Ameliorating Future Little Ice Ages While Reducing Global Warming

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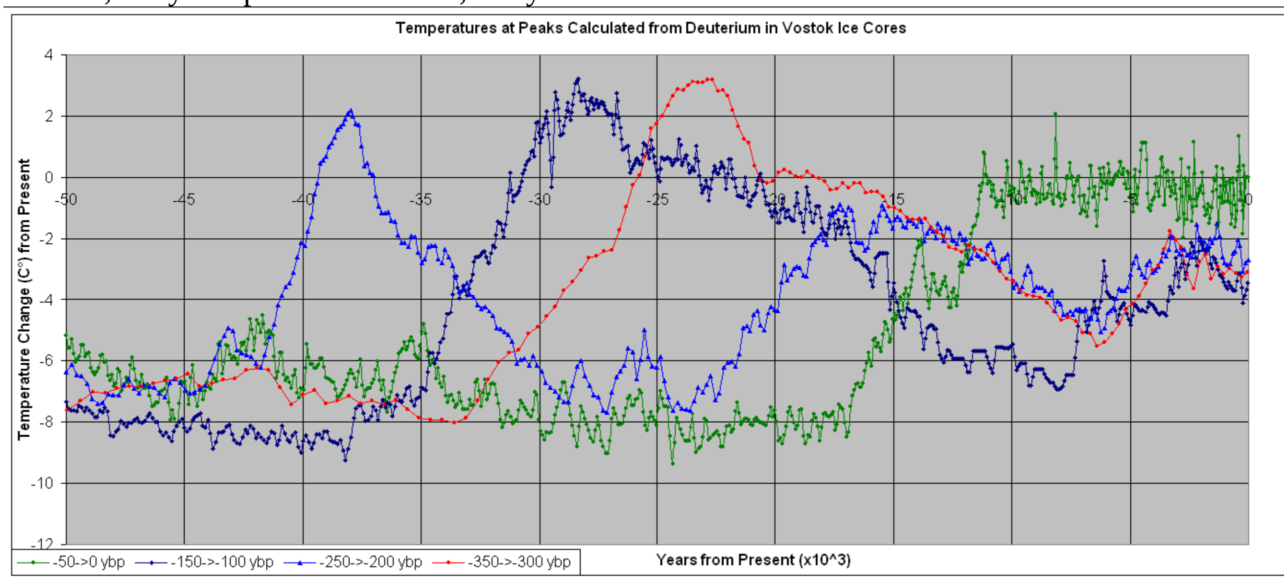
Part III: Ameliorating Global Warming

For **Part I: Solar Insolation and Ice Ages** go to http://www.Roperld.com/science/InsolationIceAges.pdf
For **Part II: Last Major Ice Age and Predictions for the Next Major Ice Age** go to http://www.Roperld.com/science/IceAgesPredict.pdf

Global Warming and Carbon Dioxide in the Atmosphere

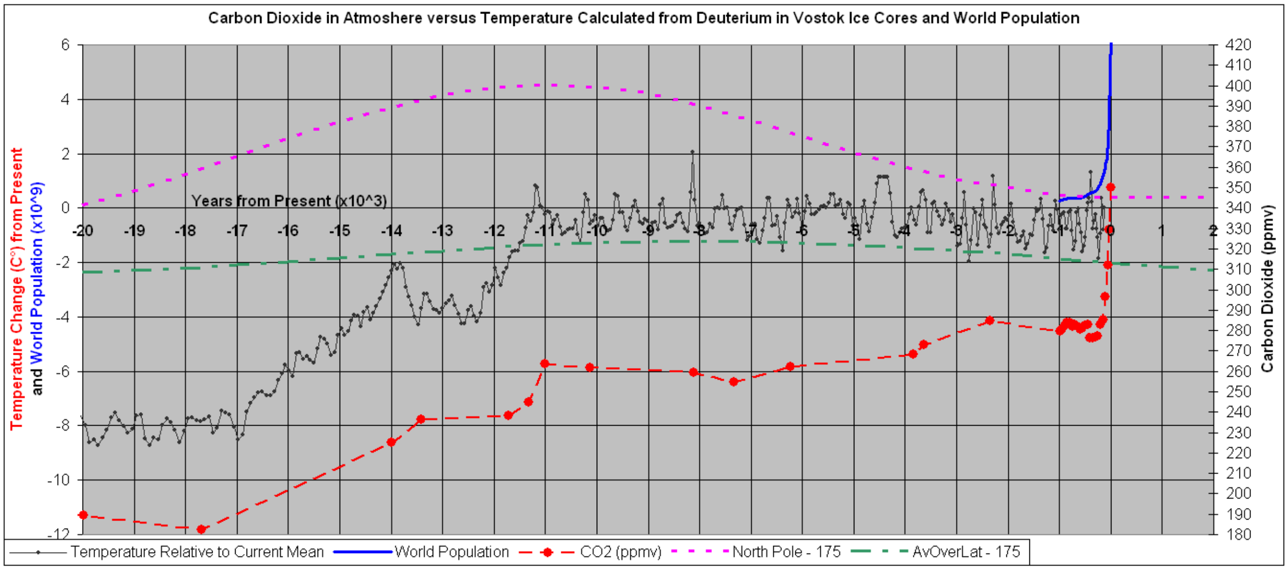
The first graph in this paper shows the strong correlation between CO_2 in the atmosphere and temperature in Antarctica. Apparently this is mainly because increasing warmer oceans increase the release of stored CO_2. Since CO_2 is an excellent greenhouse gas, the increasing CO_2 in the atmosphere as solar insolation causes the temperature to increase serves as a strong feedback to increase the temperature even more. This is probably the major reason the temperature rises so rapidly once it begins to rise.

The following graph shows the last four temperature maxima for the interglacials for the last 400,000 years plotted over a 50,000-year interval.



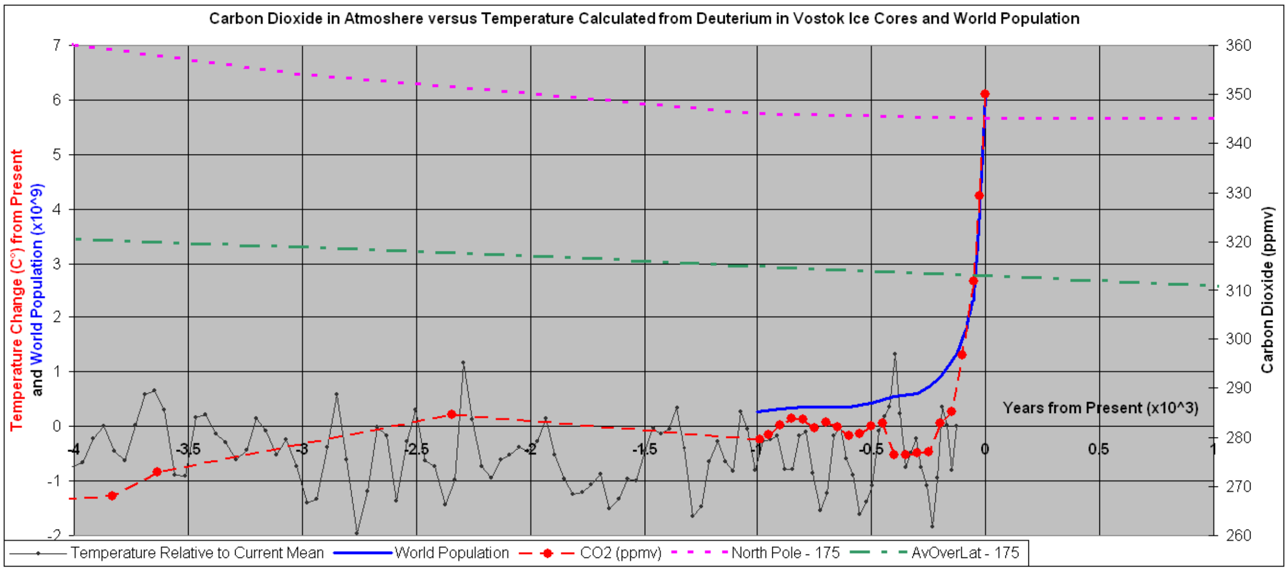
The peaks have been shifted by 100,000 years for the second peak, 200,000 years for the third peak and 300,000 years for the fourth peak, in order to visually compare the four peaks. Note the anomalously long current temperature maximum (over 10,000 years) compared to the other three earlier peaks. The following discussion makes clear why that happened.

Using the Vostok ice-core data and recent measurements of CO_2 taken from http://www.ngdc.noaa.gov/paleo/icecore/antarctica/law/law_data.html, the following graph shows the temperature and the CO_2 concentration in the atmosphere for the last 20,000 years:



Also shown is the world population since year 1000 and the North Pole insolation and average-over-latitudes insolation (less 175 watts/m^2 to make their data fit on the right-hand scale).

Now look at the last 4000 years. Note the gradual rise in CO_2 concentration relative to temperature beginning about 4000 years ago when animal agriculture and fishing became widespread. Then there was a leveling off until the last 200 years, as shown in the following graph:



Note the high correlation between temperature and CO_2 concentration until about 200 years ago, when population began to grow exponentially and hydrocarbon fuels began to be used extensively. There was a short-term dip of the insolation of about 5% about 500 years ago due to irradiance variation of the Sun; a similarly-sized peak is expected about 500 years from now (see below). So, according to the energy supplied by the Sun, the temperature should have dropped about 500 years ago and should rise in the near future. Add that to the rise in temperature increase caused by the drastic rise in CO_2 concentration, and you have global warming. The conclusion is that we need to get some of the CO_2 out of the atmosphere. An exercise for the reader is to guess how the population, CO_2 and temperature curves will extend into the next 1000 years on the graph.

Solar Irradiance

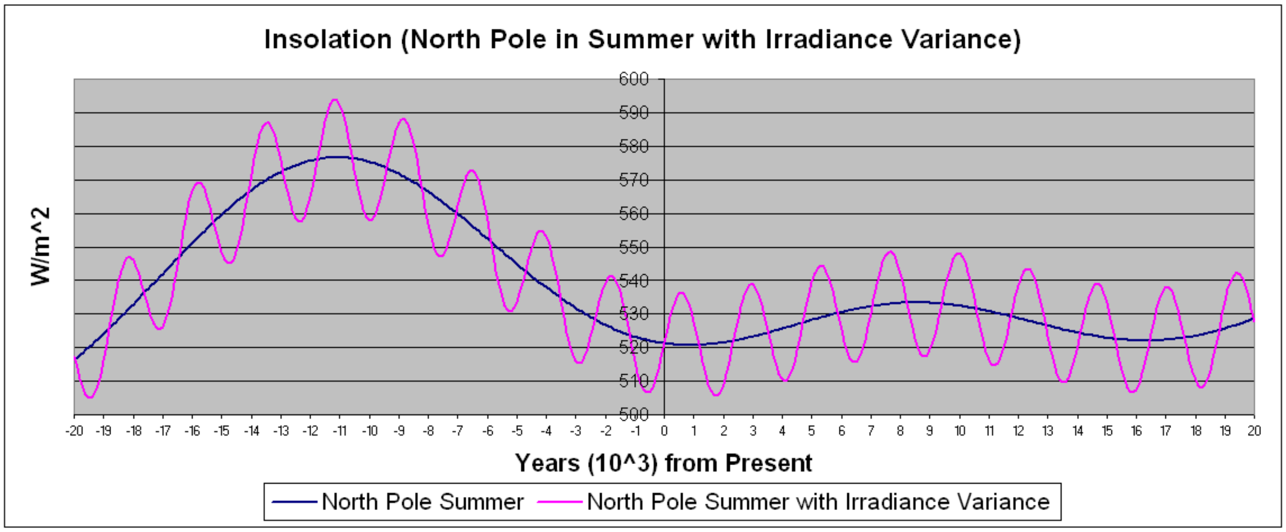
Another factor that must be considered is the variability with time of the solar irradiance. The paper "The Solar Spectral Irradiance since 1700" by M. Fligge and S. K. Solanki, Geophys. Res. Let. 27, 2157-60, 2000 (http://www.astro.phys.ethz.ch/papers/fligge/GL10884W01.pdf) indicates that the time variance of the irradiance is about 0.5% of its magnitude, a small variation compared to the Milankovitch variations. (Also, see http://www.ras.org.uk/pdfs/Solanki.pdf.) I will discuss this in more detail below.

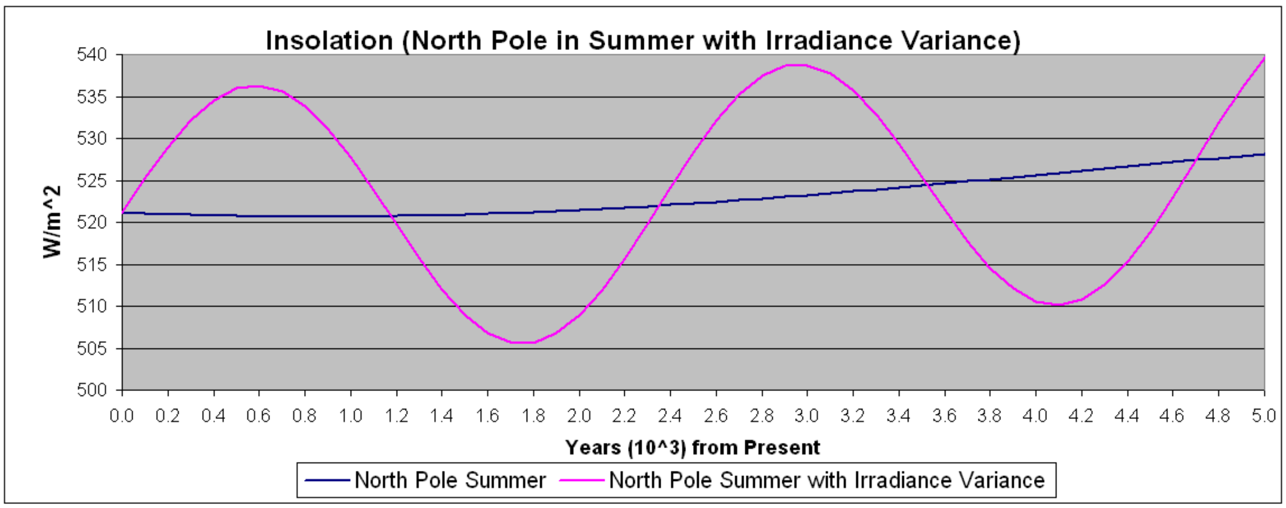
The Near Future

We are in an interglacial now, and we are probably extending it and increasing its intensity ("super interglacial"; See the two graphs immediately above.) by putting industrial gases transformed from mined carbon sources, particular CO_2, into the atmosphere. The aim of this document is to urge that we store CO_2 in earth cavities and forests to be released later during the next minor ice age or ages to try to ameliorate it/them.

Figure 43 on p. 179 of *Ice Ages: Solving the Mystery* by John Imbrie and Katherine Palmer Imbrie is a plot of general trends in global temperatures back 10,000 years, showing a period of about 2.35×10^3 years. (This is probably due to time variation in the solar irradiance.) They are called "Little Ice Ages". See: http://www.vehiclechoice.org/climate/cutler.html. (I should mention that there is some indication that this period is more like 1,500 years: http://www.agu.org/pubs/crossref/2003/2003GL017115.shtml and http://www.bjerknes.uib.no/events/Hafslo/Schulz.pdf.) The global atmospheric temperature was about $2^{\circ}C$ less than now at the valley of the last Little Ice Age. From that plot, I have devised a time-dependent factor for the variation of irradiance: $1+0.03\cos(2\pi t/2.35-\pi/2)$.

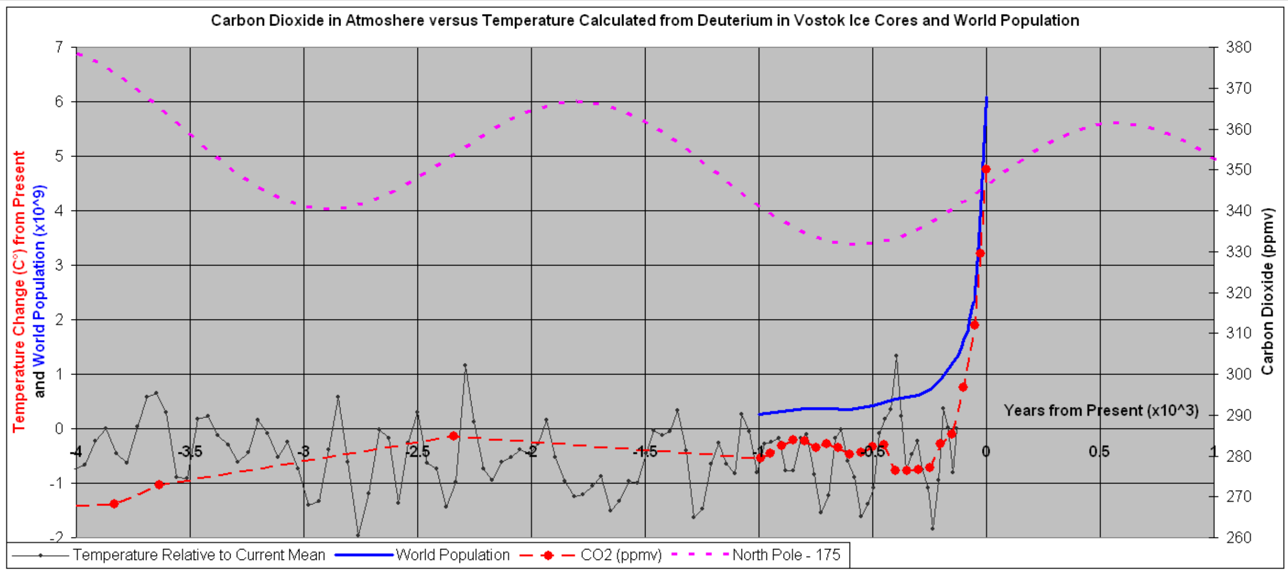
Applying this factor, one gets for North Pole insolation:





We see that, without the solar irradiance variation, the insolation would drop very slightly for almost 1000 years and then increase for about 7000 years. However, the shorter-term (2,350-year period) solar irradiance variation will superimpose an increase for about 500 years. (This is the reason it is said that the release of CO_2 into the atmosphere at this time is most unfortunate.)

Now put this supposed short-term variation of the Sun's irradiance in the previous graph of the temperature, CO_2 concentration and world population:

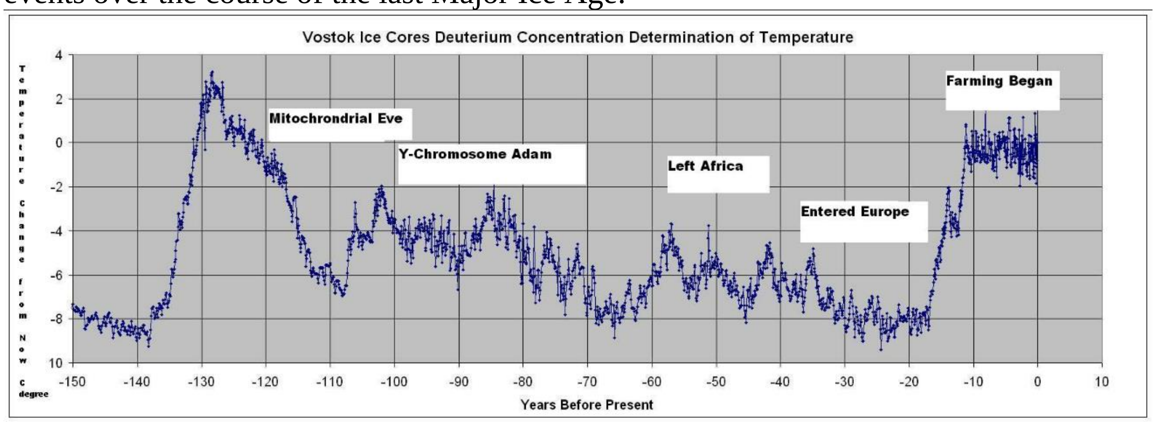


The longer-term climate forced by the earth's orbit is not the controlling factor in deciding whether to store CO_2 for nearer-term future release to ameliorate insolation decreases, the shorter-term solar irradiance variation is.

So, it may be a good idea to consider storing CO_2 now and for approximately the next 500 years to then use it to over about the next 1,000 years to ameliorate the cooling that would otherwise occur because of the decreased insolation in that period.

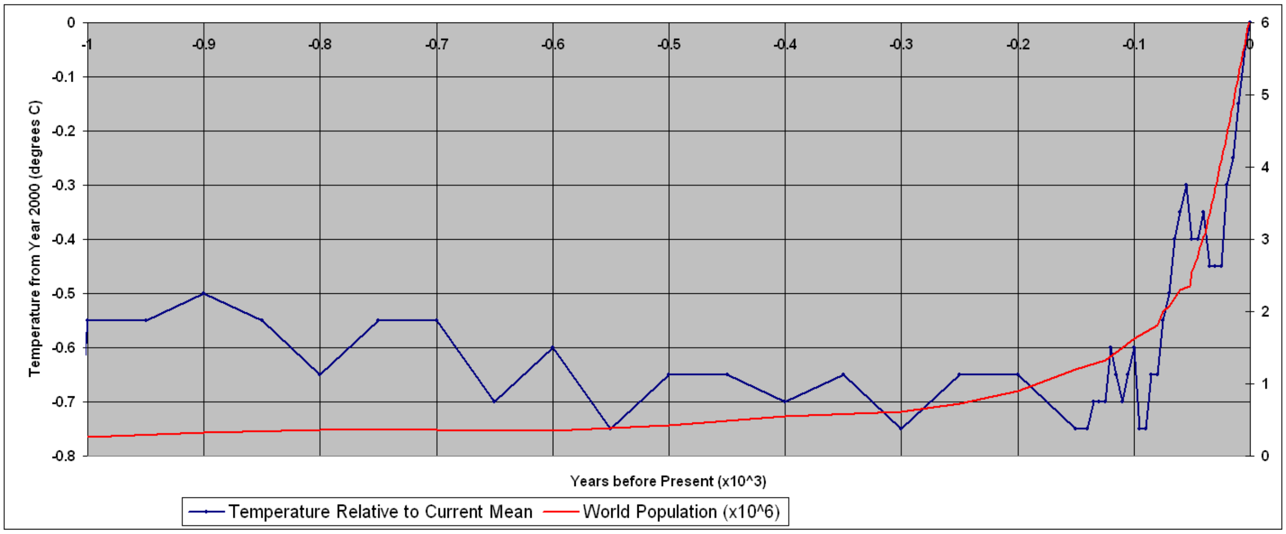
Even if the above curves are not accurate, they are probably schematically correct. Over the next few hundred years humans will probably learn more about what causes the Little Ice Ages and, thus, will be able to predict them more accurately. Even if that is not so, we will know when it gets colder.

The following graph shows the Antarctic temperatures and some significant human events over the course of the last Major Ice Age:



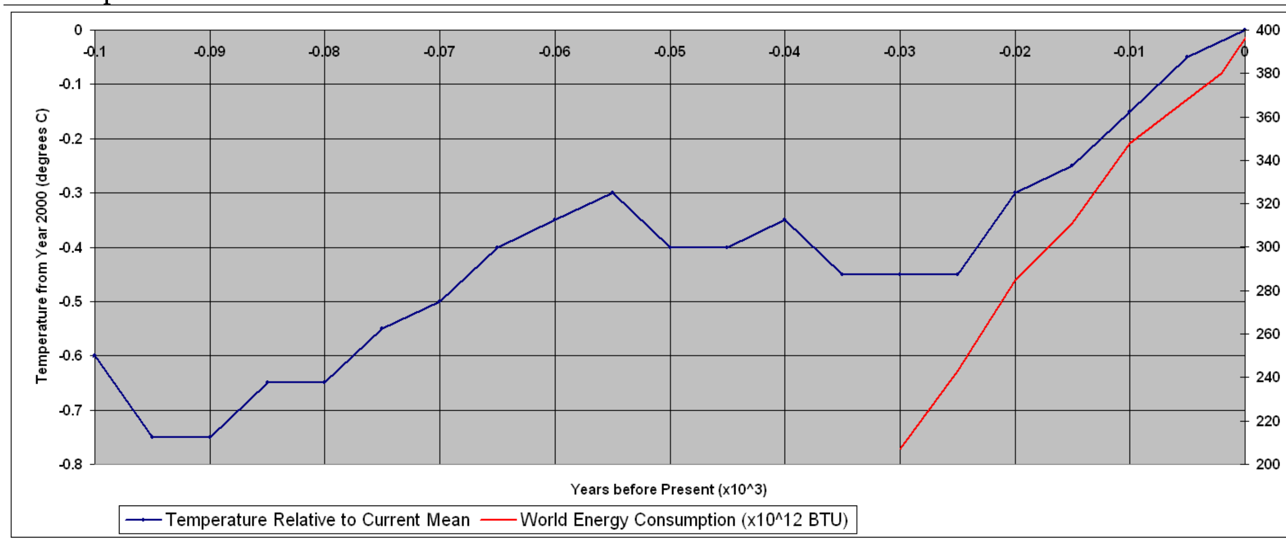
A important question is: What will happen to farming when the next Major Ice Age, which it appears will be a very cold one, happens?

I extracted temperature measurements for recent years from *Climate Change 2001: The Scientific Basis* (Report of the ICCP):



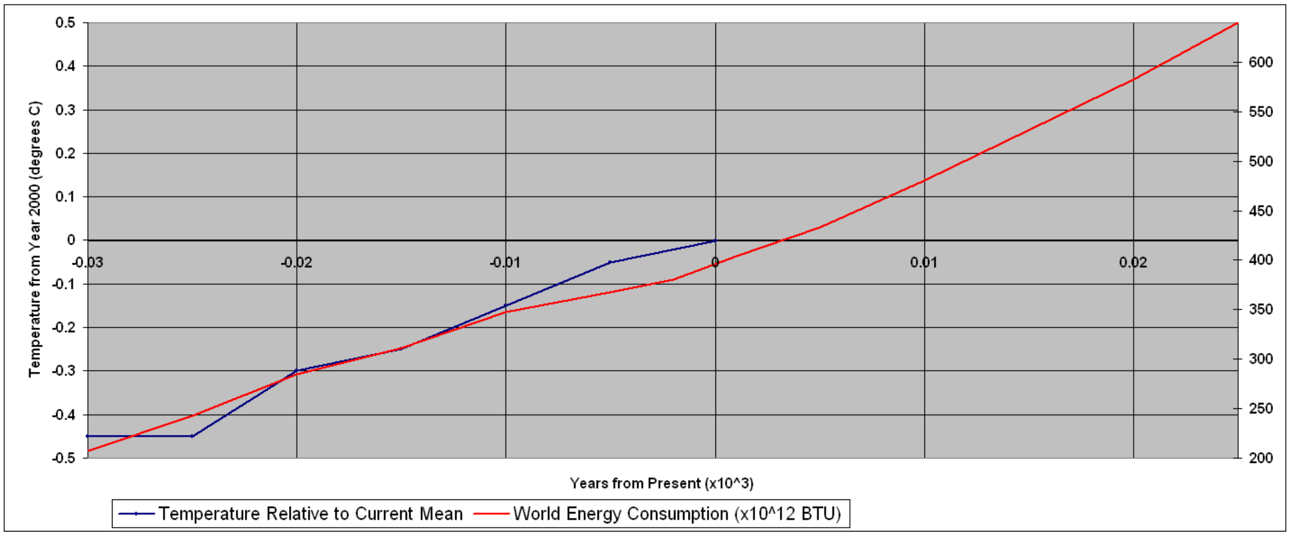
The left side is the year 1000 and the right side is year 2000.

I used http://www.eia.doe.gov/oiaf/ieo/figure_12.html to obtain the yearly World energy consumption:



The left side is year 1900 and the right side is year 2000.

The report cited projected World energy consumption into the future as follows:



The left side is year 1970 and the right side is year 2025. I leave it as an exercise for the reader to project the temperature rise up to year 2025.

Carbon Dioxide emissions, World population or World energy consumption are all reasonably good indicators of near-term future World temperatures.

Storing Carbon Dioxide for Later Use

The paper "Storing Carbon in Earth" by S. Julio Friedman (http://www.geotimes.org/mar03/feature_storing.html) describes in detail the various possibilities of storing liquid CO_2 in the earth. The best in-earth approach, with the idea of recovering it later, appears to be in depleted oil fields. Much research is now underway on CO_2 storage in the earth; it needs to have a component of finding the best way to store it such that it can be recovered in the future as needed. The paper points out that there are some naturally-occurring CO_2 fields in the earth.

Of course, CO_2 can also be stored in plants and trees. Another, probably less desirable storage location, as a liquid, is at the bottom of oceans.

How Much Carbon Dioxide Would Need to be Stored?

According to *Global Warming, A Beginner's Guide to Our Changing Climate* by Fred Pierce, 2002 (A summary of: http://www.grida.no/climate/ipcc_tar/wg1/index.htm): From about 1850 to 2000 (150 years) humans used about 290×10^9 tons of carbon as fuel, which produced an increase of about 100 ppm (parts per million) of CO_2 in the atmosphere. (Some was absorbed by oceans and used by plants and trees.) According to http://cdiac.esd.ornl.gov/trends/emis/tre_glob.htm the current rate of global carbon release is about 6.5×10^9 tons/year and is increasing at about 10^8 tons/year/year. This release has produced an increase in global atmospheric temperature of about $0.6^\circ C$ since 1975 or about $0.025^\circ C$/year. The average carbon release rate from 1975 to 2000 was

5.75×10^9 tons/year. So a reasonable estimate is that 5.75×10^9 tons/year release creates a temperature rise of about $0.025C^\circ$ /year.

There are about $4{,}000 \times 10^9$ tons of carbon left in the earth to be extracted and used as fuel, about 14 times the amount already used. If this amount were used as fuel over the next 150 years and all the produced CO_2 released into the atmosphere, the carbon released into the atmosphere would average about 25×10^9 tons/year, which would produce a temperature increase of about $0.10C^\circ$ /year, or about $10C^\circ$ over the next 100 years, truly a disastrous scenario. (The last Major Ice Age was associated with a temperature about $-10C^\circ$ below the current temperature and the Little Ice Age was about $-2C^\circ$ below present.) Instead, this amount of carbon should be stored as CO_2 in earth cavities or elsewhere for the next 500 years or longer and then released as needed as the solar irradiance decreases into the next Little Ice Age.

To ameliorate the expected $2C^\circ$ drop in temperature at the low-temperature point of the next Little Ice Age about 1,800 years from now, we would need to start at about 500 years from now releasing the stored $4{,}000 \times 10^9$ tons of carbon in the form of CO_2 at a rate of about 35×10^9 tons of carbon per century for about 1300 years, for a total of 450×10^9 tons, slightly over 1/10th of what is available. Of course, we would have to continue to release the carbon into the atmosphere for about yet another 1000 years at a decreasing rate during the temperature rise out of the next Little Ice Age. The total amount of carbon that would need to be released over the entire period of about 2,350 years of the next Little Ice Age cycle would be about 750×10^9 tons of carbon, less than one-fourth of the total available. So we could have enough left to ameliorate three more Little Ice Ages up to about 7,000 years from now.

The rough calculations described above involve several assumptions. They are not meant to produce accurate results, but are merely to discover whether the numbers are reasonable in terms of the possibility of releasing CO_2 to ameliorate one or more future Little Ice Ages. It appears that they are sufficient to ameliorate the next four Little Ice Ages.

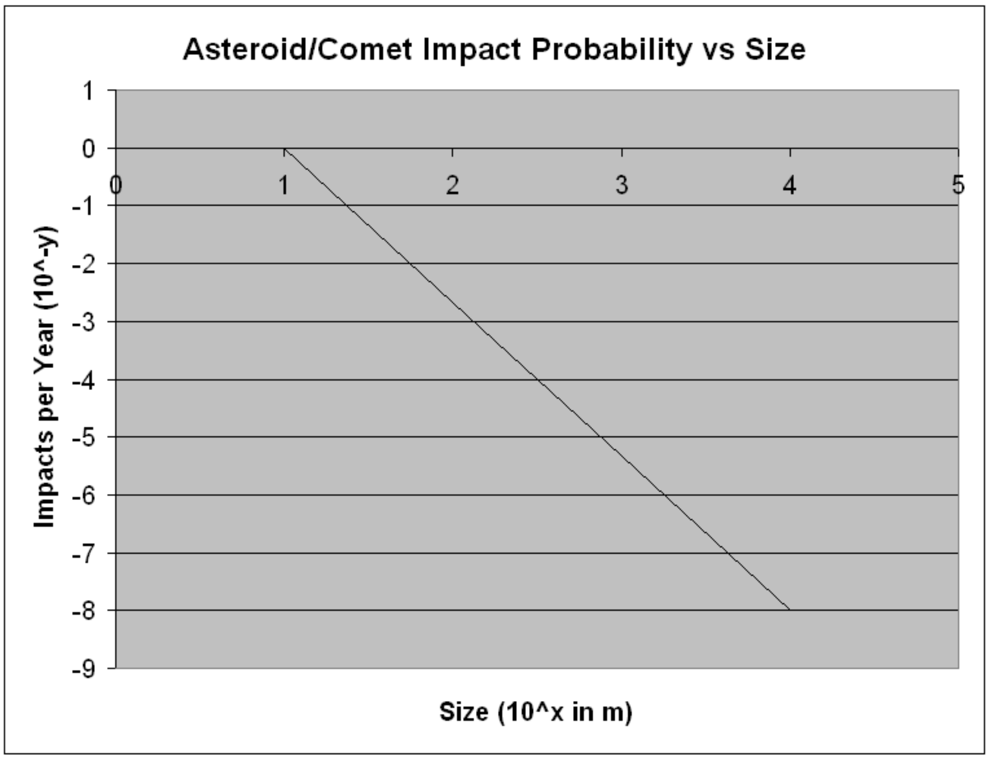
Of course, there is no hope of using stored CO_2 to ameliorate the next Major Ice Age, many little ice ages from now. We will not even be able to ameliorate the Little Ice Ages after the next four.

Of course, a very relevant question is: Is human society intellectually advanced enough to understand this situation and future-oriented enough to do something about it?

Asteroid/Comet Collisions with the Earth

When one is considering 1,000 or more years in the future, in this case trying to ameliorate future Little Ice Ages, one must also consider another event that could alter the climate: the possibility of asteroid or comet collisions with the earth.

Figure 5 on p. 31 of Rogue *Asteroids and Doomsday Comets* by Duncan Steele, plots the probabilities (impacts per year) for collisions of different diameters of asteroids and comets. Also, see Figure 8.1 on p. 165 of *Rare Earth: Why Complex Life is Uncommon in the Universe* by Peter D. Ward and Donald Brownlee. It looks something like the following:



The Tunguska event in Siberia of 1908 was due to a collision by an asteroid about 60 meters in size, whose blast felled trees over thousands of square kilometers. If that event had occurred in a populated region of the world it could have destroyed a major city, with disastrous effects on the entire world. If it had occurred in one of the oceans, it might have sent out a large tsunami that would have essentially destroyed many cities on all shores of that ocean. It released 20-50 megatons (TNT equivalent) of energy in an explosion in the atmosphere (no earth crater was formed), over ten times larger than the nuclear bombs that the US used to level Hiroshima and Nagasaki in Japan and kill about 250,000 people. This level of collision event is expected about once every 50-100 years somewhere on the earth.

Asteroids of size about 150 m are expected to collide with the earth about every 1500 years. If such an asteroid collided in a populated area or in an ocean, it would surely greatly alter the functioning of human civilization. Such a collision could greatly alter the climate for many years, because of the dust and chemicals it would splash into the atmosphere. Some call this level of collision a "civilization destroying collision". So, you ask: Why have we not heard of such destruction of civilizations in the past several thousand years? One reason may be that pockets of civilization only occupied a small fraction of the earth and luck relegated the collisions into unpopulated areas. Or the short-term changes in climate that did help to destroy some parts of civilization may have been partly due to such collisions.

For 10,000-year periods the expectation is that an asteroid of about 300 meters in diameter will collide with the earth. This is on the verge of getting through the atmosphere to form a crater on the earth or splash into an ocean. It, of course, would be civilization destroying for many places of impact on the earth.

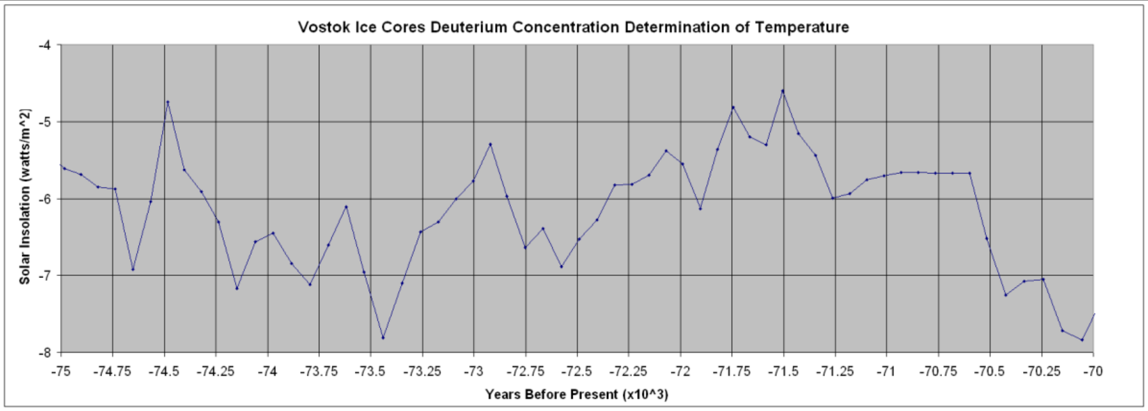
The conclusion is that planning to ameliorate the next several Little Ice Ages over the next 7,000 years, has a reasonably high probability that it will be disrupted by an asteroid collision, unless humans are able to figure out how to stop asteroid collisions. The Duncan Steele book describes efforts that are underway to detect and destroy or deflect asteroids that might collide with the earth in the future.

Volcanism and Ice Ages

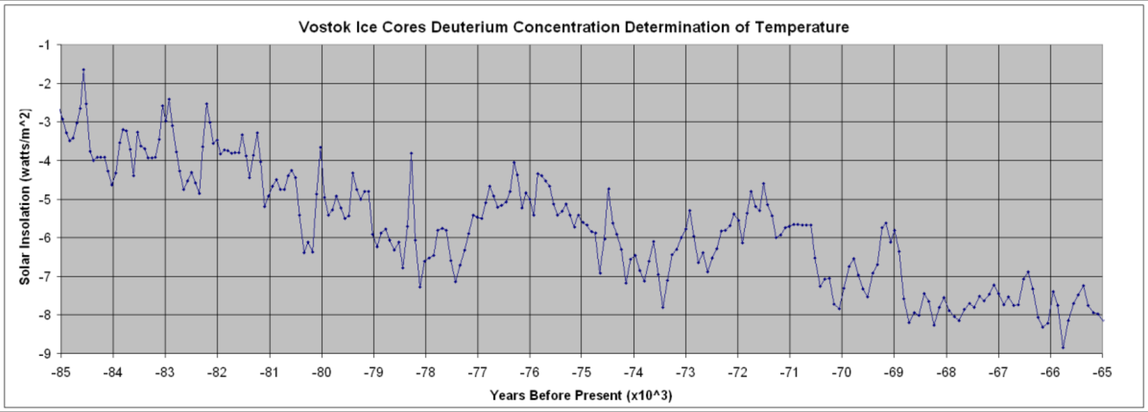
Volcanic eruptions can have large effects on short-term climate. A chronology of volcanic eruptions and their climatic effects can be found at http://www.innerx.net/personal/tsmith/13Mar93.html and in the book *Krakatoa* by Simon Winchester:

- 1883: Krakatoa: $50x10^6$ tons of aerosols into atmosphere
- 1815: Tambora: $200x10^6$ tons of aerosols into atmosphere; explosion index 7 on the 8-point energy exponential scale: 1816 "year without a summer"; 1 C° to 2 C° lower than normal.
- 1783: Laki in Iceland: $100x10^6$ tons of aerosols into atmosphere
- 536 AD: Papua New Guinea: $300x10^6$ tons of aerosols into the atmosphere
- 1650 BC: Santorini, Greece: One of the largest in the last 10,000 years.
- 74,000 ybp: Toba, Sumatra: $1{,}000x10^6$ tons of aerosols into the atmosphere; explosion index 8 on the 8-point energy exponential scale; 6-year "volcanic winter" killed many living things including most humans in a 1000-year Little Ice Age
- 120,000 ybp: El Hierro, Canary Islands: probably large tsunamis
- $2x10^6$ ybp-600,000 ybp about every 600,000 years, perhaps another eruption due soon: Yellowstone, USA: several huge calderas
- $14x10^6$ ybp: Columbia River, USA: $6{,}000x10^6$ tons of aerosols
- $65x10^6$ ybp: Deccan, India, antipodal to Chixalub comet collision in Yucatan, Mexico
- $200x10^6$ ybp: massive lava flows all over Pangea
- $250x10^6$ ybp: Siberia; probably related to a comet collision

The following graph of Antarctic temperatures shows a dip at about 73,500 ybp when the Toba volcano erupted:



The decrease at about 70,000 ybp is due to a dip in solar insolation. That is, the entire curve shown would have been decreasing if it were not for short-term climate changes, such as the one due to the eruption of Toba. This long-term downward trend is shown in the follow graph:



Note that there are many other short-term climate changes of larger magnitude than the one due to the Toba eruption.

All of these eruptions undoubtedly caused climate changes for some period of time of decades or longer. Because of these volcanic events, solar irradiance variations of the same periods are not the only drivers of such short-term climate. Thus, solar insolation changes due to irradiance variations cannot be used to predict with much accuracy future short-term climate changes. They can predict some, but not all, changes.

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