, and two thousand officers and seamen perished.

In 1658-60, a catastrophic monsoon failure produced a widespread famine in India, especially in Gujarat whose population relied heavily on imported food. In 1659, the southeast India saw 'so great a famine', that 'the people [are] dying daily for want of food', while in Gujarat 'the famine and plague' became 'so great' that they 'swept away the most part of the people, and those that are left are few'. The drought continued in Gujarat into 1660 and the famine raged and 'the living being hardly able to bury the dead'.[2]

The Aegean and Black Sea regions experienced the worst drought of the last millennium in 1659, followed by a winter so harsh that the Danube at Girugiu (200 miles inland from the Black Sea) froze so hard in a single night that the Ottoman army marched across the ice into Romania, 'laying waste all the villages and leaving no blade of grass or soul alive anywhere'. Because of the famine, many were forced to sell their children. Transylvania also experienced meager harvests, which caused widespread starvation. An official noted in his journal that, thanks to war and the weather, 'Transylvania never knew such misery as this last year [1660]'.[2]

The cold winter of 1659-60 was very severe in England, France and Italy. It destroyed the olive trees almost completely.

Between 1660 and 1680, more typhoons struck southern China at Guangdong province than at any other time in recorded history.[2]

A disastrously wet winter and spring in 1661 in France caused another famine and the price of bread in Paris tripled. King Louis XIV bought grain in Aquitaine, Brittany and the Baltic and brought it to the capital.[2]

In 1661 in the northwest region of India and eastern Pakistan there was a severe drought that led to a famine. 'Life was offered for a loaf, but none cared for it; rank was to be sold for a cake, but none cared for it. For a long time dog's flesh was sold for goat's flesh and the pounded bones of the dead were mixed with flour and sold. Destitute at length reached such a pitch that men began to devour each other and the flesh of a son was preferred to his [son's] love. The numbers of the dying caused obstruction in the roads.'

On 18 February 1661, a great and dreadful storm struck England. The damage was estimated at a little less than 2 million [£240 million in today's currency using the retail price inflation index].

In 1662, there was a great drought in Shanghai, China. This caused a bad harvest and food was very scarce.

The winter of 1662-63 was very cold in France and England. The Seine River froze in France along with the River Thames in England. In this frost, ice skates were introduced into England from Holland. On 1 December, the king witnessed the performance of skating.

In 1663, there was an excessive wet autumn in England and as a result a great death of cattle. On 28 August there was a very great frost. Eastern France experienced cold and rainy weather during the summer also.

For 6 months in 1663, the northwest regions of Iran received neither rain nor snow, so that 'wells dried up and crops withered'.[2]

Poland experienced frost on several summer days in 1664, 1666 and 1667.[2]

The winter of 1664-65 was long and cold in England. It was very severe in France. In Belgium there were very severe frosts and heavy snowfalls. The winter in Poland was so severe that most of the wines froze and several people lost their limbs [due to severe frostbite], and others froze to death.

In 1665 in England, there were great flooding of rivers, and inundations from the sea. There was a great plague in England. In London 68,596 persons are said to have died from the plague. After an order to kill cats and dogs, it is said that 40,000 dogs and 200,000 cats were destroyed. The plague was very fatal at Derby. 'The country people refused to bring their commodities to the marketplace, depositing them outside town; then retired to a distance till the buyer had deposited his money in a vessel filled with vinegar.' At Winchester, the dead were carried out by cartloads at a time, and the plague was as bad as in London.

In 1666, there was a great drought in England. In the moors between Yeovil and Bridgewater, the dried pasture showed the outline of trees beneath. They were dug up and there was hundreds of oaks as black as ebony [petrified wood]. In England, it was intensely hot and dry. The Great Fire of London occurred. [This was the largest fire that ever occurred in London. It began on 2 September 1666 and continued for four days, and consumed thirteen thousand houses, eight-six churches and public buildings. St. Paul's Cathedral was among the number. The buildings were all destroyed on 400 streets.]

In 1666, England was struck by massive storms that contain exceptionally large hail and tornadoes. Some of the hailstones were a foot in circumference. These storms occurred on 17 July and 13 October.

On 14-15 August 1666, a great Atlantic hurricane struck the islands of Guadeloupe, Martinique and other islands in the Caribbean causing approximately 2,000 deaths. All the vessels [17 sails] in the Saints [Barbados] were driven on shore. The whole of Lord Willoughby's fleet, only two were ever heard of afterwards. All the batteries (with walls of six feet thick) near the sea were destroyed; and guns, fourteen pounders, were washed away.

In 1666, there was a great drought in Shanghai, China.

Spain suffered from harvest failures in 1665-1668 and 1677-1683, a plague epidemic in 1676-1685, and then more harvest failures in 1685-1688.[2]

Between 1666 and 1679 in most if not all regions of China, 9 out of 14 summers were either cool or exceptionally cool, and a recent study of Chinese glaciers suggests a late seventeenth-century climate on average more than 1° C colder in the west and more than 2° C colder in the northwest than today.[2]

The winter of 1666-67 was very severe in the Netherlands producing extreme cold. This occurred late in the winter season from 16 March to 1 April. The seas near Amsterdam froze completely. Several ships were stuck in the ice.

During the winter of 1666-67, Poland experienced 109 days of frost.[2]

In the years 1666 and the 3 years after, Iran experienced plagues, locusts that destroyed the harvest, and famines.[2]

In Montbéliard, France in 1667 the summer was very cold and dry. There was not a single month throughout the year in which it had not frozen.

On 1 September 1667, a tremendous hurricane desolated the island of St. Kitts in the West Indies. All the houses and building on the island were blown down. This is probably the same hurricane that moved up the Atlantic coast in the U.S. and struck in what is now Virginia on 6 September. Buried in the ruins were much goods and many people. Many lives were lost.

In 1668, a small pox epidemic killed 1/9th the population of London, England.

During the winter of 1669-70 it was intensely cold. The Little and Great Belts were frozen, and many people perished. [The Great Belt in Denmark (Danish: Storebælt) is a strait between the main Danish islands of Zealand (Sjælland) and Funen (Fyn). The Little Belt separates Fyn from Jylland.] The Danube River was frozen so hard that it carried people, horses and wagons. In Italy and France, there was severe cold. The extreme cold [in France] during January and February destroyed a large number of trees. In west-central Germany, the waters of the Rhine River froze at Koblenz, so that artistic craftsman exercised their several trades upon the ice (ice fair on the Rhine).

In Moldavia, in the summer of 1670, 'Terrible floods, frequent showers and heavy rainfall day and night raged for three months on end, destroying all the best wheat, barley, oats, millet and all types of crop. Because they lie in water and are attacked by too much moisture, they neither ripen nor can bear seeds. Nor can the grasses and herbaceous seeds in hayfields grow, for frost and water; or, if they do, they cannot be harvested [because] the sun never warms or dries up the land.' [2]

In Africa, according to a Turkish traveler in the 1670's, 'no one in Egypt used to know about wearing furs. There was no winter. But now we have severe winters and we have started wearing fur because of the cold.'[2]

In 1671, severe droughts struck many regions of China.

In 1671, excessive heat and drought destroyed the harvest in Sicily. The famine caused heavy mortality.[2]

On 8 December 1671 there was a great snowfall in England. Then on 9-11 December, a storm of freezing rain struck England. It destroyed a great many trees and made the roads impassable. Many travelers were stranded. This was then followed by a heat wave where apple trees blossomed before Christmas. The winter in France was severe and the cold lasted for three months.

In May 1672, the drought lowered the water in the l'Yssel [sometimes called Gelderse l'Jssel River in eastern Netherlands] and the Rhine River [in Germany]. The river was fordable on one arm of the river at several locations. This allowed the army of Louis XIV, to cross the river on June 5. An epidemic of measles prevailed in London, England in that year. And in Shanghai, China, a great drought struck the region.

In France, the year 1672 saw the worst harvest in a decade due to a drought followed by torrential rains, and those of the two succeeding years were scarcely better.[2]

In 1673 in England the year was a cold unseasonably bad year, and a very late lean year. Shanghai, China was struck by an unusual hailstorm. The individual hailstones weight 3 or 4 pounds.

The winter of 1673-74 was severe in the Netherlands. 'The Zuiderzee was completely frozen; 16 March we crossed it on foot, on horseback and sleigh on the ice between Stavoren and Enkhuizen.' The winter was very cold in Poland. In England, it snowed for 11 continuous days.

In England, on 7-8 May 1674, there was a great flood on the rivers Trent and Tame. An epidemic of smallpox was very violent in London, England. It destroyed 1/8th of the people. In 1674, a great storm (with lightning, thunder, large hail and tornadoes struck the Netherlands, France and Belgium causing extensive damage. The Camargue [river delta] in France was covered by the floodwaters of the Rhône River in 1674.

In 1675, much of the northern hemisphere experienced a 'year without a summer'.[2]

In November 1675, a great storm struck the Netherlands. The storm was so violent that it caused several breaches in the great dikes near Enchusen and others between Amsterdam and Haarlem. Forty-six vessels were cast away at Texel and almost all the men drowned. These breaches caused a great inundation, which caused much damage. Many people, cattle and houses were lost.

The winter of 1676-77 was extremely cold in northern France. The Seine River at Paris was frozen for 35 consecutive days. The river Meuse [Maas] was frozen from Christmas till 15 January and heavily laden wagons crossed over on the ice.

Around July 1678, there were great floods in France. The River Garonne in one night swelled all at once so mightily, that all the bridges and mills above Toulouse were carried away. In the plains which were below the town, the inhabitants who built in places which by long experience they had found safe enough from any former inundation, were by this surprised, some were drowned, together with their cattle, others only saved themselves by climbing trees or getting to the tops of houses. Others who were looking after their cattle in the field were warned by the horrible noise and furious torrents of water and fled but could not escape without being overtaken. At the exact same time the two rivers of Adour and Cave, which fall from the Pyrénées Mountains, as well as some other little rivers of Gascoygne overflowed in a similar manner and cause the same devastation. New river channels formed in the mountains by the furious torrents, which tore up the trees, earth, and great rocks.

In 1679, drought struck many regions of China. The drought caused a scarcity in the vicinity of Shanghai, China.

In 1679, another drought struck Sicily. Grain prices again reached famine level.[2]

In England in 1680 the summer was extremely hot and dry. In Wrocław, Poland, there was great heat during the summer. There was a great hailstorm in Europe where the hail was 1 foot deep. There was a great flood in Londonderry, Ireland. In the beginning of August, a hurricane struck Martinique and the Dominican Republic. Twenty-five large French ships were lost, two English ships and several Spanish ships producing a great loss of life. There was a great drought in the vicinity of Shanghai, China.

In Sahel in Africa, drought in the 1680's became so severe and so widespread that Lake Chad fell to its lowest level ever recorded.[2]

The winter of 1680-81 was intensely cold in Europe including southern France and Italy. The Little and Great Belts in Denmark were frozen, and many people perished. In England, the winter was long, severe and intensely cold. This year the cold was so severe as to split whole forests of oak trees. The cold was so severe Provence, France that it killed the olive trees.

The spring and summer of 1681 in England was extremely hot and dry. The herbs and grasses were burned, and in the air, no trace of moisture could be detected. An epidemic of smallpox was violent in London, England killing 1/8th of the inhabitants.

On 6 June 1682 a great storm struck Tortorica in the Valley of Demana in Sicily and continued for 36 hours. Great torrents of water fell from the neighboring mountains with so great rapidity, that they carried down trees of extraordinary bulk, which demolished the walls and houses of the town. Over 600 persons were drowned. It formed a new bank at the mouth of the river over 2 miles long. Several other adjacent towns received similar damage.

In 1683, a hurricane struck the east coast of Florida in the United States causing 496 deaths.

The winter of 1683-84 in England lasted for 13 weeks. The river Thames in London was frozen to a depth of 11 inches. Booths and shops were erected on the ice and a great frost fair was held. A whole street of booths, contiguous to each other, was built from the Temple Stairs to the barge-house in Southwark, which were inhabited by traders of all sorts, which usually frequent fairs and markets, as those who deal in earthenwares, brass, copper, tin, and iron, toys and trifles; and besides these, printers, bakers, cooks, butchers, barbers, coffee-men, and others, who were so frequented by the innumerable concourse of all degrees and qualities, that, by their own confession, they never met elsewhere the same advantages, every one being willing to say they did lay out such and such money on the river of Thames. Almost daily about 40 hackney coaches drove back and forth across the ice as if they were on dry land. A bullfight and a foxhunt were organized on the frozen river. A great many shows and tricks to be seen. Large fires were made on the ice. On 2 February, an ox was roasted whole and King Charles and the Queen ate part of it. Nearly all the birds perished. Many trees, plants and herbs were destroyed by the extreme cold. Many oak trees split apart with a loud bang, like a musket shot. Solid ice was reported extending for miles off the coasts of the southern North Sea (England, France and the Low Countries), causing severe problems for shipping and preventing the use of many harbors. Ice formed for a time between Dover (England) & Calais (France), with the two sides joined together. All the French ports were closed for three or four weeks, the harbors being frozen over. Ice extended nearly 24 miles off the coast of the Netherlands. The cold was very severe in northern Europe. The ice was 27 inches thick in the harbor of Copenhagen, Denmark. Almost all the rivers in Belgium and the Netherlands were crossable with loaded wagons. An extraordinary amount of snow fell in southern France.

In 1684, the drought in France was excessively severe. Jean-Dominique Cassini ranked the year 1684 among the warmest in an array spanning 82 years of great heat in Paris, France. It was also equally hot and dry in England.

In 1685, there was an epidemic of smallpox in London, England, where 1/9th of the population died.

In 1685-87, a catastrophic monsoon failure produced a widespread famine in India, especially in Gujarat whose population relied heavily on imported food. In Madras, parents gave away their children and adults sold themselves into slavery in order to avoid starvation.[2]

During the years 1686-89, there was a great drought in Italy.

In 1686, a military engineer on campaign in Romania complained 'for three years now, I haven't seen a single drop of rain'. Lakes and rivers dried up, and 'in the swampy soil, cracks were so deep that a standing man could not be seen … I doubt if there is another example of such a terrible and lasting drought.' [2]

A strong hailstorm with hailstones weighting up to 1 pound each struck Lille, Belgium on 24 May 1686 causing great destruction. In June, a flood came down from the mountains and nearly destroyed the towns of Kettlewell and Starbottom in England. The water was the height of a church steeple.

In 1687, there was a great flood in Dublin, Ireland. The lower part of the city was underwater up to the first floor and boats plied in the streets. There was also a great estuary flood in the River Severn in England. In the summer many of the rivers in England were flooded and many people drowned. When the fruit ripened on the trees, great swarms of gnats and insects appeared.

In 1688, an epidemic fever struck Ireland and England. A great typhoon struck Shanghai, China. The storm extended over 370 miles and caused great destruction of life and property in every direction.

The winter of 1688-89 was very severe in England and the river Thames was frozen. A frost fair was held on the river in London. In Germany, the winter was severely cold with great falls of snow.

In 1689, there was a famine in Northern Ireland. 'The inhabitants glad to eat rats, tallow and hides.' France experienced their driest years in 30 years. Heavy rainfall caused a great flood in Norwich, England. The long drought broke in Italy, when the country experienced great rains, which rendered the whole spring frightful and good for nothing. A great hurricane struck the island of Nevis in the West Indies killing one half of the inhabitant. Droughts struck many regions of China and as a result many wells, springs and rivers dried up.

Climatologists regard the extreme climate events and disastrous harvests during the 1690's, with average temperatures 1.5° C below those of today, as the 'climax of the Little Ice Age'. Sea temperatures around the Orkney Islands and Scandinavia in the 1690's were 5º C colder than today.[2]

In 1690, an awful snowstorm struck Scotland, which lasted thirteen days and nights. During that time nine-tenths of the sheep were frozen to death, and many shepherds lost their lives. In 1690 in Ireland, there was famine and disease.

In Italy in 1690, there was a famine from excessive rains. Around the end of March, the heavens seemed to open their bosom and pour out their whole great reservoir of water. By one night's rain, all the country about Modena, Finlan, Ferrara, Mirandola [in Northern Italy] were laid under water, deluged like a Sea. These cities standing up like little islands. This rainy weather continued the whole spring and summer, scarce one fair day. In the beginning of June, mildew appeared on the grain leading to its total destruction. Nuts alone escaped the plague.

In 1690, there was a famine in Shanghai, China from the drought. There was no harvest that season.

In the autumn of 1690 Ottoman troops in the Balkans endured from 'snow, rain and frost. The snow being as high as the horses' chest, barred the roads, and the infantry could no longer move on; many animals dying, the officers were left to go on foot.' Everyone experienced great 'shortage of provisions' and 'the hardships and sufferings they endured had never been seen before.' [2]

In 1691, Italy, and the Netherlands experienced excessively hot and dry summers. Jamaica experienced excessive heat and a severe drought.

In 1691-92, and extensive drought in China produced a widespread famine.[2]

In 1691-92 in New Spain [colony comprising Spain's possessions in the New World north of the Isthmus of Panama], hailstorms, a plague of locusts and torrential rains followed by drought and early frosts destroyed two maize harvests in a row and initiated a prolonged drought that lasted until 1697.[2]

The winter of 1691-92 was awfully severe in Russia and Germany, and many people froze to death, and many cattle perished in their stalls. Wolves came into Vienna, Austria and attacked men and women, owing to the intense cold and hunger. All the canals of Venice, Italy were frozen, and the principal mouth of the Nile River in Egypt was blocked with frozen ice for a week. There was snow for four or five days in the vicinity of Shanghai, China. Men, horses, and animals froze to death. For half a month it was so cold that no one went abroad.

In 1692 in Northern France and England, there were heavy rains and great floods

In 1693 there was excessive scorching heat and a great drought in Italy. In England, the heat was intense in September. There was a scarcity of all sorts of grains in England. Many poor people in Essex resorted to making bread from turnips. In France, there was an awful famine. It was excessively hot during the spring and summer in Germany. A plague of locusts struck Wales. A severe cold spell struck England in October, which lasted for 4 or 5 weeks. This cold spell also struck Ireland, France, the Netherlands and Belgium. In Virginia in the U.S. there was a great storm, which stopped the course of ancient [river] channels. Some rivers were stopped up and channels opened for others that were so large as to allow them to be navigated [by ships].

During the winter of 1693-94, the winter was severe in Europe with great snowfalls and cold. In Germany and Italy, the frost was severe in November and December. Italy experienced much snow.

In Italy, there was burning hot droughty summer in 1694, in which five months passed without one shower of rain. In Paris, France, it was the second driest year in 30 years. From 1694-1699 in Scotland, there was a famine. In England, there was a great dearth from rains, colds, frosts, snows; all bad weather. On 27 September 1694, a hurricane struck offshore Barbados in the Lesser Antilles causing more than 1,000 deaths. The severe sandstorm struck Scotland on 2 November 1694. The village Culbin was covered over and lost for 230 years. In 1694, there was a great drought in the vicinity of Shanghai, China. This resulted in a bad harvest and a scarce year.

In 1694 a drought in the African interior meant that the Nile River scarcely rose and receded quickly, leading to a famine in Egypt. Conditions worsened in 1695, with both continued drought and plague.[2]

During the winter of 1694-95, England experienced frost for 7 weeks. There was continuous snow for 5 weeks. The cold was so intense that forest trees and oaks were split by the cold. The cold in northern France and southern Germany was reported to be intense. Sea ice completely surrounded the whole island of Iceland. In China, there was ice on the Huangpu River.

In western Czech Republic during June, the summer was very cold and 3 intense frosts occurred leading to famine. At Poznań, Poland, the summer and harvest of 1695 was one continuous winter of cold rain, raw frosts, and mildew.

In the years 1694 to early 1697, cold winters and cool and wet springs and autumns led to extreme famine in northern Europe, particularly in Finland, Estonia, and Livonia. It is estimated that in Finland about 25–33% of the population perished, and in Estonia-Livonia about 20%. The famines to a lesser extent also affected Sweden (especially in the northern region), Norway, and northwestern Russia. The famine decimated the population of Finland and Estonia-Livonia either through prolonged starvation, epidemics and other diseases promoted by undernourishment, or the reliance on unwholesome or indigestible foods, and the contamination of water supplies.

> In Estonia in 1696, landlords could no longer feed their farmhands and servants and began dismissing them. Many of these recently unemployed along with destitute, hungry peasants turned to begging. Even some members of the nobility were reduced to this state. In the autumn of 1696, the famine became terrible. There was a pronounced rise in the death rates. 'The peasants died like flies.' Bodies of the dead were lying everywhere. The winter of 1696-97 was extremely harsh. The snow was very high so corpses were left unburied until springtime and then placed in mass graves. Cases of cannibalism were reported in Estonia.
>
> In Finland in 1697, the famines, death and epidemics closely followed. This famine was so horrific that it brought on cases of cannibalism. In Ostrobothnia, Finland, 'parents ate the corpses of their children, and children of their parents, brothers and sisters.' In northern Karelia, Finland, court documents describe cases of cannibalism. In one township in Karelia, there were so many funerals that the church bell cracked. Storehouses and manor houses were plundered.

In Finland, some 500,000 people perished during the famine years of 1694, 1695 and 1696.[2]

In the upland regions of Scotland, cold and wet weather caused the harvest to fail every year between 1688 and 1698.[2] In the cold-wet hunger years of 1695-99, Scotland lost between 5% and 15% of its people.[21] The upland region of Scotland lost up to 1/3 of its population due to a 7 year famine.[2]

Rivers over a great part of Europe were in heavy floods in 1695-1697. Many of the rivers and lakes remained frozen for comparatively longer periods of time and didn't thaw until the late spring. In Italy, there were profound deluges in 1695. The Po River in northern Italy overran meadows, fields, and destroyed crops, leading to a severe famine in the area. Lake Zurich, Lake Constance and Lake Neuchâtel froze completely and one could walk over them as one would travel over a bridge. There were ice flows in the River Thames in England.

During the summer in June 1695, it snowed as far south as Lviv in the Ukraine.[2]

In October 1695, a hurricane struck offshore the Caribbean Island of Martinique causing greater than 600 deaths.

During the winter of 1695-96, the cold in England, the Netherlands and northern Germany was extreme. At Poznań, Poland, after 10 December 1695, there came a great snow and a strong frost, which had no thaw or remission till 10 March 1696. All corn and herbs died and rotted under the snow.

In 1696 in England, 200 sail of colliers and some coasters were lost, with all their crews in a great storm, in the bay of Cromer, in Norfolk. It was a very bad year for crops in England and food was very scarce.

The winter of 1696 was colder than had been known in New England in the United States, since the first arrival of the English. During a great part of the winter, sleighs and loaded sleds passed on the ice from Boston as far as Hull, Massachusetts. So great a scarcity of food, afterwards during the next year, had not been known; nor any grain ever been at a higher price.

The area around Poznań, Poland went without rain in 1696; hence a great scarcity in 1697.

The cold in England during the winter of 1696-97 was very severe. In central Germany, it was intensely cold during January and February. In the United States, the winter was intensely cold in the American northeast. Boston harbor was frozen as far down as Nantucket. The Delaware River was closed with thick ice for more than three months so that sleighs and sleds passed from Trenton to Philadelphia, and from Philadelphia to Chester on the ice.

On 29 April 1697, a great hailstorm struck Wales and England. The hailstones killed many seafowl, land fowl, lambs, and calves including a large mastiff. Several persons had their head broken. It knocked down horses and men. The storm was 2 miles wide and had a track of 60 miles. Some of the hailstones ranged in size up to the size of a man's fist and some weighed ¾ of a pound. The hailstones broke many windows, destroyed crops. Trees were broken and shattered to pieces. On 4 May, another hailstorm struck England with hailstones 14 inches in circumference. This storm also caused excessive damage, killing people and splitting some oak trees in two. Another hailstorm struck Wales and England on 6 June, destroying poultry, gardens, crops and windows.

In 1697, it was a bad year for the crops and food was very scarce in England. In the same year there was a great drought in the regions around Shanghai, China.

The winter of 1697-98 was severe in England. On 25 November, the ice was 3 inches think in London. But in December it was so warm that people could not bear their bedclothes. Then there was a snowfall 12 inches deep. In January, there were great snowfalls and deep drifts. Towards the end of January, the ice on the water was 8 inches thick. On 14 February, there was a great snowstorm that blocked up the roads with snow several yards deep. On 3 May, there was a great deep snow over all of England. On 15 May, the woods were like winter.

The year 1698 was a very wet year in England. Most of the grains harvested were wet and almost useless. In the north it was not harvested until almost Christmas. And in Scotland, they were reaping in January and beating the deep snow off it, as they reaped the poor green empty crop. Bread made from what was harvested would not stick together, but fell in pieces, and tasted sweet as if made of malt.

The winter of 1698-99 in England produced the coldest year between 1695 and 1742. The River Thames was full of ice. In Germany, there were frequent snowfalls. Towards the end of March there was a great snowfall and the cold continued until May. Poland experienced similar weather. There was a famine in Poland at the time and many people were consuming unwholesome foods.

In 1699, a powerful cyclone struck Sunderbans coast, Bangladesh causing 50,000 deaths.

The weather of 1699 in Germany produced a crop of wheat with black spots. The wheat was unwholesome and caused nausea both in man and beast. There was a great scarcity and dearth. In 1700, there was a famine in England from the rain and cold of the previous year.

On 14 September 1700, a hurricane struck Charleston, South Carolina in the United States and threatened its total destruction.

On the Feast of Candlemas [2 February] 1701, there arose in Paris, France, a furious hurricane. No one remembered having seen anything like it. The top of Saint Louis Church sank in on the assistants. This hurricane destroyed the kingdom.

The summer of 1701 in France was the most remarkable since the year 1682 because of its long duration of the heat and its high temperatures. In Italy, it produced intolerable heat. There was an excessively warm summer in England. Russia suffered from a major famine in 1701. Many of the famines in Russia were accompanied by such horrors as eating of bark, grass, and dung, and cannibalism. In 1701 in Moscow, pies were made of human meat and sold openly in the streets.

In 1702, England suffered a drought. The summer was excessively hot.

A great gale struck England from 26 November to 1 December 1703. Thirteen British men-of-war were lost, and their 1,519 officers and seamen perished. On the River Thames near London, almost 700 ships were smashed together in one great heap. The number of persons drowned in the floods of the Severn and Thames rivers in England, and lost on the coast of the Netherlands, and in ships blown from their anchors and never heard of afterwards, is thought to have been 8,000. Around 123 people were killed on land in England during this storm. The loss sustained in London alone was calculated at well over £2 million. [In present currency, that would be equivalent to over £300 million using the retail price inflation index.] The city of London was devastated. The houses looked like skeletons and there was a universal air of horror on the people who emerged from their homes after the storm. The city streets were rubble heaps of roof tiles and slates that fell from the top of houses. About 2,000 chimneys were blown down. Over most parts of south Britain and Wales, the tallest and stoutest timber trees were uprooted or snapped in the middle. It was estimated that 25 parks in several counties each lost a thousand trees and those of New Forest, Hants above four thousand. Many cattle and sheep perished. In one place 15,000 sheep were drowned. It was called the Great Storm, and probably the most terrible that ever occurred in England. Defoe says, 'Horror and confusion seized upon all, no pen can describe it, no tongue can express it, no thought conceive it, unless some of those who were in the extremity of it.'

The Great Storm reached beyond England. In Dunkirk, France, the 23-27 vessels in the road [roadstead] were dashed to pieces at Peer Heads. The effects of the storm were felt in Dieppe and in Paris and in the northeast countries such as the Netherlands. Her Majesty's ship *Association*, a second rate of 96 guns was anchored off Long Sand Head [in the Thames Estuary] during the hurricane. She was driven from her anchor and almost floundered taking in vast quantities of water. She was then driven north to the bank of Belgium, then the coast of the Netherlands to the entrance of the Elbe River where the storm was almost as violent as it was when they broke anchor in England. She was then driven to the coast of Norway.

In 1703, there was a famine in southwestern Pakistan.

In 1704 in England, the weather was the hottest and driest summer known in the previous 20 years. By October, there was a scarcity of water for cattle. The summer produced remarkable lightning and thunder storms. In Venice, Italy, the drought was so considerable that water had to be fetched five leagues [15 miles].

The winter of 1704-05 was intensely cold and stormy in the Philadelphia, Pennsylvania in the U.S. In December, snow fell to the depth of three feet on the level. The Delaware River was fast with ice two feet

(0.6 meters) thick, from the 10 December 1704 to the 10 March 1705. People brought loads over the ice. All the roads were shut and there were no post for 6 weeks.

In 1705, there were great rains and floods over the continent of Europe. On 11 August in England, there was a dreadful storm or hurricane. There were 800 sailors lost. The news was fill of losses by sea and by land. Another storm struck Ireland. Half of Limerick was drowned. The ships came onto the keys. Such a flood was never was seen before. On the 29 December, a dreadful storm struck France. Tides rose up in the Loire River, 25-feet beyond normal and 118 ships, 6 of them Men-of-War were driven ashore.

The summer of 1705 produced extreme heat in southern France. In Montpellier, France, the fearsome heat appeared July 17 and lasted until August 30, almost without interruption. 'In my memory,' Francois de Plantade, an assistant of Cassini wrote, 'is not to find similar to this day, the air almost as hot as hell, as that which emanates from the furnace of a glass factory, and found no' other refuge than the basement. Everyone was choking and took refuge in the cellars. At several places, eggs were boiled in the sun. In Hubin's thermometer, the liquid broke through the top. Amonton's thermometer, although it was attached to a place where the air had no free access, rose almost to the degree in which it melts the tallow. A famous academician measured the temperature at 107.6° F (42° C) degrees in the shade and 212° F (100° C) in direct sunlight, the temperature of boiling water. The greater part of the grape vines burned on that single day, a phenomenon that had not happened in living memory in this country. Paris and Lyon suffered from a drought.

In 1705 in Shanghai, China there was a great drought.

During the summer of 1706, there was extreme heat and drought in England and northern Europe. In Germany, the great drought affected the cow's milk. The year also produced some great floods. On 16 July a great rainstorm struck Denbigh, Whales where it rained for 30 hours continuously. All the rivers in Denbighshire, Flintshire, and Merionethshire overflowed, and destroyed the crops, and a dozen large bridges. Great oaks were uprooted and swept away. On 7 October, there was a prodigious flood in the north of Ireland, which broke down several bridges.

In 1706 during the summer, there was a drought in the vicinity of Shanghai, China. Then in the autumn, there were continuous rains and floods and a dearth and famine.

In England on 7 and 8 July 1707 was the greatest heat that had been observed in 46 years. Many horses on the road died. In Paris, France the heat was very great and on 21 August was measured at 98.4° F (36.9° C). Many of Prince Eugene's Army died of heat in their march from Italy these two days. May through August was all very dry in Italy. On 3 and 26 July, there were great floods in Ireland. In 1707 in London, England, there was an extraordinary fall of flies. These insects covered the clothes of persons and lay so thick that the impressions of the people's feet were visible on the pavement, as they are in a thick fall of snow.

In England, the summer, spring and harvest of 1708, was the coldest of any summer since 1647 (except for the year 1698). This weather preceded one of the coldest winters in the past 58 years.

The winter of 1708-09 produced a severe frost throughout Europe. In France, Italy, Spain, Germany and all the northern countries there was a very severe cold. In England, the winter became known as the Great Frost, while it in France entered the legend as Le Grand Hiver. In France, even the king and his courtiers at the Palace of Versailles struggled to keep warm. On 9 January 1709 in England, it was extremely cold. The frost was so intense that in less than 24 hours rivers froze, so as to bear loaded wagons. Urine froze under the bed [in bed pans], though there was a good fire in the room. Bread and meal were all ice. Bottled beer in deep cellars froze. Horses' feet were frozen to the ground. Cattle, sheep and birds perished. Coaches were driven over the ice on the River Thames. Large booths were built upon the ice and large fires were made on it. Great quantities of snow fell, and the storm continued for three months. In Edinburgh, Scotland, the frost lasted from early in October until the end of April. In Italy, the cold was greater than for the past 20 years, and most of the oranges and lemons perished. The Sea was frozen both on the Coast of Genoa and Livorno, Italy. The Adriatic Sea, and the Mediterranean Sea from Genoa, Italy, by Marseilles, France to Sète, France, frozen. All the rivers in France, except perhaps the Seine in Paris and the Rhone to Viviers, were completely frozen. The large lakes and pond in the Languedoc and Provence also froze. The freezing up of the Thau Lake, very deep, very stormy, and was so complete and so solid that it opened an unknown road connected up with the Sea from Balaruc and from Bouzigues to Sète on the ice. Finally, even the sea froze off the coast of Sète, of Marseille and in the English Channel. People drove across the ice of Lake Constance and Lake Zurich with loaded wagons/coaches. Frosts and snows of 1709 ruined the majority of crops. All the olive trees died from Perpignan to Nice in France. There were many deaths in Venice, Italy. Venetians were able to skid across the frozen lagoon in Italy. On the Italian coast, several mariners on board a British man-of-war died of the cold, and several lost part of their fingers and toes. Eighty French soldiers were killed on the road by the cold near Namur, Belgium. At Paris, France, 60 men and many cattle were frozen to death. Roads and rivers were blocked by snow and ice, and transport of supplies to the cities became difficult. Paris waited three months for fresh supplies. The Ebro River was frozen over in Spain. Portugal also felt the severity of cold. Ink froze in a writer's pen, even though there was a good fire in the room. In Scandinavia, the Baltic Sea froze so thoroughly that people could walk across the sea as late as April. In Switzerland, hungry wolves became a problem in villages. At Copenhagen, Denmark on 4 May 1709, the ice in Copenhagen harbor was 27 inches thick. On 9 April, people crossed the ice from Denmark to Schonen. The winter was very severe in Northern Germany. In Germany many cows were frozen to death in their stalls. And many travelers on the road were frozen to death, or lost their hands, feet, noses, or ears, and others fainted, and were in great danger of life or limb, when brought to soon near the fire.

During the 'Great Winter', the temperature in Paris, France, fell to -9º C on the night of 5-6 January 1709 and stayed well below freezing for almost three weeks. Saintes on France's Atlantic coast received 24 inches of snow. The temperature on France's Mediterranean coast plunged to -11º C. January 1709 was the coldest month recorded in the past 500 years. Although temperatures rose in February, they fell again just as the winter cereal crops began to sprout, killing them all. The price of grain reached it highest level of the entire *ancien regime*. 600,000 French men and women died during the Great Winter.[2]

In 1709 in France, fortunately, some prudent farmers had plowed their fields and sown them with winter cereal fields and barley. These were the bread grains in times of scarcity. People ate aronswurzeln, couch grass and asphodel. The famine was so great that a regulation was issued in April, which directed kitchens under penalty, even capital punishment to all citizens without distinction and the communities in to state their stores of grain and food. Equally significant were the result of an unprecedented thaw floods. The Loire River broke through its embankments, rose to a height not seen in two centuries, burying everything in its course.

In 1709, there was a famine in Scotland from the rains and cold. There was a scarcity of food in England because of a late spring, the cold weather continued until June or July. In the vicinity of Shanghai, China, there was continuous rain and floods in autumn. Rice was very dear, owing to flood, which caused a famine.

In May 1710 in England, the ground was exceedingly dry and cracked. Barley and peas were burnt. Vermin devoured all the fruits and the leaves of trees, so they were as naked as in winter. There was an epidemic of smallpox in London, England that killed 1/8th of the population.

During the winter of 1710-11 in England, the frost was severe from18 January until March. Ice formed 3 inches thick on the coast. It froze indoors in the bedchambers.

In the region of Carniola, Austria [now Slovenia] in 1711, there was a famine from rain and mildew. This famine continued for several years.

On 11-13 September 1711, the city of Mobile, Alabama in the U.S. was almost destroyed by a hurricane from a storm surge in Mobile Bay that overflowed the town. This hurricane also destroyed churches and building in New Orleans, Louisiana.

In 1712, there was excessive heat in low-Hungary [parts of Hungary, Slovakia and Croatia]. The summer was very hot in southern France. It caused the springs, creeks, small rivers and lakes to dry up and destroyed the crops. In southern France, there was a severe drought.

On 28 August 1712, a terrible hurricane struck the island of Jamaica. It destroyed several ships belonging to London and Bristol and fourteen ships belonging to the island. In the harbor of Port Royal and Kingston, four hundred sailors were drowned. Many people were killed by destruction of houses and the sugar works.

In England, the years between 1713-1719 produced a moderate drought. There were few rains but there were rich dews. The years 1714, 1717, 1718, and 1719 produced very hot summers.

In 1714 in London, England, there was an epidemic of smallpox. One-ninth of the population died.

In the year 1715 more than one third of the population of France (6 million people) perished from hunger and destitution. The cause of this famine and those that followed was due to taille (land tax). France is a land of good soil and fine weather, almost like a Garden of Eden. But for over a hundred years leading up to the French Revolution in 1789, it became a land of dire want and famines. Taille robbed the peasants of even their meager existence.

On 30 July 1715, a hurricane struck the southern Bahamas and the Straits of Florida in the United States. The storm caused between 1,000 and 2,500 deaths.

In 1715 during the summer, there was a great drought in the vicinity of Shanghai, China.

The winter of 1715-16 was recorded as being intensely cold throughout Europe. On 22 January 1716, the temperature in Paris, France was -4° F (-20° C). The Seine River froze over in Paris. Frost fair was held on the River Thames in London, England. Streets of booths were erected on the ice and an ox roasted on it, coaches driven, and many diversions exercised above the bridge. So strong was the ice below the bridge, that people walked and ice-skated. Dawkes' News Letter of the 14th of January says, 'The Thames seems now a solid rock of ice; and booths for sale of brandy, wine, ale, and other exhilarating liquors, have been for some time fixed thereon; but now it is in a manner like a town; thousands of people cross it, and with wonder view the mountainous heaps of water that now lie congealed into ice. On Thursday a great cook's-shop was erected, and gentlemen went as frequently to dine there as at any ordinary. Over against Westminster, Whitehall, and Whitefriars, printing presses are kept on the ice.'

Appendix B
Implication for Future Little Ice Age Events

In his book *Global Crisis*, Geoffrey Parker describes the catastrophic effect of climate change during the Little Ice Age in the 17th century.[2] He describes three regions that were greatly affected. These were marginal lands, cities, and macro regions. Marginal lands were vulnerable because they produced enough to feed all their people only during years of optimal harvest. Macro regions, because they specialized in cash crops, were vulnerable to climatic disruptions to trade and transportation. Few large cities existed in the 17th century, but the climatic changes were devastating. Today large cities are the mainstay and cover the globe. As a result, I thought it would be worth a short discussion to describe the vulnerabilities of cities threatened by a return to Little Ice Age climate.

Unlike the present time, there were only a limited number of large cities in the mid-seventh century. Beijing, China the largest city in the world had in excess of one million inhabitants. Nanjing, China had almost as many inhabitants. Six other Chinese cities numbered 500,000 citizens or more, while a score had 100,000 or more. The Mughal Empire in India, the most urbanized area in the world after China, included three cities with 400,000 or more inhabitants, and another nine with over 100,000. By 1850, 2.5 million Japanese, perhaps 10 per cent of the total population, lived in towns. By contrast in the Americas, only Mexico City and Potosi in Peru exceeded 100,000 inhabitants. While Africa's only metropolis was Cairo, Egypt with perhaps 400,000 residents. In Europe, the population of Istanbul, the capital of the Ottoman Empire, may have approached 800,000, but no other city came close. Only London, Naples and Paris exceeded 300,000. Ten other European cities numbered 100,000 inhabitants or more. While in Holland over 200,000 people lived in ten towns within a 50-mile radius of Amsterdam.[2]

Every metropolitan area requires adequate housing, fuel, food and fresh water, as well as schemes to manage traffic, fight fires and sanitation. Failure to provide these essential services created the 'urban graveyard effect'.

Little Ice Age climate produced major weather extremes and one of these extremes were severe summer droughts. The heat and dryness created by major droughts turned cities into tinderboxes that were ripe for Great fires. In 1666, the 'Great Fire' of London destroyed St Paul's Cathedral, the Guildhall, the Royal Exchange, 84 churches and 13,000 houses, leaving 80,000 people homeless and causing £8 million in damages [£1.2 billion in today's currency using the retail price index inflation rate]. The culprit was an unusually hot and dry spring, temperatures in the summer of 1666 rose 1.5° C above normal, and a precipitation shortfall of 6 inches turned London into a tinderbox. These same conditions prevailed in much of northwestern Europe in that year, giving rise to fires in a score of German cities.[2]

London was not the only city where unusual droughts in the mid-seventeenth century produced a 'Great Fire'. In Moscow in 1648, after several months without rain, 'within a few hours more than half the city inside the White Wall, and about half the city outside the wall, went up in flames'. Some calculate that 50,000 homes and 2,000 people perished in this conflagration. A large part of the new Mughal capital Shahjahanabad (now Delhi, India) burnt down in 1662. Istanbul, Turkey suffered more (and more devastating fires) in the seventeenth century than in any other period of its history: one in 1660, once again after a prolonged drought, burned down 28,000 houses and several public buildings. Major blazes also regularly devastated Edo, the largest city in Japan, notably the Meireki fire of 1657 – which like those in Moscow in 1648, Istanbul in 1660 and London in 1666, broke out after an abnormal drought. Three separate conflagrations [1657, 1661, 1668] combined to destroy three-quarters of Edo, including 50,000 homes of merchants and artisans, almost 1,000 noble mansions and over 350 temples and shrines. Around 160,000 people perished in these Edo fires.[2]

Little Ice Age climate produced major weather extremes and one of these extremes were great floods. Many cities grew up along major rivers and lakes. During exceptionally cold winters the rivers would freeze.

Springtime was a time of flooding. The ice in rivers would break up and create large ice jams near the bends of rivers that would flood the cities and countryside and tear down bridges. The snowmelt would add significant water volume to the rivers increasing the flood levels. When the ice jams suddenly burst, they would send a wall of water downstream, which would cause major devastation to cities.

Little Ice Age climate produced major weather extremes and one of these extremes were great ocean storms. The great storm of 26 November to 1 December 1703 that struck London and then Europe is an example. Another example is the great storm that struck the Netherlands in 1646. Some cities are major sea transportation hubs located along coastlines and these cities are vulnerable to this threat. Some major cities are located at or below sea level, which increases their vulnerability to such storms.

Adverse weather experience during Little Ice Age climate can disrupt the transportation of food and fuel into cities. For example due to the extreme cold and snow in Paris, France, transportation routes were blocked during the winter of 1708-09, the city waited for 3 months for fresh supplies to arrive.

The great famines caused by the effect of extreme Little Ice Age weather on crop production in the past promoted mass migration and much of this flowed into cities. The additional people stressed the capacity of the cities to provide essential services. Because people are tightly compacted into cities, it makes them very vulnerable to a rapid spread of disease and epidemics. Modern cities are equipped with efficient sanitation and water purification systems. But these systems can be compromised by extreme weather. Also large cities today are major air transportation hubs that permit almost instantaneous spread of diseases. Weather extremes and famine weaken the human body and they also contributed to the susceptibility to sickness. Periods of continuous rainfall turn some regions into swamplands that produced an abundance of mosquitoes that spread malaria and other plagues.

Appendix C
Further Discussion on the Cloud Theory

In 2009 I made several observations about Cloud Theory.[23] These observations and analysis are still applicable today.

1. The Cloud Theory does not apply to the entire globe but rather the Earth's oceans. The primary source of ionizing radiation over the oceans comes from Galactic Cosmic Rays (GCRs). The primary source of ionizing radiation over land [the continents] comes from surface mineralization.

2. Although much of the present research focuses on chemical seeding of water molecules (such as sulfur, ammonia), one major source has been overlooked. Salt can act to capture ionic charge. It is readily available from marine salt spray.[22]

> As waves break in the ocean, a great number of bubbles are formed underwater. These are referred to as the alpha plume. The bubbles percolate up to the surface forming oceanic white caps and sea foam. One of the properties of ocean seawater is its high surface tension. As air bubbles burst, seawaters high surface tension causes the surrounding water to snap back into the depression left by the bubble. As a result, small droplets of seawater are injected into the atmosphere. The rate ocean salt water aerosols (henceforth referred to as marine aerosols) are generated above the surface of the ocean is controlled by the wind speed [Monahan et al. 1983]. Wind speeds greater than 9 m/s, which could be viewed as a minimum threshold, produce great number of spume droplets as the wave crests and are torn apart by the wind. O'Dowd and Smith [1993] have observed sea salt CCN concentrations up to 100 per cc at wind speeds of 20 m/s. Monahan and O'Muircheartaigh [1986] estimated the flux of marine aerosols varies as the cube of wind speed. Hurricanes can generate great surface wind speeds (exceeding 80 m/s) and loft these marine aerosols to very high altitudes in convection updrafts. Marine aerosols can be an important source of cloud condensation nuclei. In addition, the salts in the marine aerosols have the effect of making the water molecules cluster, become more ordered, thus harder to pull apart and evaporate.
>
> Marine aerosols can be raised from the surface of the ocean to great heights by strong updrafts. In September 1997, hurricane Nora traveled up the Baja Peninsula and fell apart leaving behind a cirrus cloud blow off. This gave a team of scientist a unique opportunity to study in fine detail, the unusual cirrus event using the Facility for Atmospheric Remote Sensing (FARS) and the research aircraft and ground based sensors at the Cloud and Radiation Testbed (CART). From the study Sassen et al. [2003] concluded the mode of cirrus particle nucleation involved the lofting of sea salt nuclei in strong updrafts into the upper troposphere. This process produced a reservoir of haze particles evolving into halide-salt-contaminated ice crystals.
>
> Seawater is an effective ion transport carrier with a specific electrolytic conductivity of 53 mS/cm at 25º C. For example, seawater is used as an electrolyte in magnesium water-activated batteries. This type of reserve battery was developed in the 1940's to meet the emerging military needs for high energy density batteries for applications in electric torpedoes, sonobuoys, weather balloons, air-sea rescue equipment, pyrotechnic devices, marine markers and emergency lighting. Seawater reserve batteries have been built that produce up to 460 kW of power [Koontz and Lucero, 2002].

3. The link between the intensity of the sun's magnetic field and surface ocean temperature is non-linear.[23] This leads to the observation that the Earth's climate system is fairly robust. Medium to high levels of solar magnetic field strength produce fairly stable warm temperatures in ocean climates. It is only when the sun is magnetically quiet does temperatures take a dramatic plunge.

Because the area represented by the oceans is large; a long-term change in low-level clouds over the ocean should have a significant effect on planetary temperature. Most of the natural background radiation over the oceans is derived from cosmic radiation rather than natural sources. As a result, the effect of GCR cloud modulation is greatest over the oceans where there is less dust to form clouds and there is a shortage of cloud forming ions. Rain removes the ions, so they must be constantly replenished.

One method of measuring the sun's magnetic strength is by measuring the production of sunspots. But Georgieva recommends a better method by measuring the ability of the magnetic field wrapped in the solar winds to interact and distort the Earth's magnetic field. The high-speed solar wind stream is produced by Coronal Mass Ejections, Coronal Holes and Magnetic Clouds. The geomagnetic activity reflects the impact of solar activity originating from both closed and open magnetic field regions on the sun, so it is a better indicator of solar magnetic activity than sunspot number which is related to only closed magnetic field regions.[24] This geomagnetic distortion "AA index" has been measured at two locations on the opposite side of the globe, one in Great Britain and the other in Australia, since 1868 A.D. [Ap Index may be a more accurate parameter to work with but unfortunately, the Ap Index dataset only goes back to 1932 A.D.] Refer to Figure 7 on next page. Figure 7 graphs global monthly ocean temperature anomalies in relationship to the "AA index" for the past 120 years.

The observed relationship is described by the formula:

Ocean Surface Temperature Anomaly = 0.203 ln (AA Index) – 0.778°C

This figure was derived using the Smith-Reynolds Extended Reconstructed Sea Surface Temperature (ERSST.v3)[25]. The time series in ASCII format was accessed through ftp://eclipse.ncdc.noaa.gov/pub/ersst/pdo/ by selecting dataset [aravg.mon.ocean.90S.90N.asc]. This monthly dataset was used which covers Sea Surface Temperature (SST) for the period from January 1880 to October 2007 for the entire ocean from 90° North latitude to 90° South latitude. The temperature anomalies are computed from the analyzed monthly field minus the climatology for that month using the years 1971-2000 as a baseline. The second parameter used was the monthly "AA Index" which covers the period from January 1868 to September 2007.[26] [The time series is accessed by selecting the dataset *AA_Month.*] Since major volcanic eruptions are believed to affect Earth's climate, the database provided by the Smithsonian National Museum of Natural History on Large Holocene Eruptions was used to filter out this climatic effect.[27] All eruptions with a Volcanic Explosivity Index (VEI) of 6 or greater were identified and the temperature data from the time of eruption until two years later were deleted from the dataset. These eruptions include Krakatau (27 Aug. 1883), Santa Maria (24 Oct. 1902), Novarupta (6 Jun. 1912) and Pinatubo (15 Jun. 1991).

The observed trend is fairly weak with a correlation coefficient of only [0.36]. I suspect this is primarily due to the larger scatter in the existing temperature record. It is my belief that as the Earth enters a period of global cooling brought on by the next solar grand minima; this trend will be refined and become obvious.

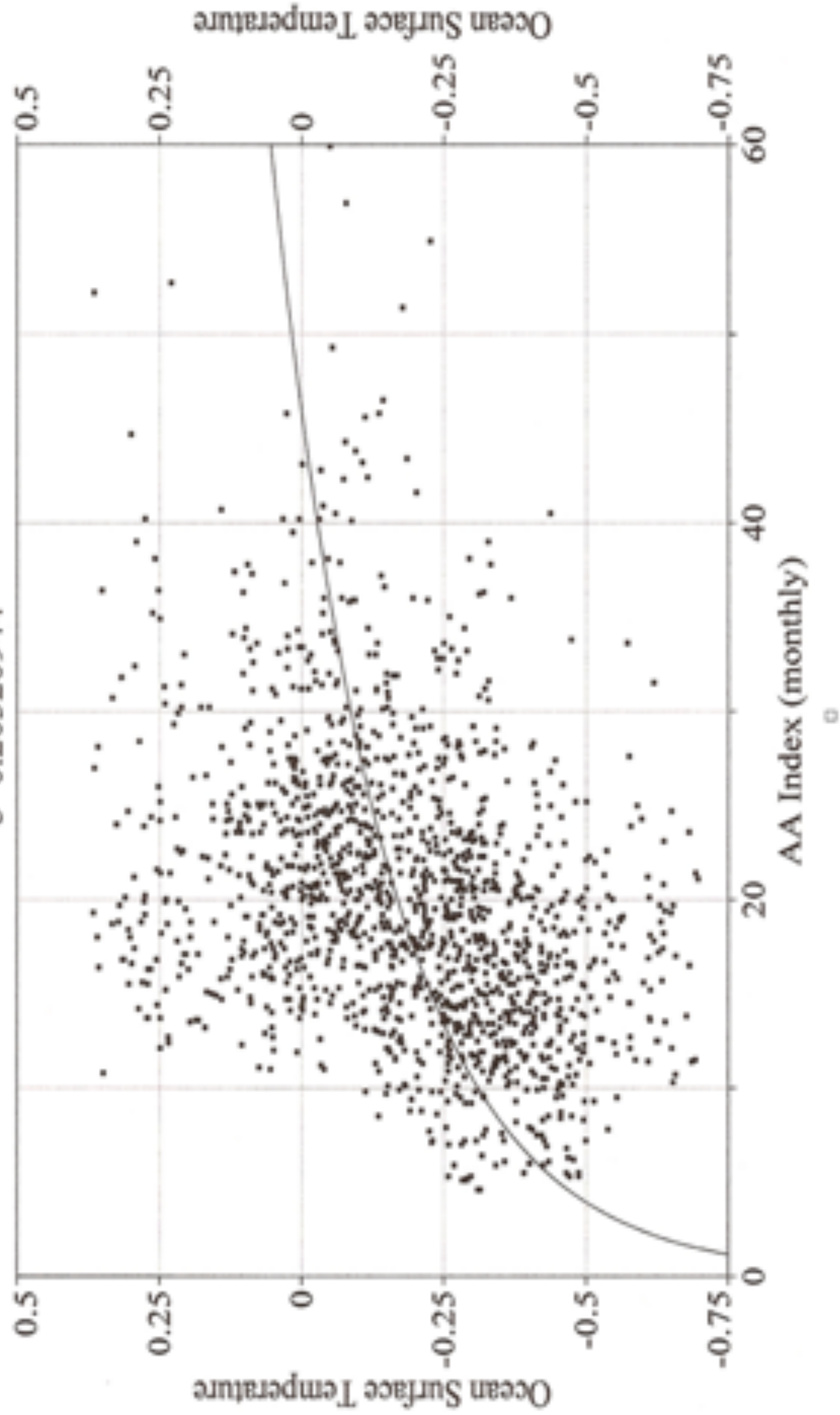

Figure 7. Ocean Surface Temperature as a Function of AA Index

Rank 1 Eqn 13 y=a+blnx

r^2=0.13278604 DF Adj r^2=0.13157654 FitStdErr=0.20201121 Fstat=219.72429

a=-0.77768987

b=0.203209944

One might question if the natural log drop-off as the "AA Index" approaches zero is a real phenomena. Figure 10 shows an ocean surface temperature reconstruction in the Sargasso Sea, a 2 million square mile region of the Atlantic Ocean as determined by isotope ratios of marine organism remains in sediment at the bottom of the sea. During the depths of the Little Ice Age, ocean temperatures were approximately 1°C colder than present. Although the Maunder Minimum preceded the start of "AA Index" measurements; it is my opinion that the Maunder Minimum represents a timeframe when this parameter approached zero. When an "AA Index" of near-zero (0.1) is entered into equation; it produces a temperature drop of approximately 1°C as compared to present day temperatures. Thus there appears to be agreement between the formula and observed sea temperatures on the extremes of the quiet sun.

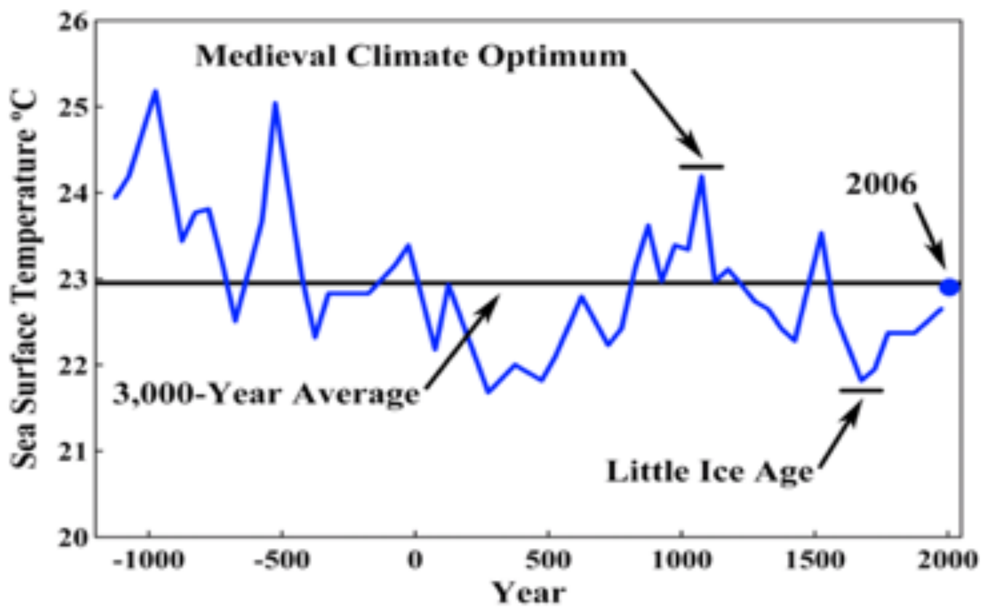

Figure 10. Surface temperatures in the Sargasso Sea, a 2 million square mile region of the Atlantic Ocean, with time resolution of 50 to 100 years. The horizontal line is the average temperature for this 3,000-year period. The Little Ice Age and Medieval Climate Optimum were naturally occurring, extended intervals of climate departures from the mean.[28]

Appendix D
Source of the Moisture in the Reaction Zone

The moisture that is transformed into diamond dust comes from three sources. These are the upwelling of frozen ices from the lower atmosphere, water vapor from massive volcanic eruptions, and fragments of comets that evaporate as they burn up in Earth's atmosphere.

Upwelling of Moisture from Lower Atmosphere

One source of moisture comes from the lower atmosphere. An upwelling of frozen ices from the lower atmosphere into the reaction zone (the top layer of ozone) where the ices are melted and evaporated and then as they fall out of the reaction zone are refrozen in the form of diamond dust. Refer to Figure 6. This moisture normally originates in the main Polar Jet Stream where the Ferrel cell lifts the moisture into the reaction zone. The other uplift occurs near the equator where the Hadley cell uplifts the moisture into the reaction zone and eventually into the Subtropical Jet Stream. Most of this moisture freezes during the uplift into ice particles.

Water Vapor from Massive Volcanic Eruptions

Volcanoes are rated by their explosive force. The Volcanic Explosivity Index (VEI) provides a means of measuring the relative explosiveness of volcanic eruptions. The largest volcanoes, those with VEI's of 7 and 8 produce eruptions capable of ejecting vast amount of water vapor into the upper Stratosphere. These massive volcanic eruptions are rare. The Super-Colassal eruption (VEI of 7) occurs at a frequency of approximately every 1,000 years (or greater) and is capable of producing a plume height of greater than 40 kilometers. The Mega-Colossal eruption (VEI of 8) occurs at a frequency of approximately every 10,000 years (or greater) and is capable of producing a plume height of greater than 50 kilometers.[29] The last massive volcanic eruption was the Tambora eruption of 1815. It was rated as a 7 on the VEI scale. This eruption produced a very distinct cooling trend. But in my opinion, an analysis of weaker volcanic events (VEI's of 6 or less) over the past two millennia did not display detectable cooling trends, which were observable beyond normal climate variability.[21]

An erupting volcano will release gases, tephra, and heat into the atmosphere. The largest portion of gases released into the atmosphere is water vapor. Water vapor constitutes 70 to 95 percent of all eruption gases. The rest consists of carbon dioxide, sulfur dioxide and traces of nitrogen, hydrogen, carbon monoxide, sulfur, argon, chlorine and fluorine. In the case of the Tambora eruption, I will suggest that the observed cooling was due to the ejection of water vapor into the Earth's upper atmosphere where it is reformulated into microscopic ice crystals known as "diamond dust". The measured cooling did not begin until almost a year after the volcanic eruption. ***If the cooling were due to other trace ejected gases such as sulfur gases, then one would expect the cooling to begin almost immediately. The long time delay implies a substantial transformation process in the upper atmosphere that can be directly tied to the primary gas, water vapor.***

The Tambora eruption occurred on 10 April 1815 on Sumbawa Island in *Indonesia*. It was rated as a 7 on the Volcanic Explosivity Index (VEI). The volcanic eruptions of this size are very rare events typically occurring on a millennium scale. Analysis of Charles Peirce's temperature data shows that the eruption did not begin to affect Philadelphia, Pennsylvania's weather in the *United States* until 11 months later in March 1816. Then temperatures were depressed for nine months before recovering. Refer to Figure 11. At its greatest extent, temperatures were 7.7° F (4.3° C) colder than average Dalton Minimum monthly averages. This year was known as the "Year Without Summer". But that does not really begin to describe the event for the people of Philadelphia, the Northeast *United States* and *Canada*. It was the year when a hard killer frost occurred in every month of the year.[21]

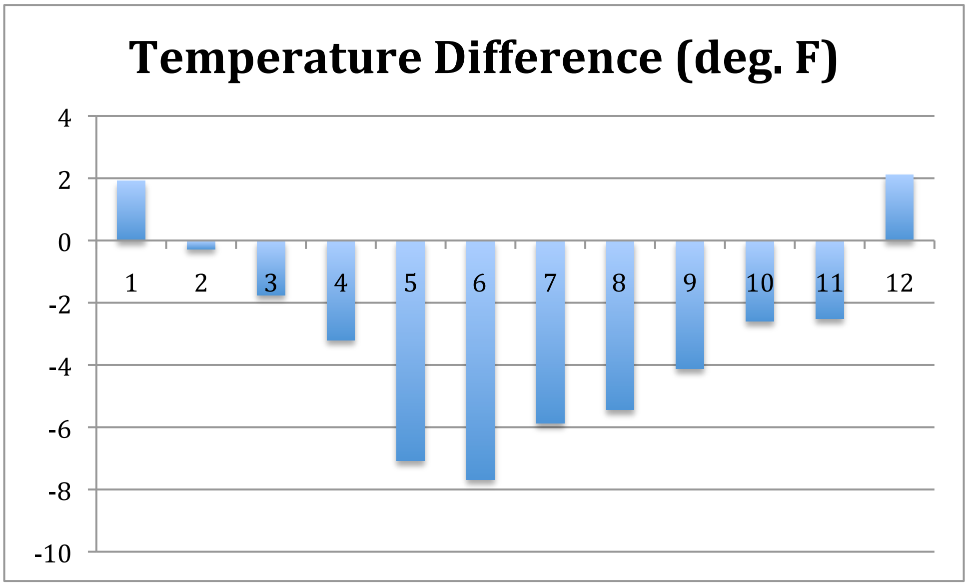

Figure 11. This chart shows for Philadelphia, Pennsylvania the observed monthly temperatures difference between the year 1816 and the average monthly temperatures during the rest of the Dalton Minimum (years 1798-1815 and 1817-1823).

Paris *France* experienced a very similar temperature anomaly. The summer of 1816 was the coldest in the first half of the 19th century. The average temperature in Paris during the summer was only 59.5° F (15.3° C); that was 5.4° F (3° C) less than the average summer temperature. This was a disastrous year in Paris. The average temperature during the period of vegetation: [21]

	Average Summer Temperature for 1816	Long Term Summer Average Temperature	Monthly Temperature Anomaly
April	(49.8° F, 9.9° C)	(49.66° F, 9.81° C)	(+0.14° F, +0.09° C)
May	(54.9° F, 12.7° C)	(58.15° F, 14.53° C)	(-3.25° F, -1.83° C)
June	(58.6° F, 14.8° C)	(63.21° F, 17.34° C)	(-4.61° F, -2.54° C)
July	(60.1° F, 15.6° C)	(66.27° F, 19.04° C)	(-6.17° F, -3.44° C)
August	(59.9° F, 15.5° C)	(65.21° F, 18.45° C)	(-5.31° F, -2.95° C)
September	(57.2° F, 14.0° C)	(59.85° F, 15.47° C)	(-2.65° F, -1.47° C)
October	(52.9° F, 11.6° C)	(51.75° F, 10.97° C)	(+1.15° F, +0.63° C)

This extreme cold year also ravaged *Europe*, *Africa*, the *West Indies* and Northern *China*. The volcanic eruption also affected the rain patterns in 1816. The cooler temperatures delayed India's summer monsoon. It brought late torrential rains to India that spawned cholera epidemics. The monsoon in *China* caused massive floods in the Yangtze Valley.[21]

Water Component of Comet Fragments

Another source of water is from the reformulation of comet ices as they pass through the reaction zone. The nucleus of a comet has been described as a dirty snowball. The nucleus is primarily composed of water ice. It contains other frozen substances including methane, ammonia and carbon dioxide and small amounts of solids such as dust grains and hydrocarbons. Comets that pass into Earth's outer atmosphere travel at speed of 20 to 50 kilometers/second (45,000 to 110,000 miles per hour).

The Earth is impacted by approximately 10 million small comets or comet fragments each year. Many of these are in the 20 to 40 ton range. These fragments are generally broken up by electrostatic stress at altitudes of around 1,300 kilometers (800 miles) above the surface of the earth. These atmospheric impacts are believed to be the cause of noctilucent clouds of ice crystals formed around meteoric dust. These clouds are formed around 55 miles [90 kilometers] above the earth's surface.[30] As these ice crystals fall into the reaction zone, they can melt and be reformulated into diamond dust ice crystals.

There are times when larger comet fragments collide with Earth and I suspect they produce havoc with the climate. Over the course of history, a phenomenon called "dry fog" has been observed on rare occasions. It is my belief that a comet impacts were responsible.

For example in 1783, an extraordinary dry fog extended intermittently over the whole of Europe and part of Asia. The remarkable thing about this fog was that it was phosphorescent and at nighttime, the light it yielded was sufficient to read by. The fog in some places permitted only less than one mile visibility. It also allowed people to look directly at the sun without being dazzled. It was first observed on 9 May at Copenhagen, Sweden; on 6 June at La Rochelle, France; on 14 June at Dijon, France; on 16 June at Manheim [now Mannheim], Germany and at Rome, Italy; on 19 June in the Netherlands; on 22 June in Norway; on 23 June on Saint Gothard [St. Gotthard, Switzerland] and in Hungary; towards the end of June in Syria; and by 1 July on the tops of the Altai Mountains [a mountain range located where Russia, China, Mongolia and Kazakhstan come together].[21]

One of the first great American scientist, Benjamin Franklin recorded his observations of the extraordinary dry fog in a lecture on 22 December 1784: "During several of the summer months of the year 1783, when the effect of the sun's rays to heat the earth in these northern regions should have been greater, there existed a constant fog over all *Europe*, and a great part of *North America*. This fog was of a permanent nature; it was dry, and the rays of the sun seemed to have little effect towards dissipating it, as they easily do a moist fog, arising from water. They were indeed rendered so faint in passing through it, that when collected in the focus of a burning glass they would scarce kindle brown paper. Of course, their summer effect in heating the Earth was exceedingly diminished. Hence the surface was early frozen. Hence the first snows remained on it unmelted, and received continual additions. Hence the air was more chilled, and the winds more severely cold. Hence perhaps the winter of 1783-84, was more severe, than any that had happened for many years." He then went on to suggest that the cause of the dry fog was an asteroid/comet impact on Earth. "The cause of this universal fog is not yet ascertained. Whether it was adventitious to this earth, and merely a smoke, proceeding from the consumption by fire of some of those great burning balls or globes which we happen to meet with in our rapid course round the sun, and which are sometimes seen to kindle and be destroyed in passing our atmosphere, and whose smoke might be attracted and retained by our earth…" [21]

Over a hundred years later in 1908, a similar "phosphorescent fog" phenomenon was observed. On 30 June 1908 near the Podkamennaya Tunguska River in what is now Krasnoyarsk Krai, Siberia, *Russia*, there was a massive explosion caused by the impact of a small asteroid or comet. The impact was believed to be a bolide air burst rather than a surface impact since no crater was found. In 1930, the British astronomer, F.J.W. Whipple suggested the Tunguska body was a small comet. The comet hypothesis was further supported by the glowing skies (or "skyglows" or "bright nights") observed across Europe for several evenings after the impact, possibly explained by dust and ice that had been dispersed from the comet's tail across the upper atmosphere.[21] In London, England, people could read newspapers and play cricket outdoors at midnight.

According to Tom Slemen: "The first reports of a strange glow in the sky [from the Tunguska event] came from across Europe. Shortly after midnight on 1 July 1908, Londoners were intrigued to see a pink phosphorescent night sky over the capital. People who had retired awoke confused as the strange pink glow shone into their bedrooms. The same ruddy luminescence was reported over Belgium. The skies over Germany were curiously said to be bright green, while the heavens over Scotland were of an incredible intense whiteness, which tricked the wildlife into believing it was dawn. Birdsong started and cocks crowed - at two o'clock in the morning. The skies over Moscow were so bright; photographs were taken of the streets without using a magnesium flash. A captain on a ship on the River Volga said he could see vessels on the river two miles away by the uncanny astral light. One golf game in England almost went on until four in the morning under the nocturnal glow, and in the following week The Times of London was inundated with letters from readers from all over the United Kingdom to report the curious 'false dawn'. A woman in Huntingdon wrote that she had been able to read a book in her bedroom solely by the peculiar rosy light." [21]

References

1. **I.G. Usoskin, S.K. Solanki,** and **G.A. Kovaltsov** (2007) Grand minima and maxima of solar activity: new observational constraints, *Astronomy & Astrophysics*, **471**, pp. 301-309, doi:10.1051/0004-6361:20077704, URL: http://cc.oulu.fi/~usoskin/personal/aa7704-07.pdf [cited 14 April 2009].
2. **Geoffrey Parker**, Global Crisis (War, Climate Change & Catastrophe in the Seventeenth Century), 2013, Yale University Press, New Haven and London, pp. 55-73, 77.
3. **National Oceanic and Atmospheric Administration (NOAA)**, Solar Proton Events, *Solar Proton Events Affecting the Earth Environment*, URL: http://umbra.nascom.nasa.gov/SEP/ [cited 11 February 2016].
4. **GeoForschungsZentrum, Adolf-Schmidt-Observatory in Niemegk, Germany**, *Ap Monthly Index*, URL: http://wwwuser.gwdg.de/~rhennin/kp-ap/ap_monyr.ave [cited 24 May 2016].
5. **National Aeronautics and Space Administration (NASA)**, *SORCE's Solar Spectral Surprise*, 2010 , URL: http://www.nasa.gov/topics/solarsystem/features/solarcycle-sorce_prt.htm [cited 6 May 2016].
6. **National Aeronautics and Space Administration (NASA)**, Science News, *A Puzzling Collapse of Earth's Upper Atmosphere*, 2010, URL: http://science.nasa.gov/science-news/science-at-nasa/2010/15jul_thermosphere/ [cited 6 May 2016].
7. **Government of Canada**, *Solar radio flux - Plot of Monthly Averages*, 2016, URL: http://www.spaceweather.gc.ca/solarflux/sx-6-mavg-en.php [cited 6 May 2016].
8. **S.A. Starodubtsev, I.G. Usoskin, A.V. Grigoryev** and **K. Mursula,** (2005) Long-Term Modulation of the Cosmic Ray Fluctuation Spectrum: Spacecraft Measurements, 29th International Cosmic Ray Conference Pune, 2, pp. 247-250. URL: http://cc.oulu.fi/~usoskin/personal/ICRC2005_yaku.pdf [cited 27 May 2009].
9. **H. Svensmark** and **E. Friis-Christensen** (1997) Variation of cosmic ray flux and global cloud coverage - a missing link in solar-climate relationships, *Journal of Atmospheric and Solar-Terrestrial Physics*, **59** (11), pp. 1225-1232, URL: http://atoc.colorado.edu/wxlab/atoc7500/svensmark1.pdf [cited 13 January 2010].
10. **H. Svensmark, J.O.P. Pedersen, N.D. Marsh, M.B. Enghoff** and **U.I. Uggerhoj** (2007), Experimental evidence for the role of ions in particle nucleation under atmospheric conditions, *Proceedings of the Royal Society A: Mathematical, Physical and Engineering Sciences* **463** (2078) pp. 385-396, doi:10.1098/rspa.2006.1773 URL: http://rspa.royalsocietypublishing.org/content/463/2078/385 [cited 18 January 2010].
11. **Jasper Kirkby** et. al, (2011) *Role of sulphuric acid, ammonia and galactic cosmic rays in atmospheric aerosol nucleation*, Nature **476**, 429–433 (25 August 2011), doi:10.1038/nature10343.
12. **Svensmark, Enghoff**, and **Pedersen**, (2013) *Response of cloud condensation nuclei (>50 nm) to changes in ion-nucleation*, Physics Letters A, Volume **377**, Issue 37, 8 November 2013, Pages 2343–2347.
13. **W. Schwerdtfeger** (1970), The climate of the Antarctic*, Climates of the Polar Regions. World Survey of Climatology*, Vol. 14, pp. 253–355.
14**. U. Radok,** and **R.C. Lile** (1977). A year of snow accumulation at Plateau Station, *Meteorological Sutdies at Plateau Station, Antarctica, Antarctic Research Series*, Vol. 25, American Geophysical Union, pp 17-26.
15. **B. van Gell, O.M. Raspopov, H. Renssen, J. van der Plicht, V.A. Dergachev,** and **H.A.J. Meijer** (1999) The role of solar forcing upon climate change, *Quaternary Science Reviews*, **18**, 331-338.
16. **Curtis P. Rinsland, Chris Boone, Ray Nassar, Kaley Walker, Peter Bernath, John C. McConnel**, and **Linda Chiou** (2005) Atmospheric Chemistry Experiment (ACE) Arctic stratospheric measurements of NO_X during February and March 2004: Impact of intense solar flares, *Geophysical Research Letters*, Vol. **32**, L16S05, doi:10.1029/2005GL022425.
17. NASA/Jet Propulsion Laboratory (2005, May 2), Solar Storms, Arctic Winds Swirl in a Double Dip Cone of Ozone Loss, *Science Daily*, Retrieved December 30, 2010 from http://www.sciencedaily.com/releases/2005/05/050502093904.htm
18. **D.A. Degenstein, N.D. Lloyd, A.E. Bourassa, R.L. Gattinger** and **E.J. Llewellyn** (2005) Observations of mesospheric ozone depletion during the October 28, 2003 solar proton event by OSIRIS, *Geophysical Research Letters*, Vol. **32**, L03S11, doi: 10.1029/2004GL021521.
19. **University of Alabama in Huntsville**, *Lower Troposphere (T2LT) Satellite Temperature Dataset*, Version 5.6, URL: http://vortex.nsstc.uah.edu/data/msu/t2lt/uahncdc_lt_5.6.txt [cited 17 March 2016].
20. **William Robertson**, The History of the Discovery and Settlement of America, 1826, Jones & Company, London, pp 80-82.
21. **J.A. Marusek** (2010), A Chronological Listing of Early Weather Events, *Impact*, Revision 7, URL: http://www.breadandbutterscience.com/Weather.pdf [cited 22 February 2016].
22. **J.A. Marusek**, (2006) *The Relationship between Cosmic Rays and Hurricanes*, 2nd International Conference on Global Warming and the Next Ice Age, Los Alamos National Laboratory, 17-21 July 2006.
23. **J.A. Marusek**, (2009) *Solar "Grand Minima Threat Analysis*, Impact, URL: http://www.breadandbutterscience.com/SGMTA.pdf [cited 9 May 2016].
24. **K. Georgieva, C. Bianchi and B. Kirov** (2005) Once again about global warming and solar activity, *Mem. S.A.It.,* **76** (969), URL: http://sait.oat.ts.astro.it/MSAIt760405/PDF/2005MmSAI..76..969G.pdf [cited 3 January 2008].
25. **National Climate Data Center, NOAA**, Extended Reconstructed Sea Surface Temperature (ERSST.v3), URL: http://www.ncdc.noaa.gov/oa/climate/research/sst/ersstv3.php#desc [cited 8 January 2008].
26. **National Climate Data Center, NOAA**, Solar Data, URL: ftp://ftp.ngdc.noaa.gov/STP/SOLAR_DATA/RELATED_INDICES/AA_INDEX/ [cited 17 December 2007].
27. **Smithsonian National Museum of Natural History**, Large Holocene Eruptions, URL: http://www.volcano.si.edu/world/largeeruptions.cfm [cited 17 December 2007].
28. **A.B. Robinson, N.E. Robinson, and W. Soon** [2007] Environmental effects of increased atmospheric carbon dioxide, *Journal of American Physicians and Surgeons* **12**, pp. 79-90, URL: http://www.oism.org/pproject/s33p36.htm [cited 10 January 2008].
29. **National Aeronautics and Space Administration (NASA)**, Volcanoes, *Exploring the Environment: Global Climate Change*, URL: http://ete.cet.edu/gcc/?/volcanoes_explosivity/ [cited 22 February 2016].

30**. University of Iowa**, Physics Department, *The Small Comets Frequently Asked Question List*, Version 3.0, 9 April 1999, URL: http://smallcomets.physics.uiowa.edu/faq.htmlx [cited 22 February 2016].
31. **Scott A. Mandia**, The Little Ice Age in Europe, URL: http://www2.sunysuffolk.edu/mandias/lia/little_ice_age.html [cited 10 January 2010].
32. **Lawrence Solomon**, The Deniers: Our spotless sun, *National Post*, 31 May 2008, URL: http://network.nationalpost.com/np/blogs/fpcomment/archive/2008/05/31/the-deniers-our-spotless-sun.aspx [cited 9 January 2010]
33. **National Aeronautics and Space Administration (NASA)**, Cosmic Rays Hit Space Age High, 29 September 2009, URL: http://science.nasa.gov/headlines/y2009/29sep_cosmicrays.htm [cited 10 January 2010].