Food Security and Climate

What happens if the world warms?
What happens if the world cools?

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Outline

Overview

The topic of global warming and climate change is among the most contentious scientific debates of the 21th Century, with implications for agricultural production, energy policy, environmental policy, taxation, insurance, scientific discourse, and more. This paper from WeatherBELL Analytics LLC, written by esteemed meteorologist Joseph D'Aleo, examines the likelihood of future warming or future cooling around the globe and in specific growing areas, and the implications under both of these scenarios for agricultural production and food security. For anyone in the agricultural production chain, for investors, and for anyone impacted by the cost of food commodities, this paper is a must-read.

Preface

There is no doubt that the earth has warmed over the last few centuries since the end of the Little Ice Age. What is not clear is how much and why the earth has warmed. Unfortunately, this has become a political hot-button issue rather than a scientific question to be debated out in the open. As a result, most agribusiness professionals and investors are not aware of all of the possibilities. This paper will attempt to prepare the reader with as much information as possible to comprehensively plan for all of the possible climate scenarios that might occur later in the 21st Century.

2. Introduction

Advances in technology and biotechnology have produced a revolution in the world's ability to produce food for a rapidly growing population over the past century. Although industrialization has justifiably received most of the credit for the economic boom of the 20th century, high rates of economic growth are, at their core, dependent on the global food supply.

Due to rapid upward mobility in the developing world, a big challenge for agriculture going forward is to produce as much food over the next 40 years as has been produced in the last 10,000 years1, on about the same amount of land. Despite technological advances, farmers have not repealed the fundamental laws of nature and still must contend with forces beyond their control, most notably the weather. Changes in the weather and climate give agriculture its own economic cycles, often unrelated to the general economy.

While climate changes are inevitable and part of earth's natural history, the predominant question today is whether and by how much civilization is affecting the global climate. Projections over the past few decades based on greenhouse gas emissions have not measured up against observations. After further research, these errors are usually found to be because of the natural influences of the oceans, atmosphere and the sun.

This raises the question whether civilization's influence is really greenhouse gas driven and global in scope or local (e.g. urbanization and land use changes). Is CO2 a problem or a benefit to agriculture? What impacts does it have on agriculture?

Unfortunately, this has become a political hot-button issue rather than a scientific question to be debated out in the open. As a result, most investors and agribusiness professionals are unaware of all of the future possibilities. This paper will attempt to prepare the reader with as much information as possible to comprehensively plan for all of the possible climate scenarios that might occur later in the 21st Century.

Introduction - The projected effect of a warming

The IPCC Working Group II Report for Policymakers issued in March 2014 addressed food security and crop production.
The report stated:

> For the major crops (wheat, rice, and maize) in tropical and temperate regions, climate change without adaptation is projected to negatively impact production for local temperature increases of 2°C or more above late-20th-century levels, although individual locations may benefit (medium confidence).
>
> Projected impacts vary across crops and regions and adaptation scenarios, with about 10% of projections for the period 2030-2049 showing yield gains of more than 10%, and about 10% of projections showing yield losses of more than 25%, compared to the late 20th century. After 2050 the risk of more severe yield impacts increases and depends on the level of warming. Climate change is projected to progressively increase inter-annual variability of crop yields in many regions.

According to the Los Angeles Times:

> One of the [IPCC] panel's most striking new conclusions is that rising temperatures are already depressing crop yields, including

conclusions is that rising temperatures are already depressing crop yields, including those of corn and wheat. In the coming decades, farmers may not be able to grow enough food to meet the demands of the world's growing population, it warns.

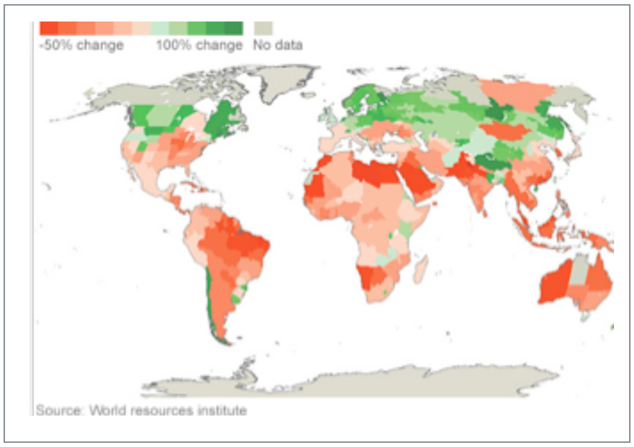


Figure 1. Crop Yields as projected by the World Resources Institute under a future warming of 3°C (Los Angeles Times).

In the article, the Los Angeles Times used the map in Figure 1 for the future of crops with a 3°C (5°F) warming. Currently, corn is grown in such varying places as North Dakota, Minnesota, Georgia, Alabama, Mexico and India. The variance of the temperatures in the growing seasons of these areas far exceeds (in fact, more than doubles) the 3°C change cited in Figure 1.

The main assumption in these studies is that farmers will not adapt to a changing climate and continue to use the methods and varietals they use in the present.

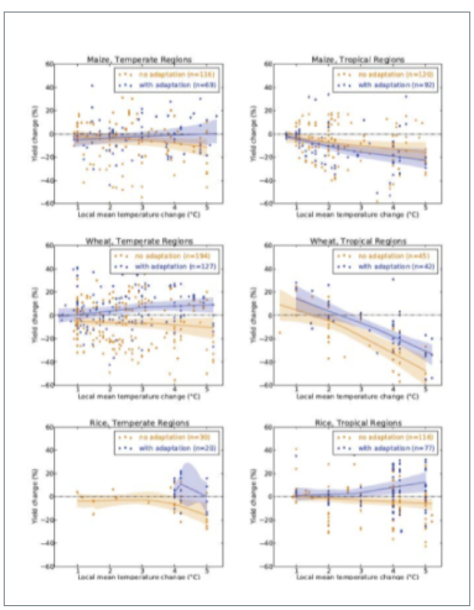


Figure 2. The IPCC shows yield change projections with (blue) and without (orange) adaption for a variety of crops.

The U.S. National Climate Assessment, publicly released in May 2014, simply restates the findings in the IPCC AR5 WGII Report.

3. What caused recent climate shifts?

3a. Ocean Cycles' Impact on Rainfall, Drought and Temperatures

There is seasonal climate variability through El Niño and La Niña (formally known as the El Niño Southern Oscillation, or ENSO), which have major impacts on temperatures and precipitation in the growing areas. In the United States, for example, the prior season's ENSO state influences the winter season storm tracks, which create antecedent conditions that can predispose growing areas to summer heat or drought or good growing conditions.

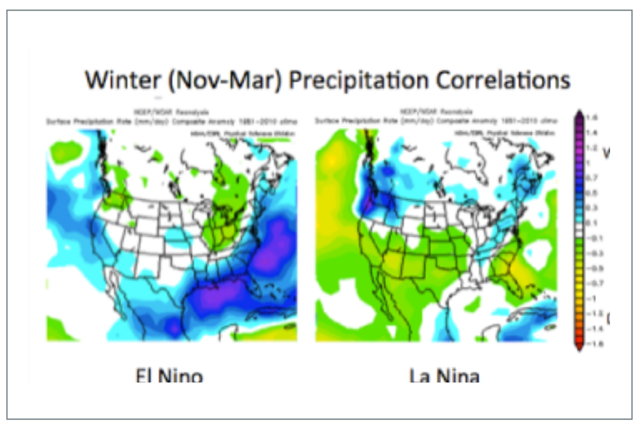


Figure 3. Winter (November through March) precipitation during El Niños (left) and La Niñas (right).

Across the United States, El Niños bring a southern storm track in the winter, with heavy precipitation across the South, but drier conditions to the north. This leads to northern growing areas vulnerable to a change toward the regime that favors dryness across the north. This occurred in the drought summer of 1988 when, after two El Niño winters, a strong La Nina came on.

La Niñas favor dryness in the North-central U.S., which in 1988 built on the antecedent conditions. La Niña's winter storm tracks are primarily farther north, bringing heavy precipitation to the northern tier but leaving the southern United Sates from California across the Southwest, the southern Plains and into Florida drier than normal. This makes these southern areas vulnerable to stronger than normal heat ridges and drought during the following summer.

Summers in developing El Niños (like 2014), shown in red in Figure 4 and Figure 5, tend to be normal to cool and normal to wet, with improved crop productivity.

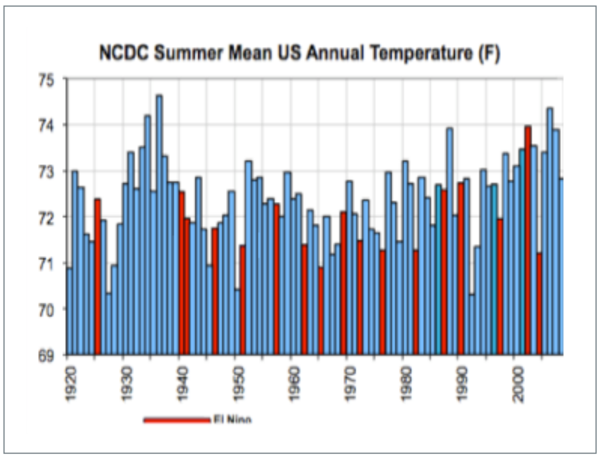


Figure 4. Average summer temperatures for the Continental United States from 1920-2009. El Niño years are highlighted in red.

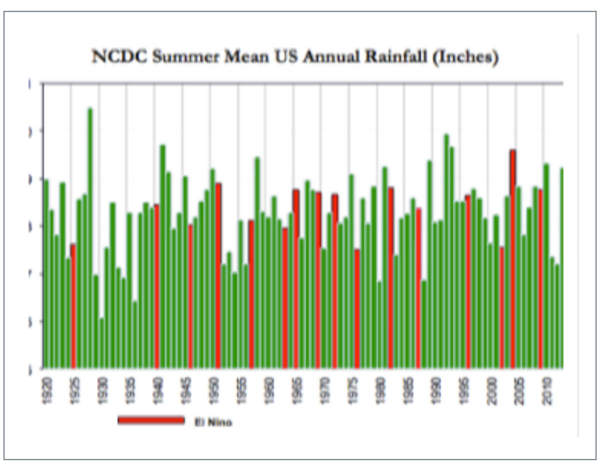


Figure 5. Average summer rainfall for the Continental United States from 1920-2009. El Niño years are highlighted in red.

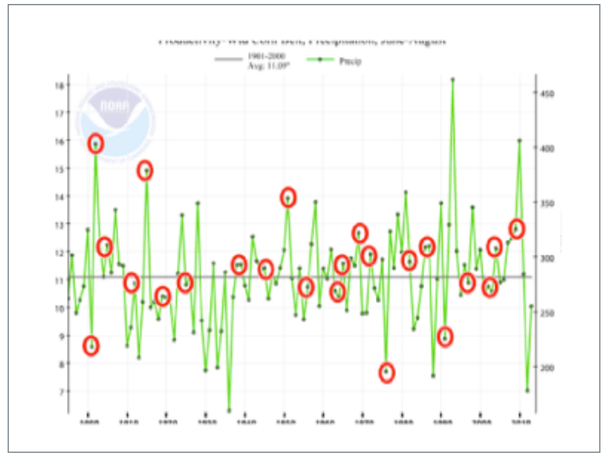


Figure 6. Of the 24 summer El Niños, 21 had normal to above normal precipitation in the highest production areas of the Corn Belt.

3b. Decadal Scale: The PDO and AMO

Multidecadal cycles have a lot to do with El Niño and La Niña frequency, strength, duration and impacts. As a result, they predispose areas in the United States to increased or decreased drought risk. They also control the multidecadal warming and cooling, which will be demonstrated in this paper to follow a predictable, well-established cycle that is approximately 60-years long.

The frequency of El Niños and La Niñas (ENSO) are largely determined by the state of the Pacific Ocean gyre. First discovered in the middle 1990s (Mantua et al., 1997), the "Pacific Decadal Oscillation" (PDO) is a long-lived El Niño-like pattern of Pacific climate variability. While the two climate oscillations have similar spatial climate fingerprints, they have very different behavior in time.

Two main characteristics distinguish the PDO from ENSO: first, 20th Century PDO "events" persisted for 20-to-30 years, while typical ENSO events persisted for 6 to 18 months; second, the climatic fingerprints of the PDO are most visible in the North Pacific/North American sector, while secondary signatures exist in the tropics (the opposite is true for ENSO).

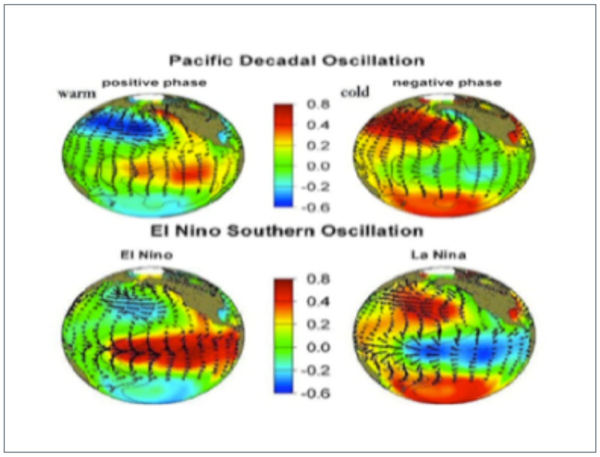


Figure 7. Ocean temperature anomalies and wind patterns in the positive and negative phases of the Pacific Decadal Oscillation (top) and the positive (El Niño) and negative (La Niña) phases of ENSO (bottom). Image from the University of Washington.

Thus, it is not surprising that the PDO predisposes the Pacific towards El Niño or La Niña. The warm PDO favors El Niño with increased frequency, strength and duration over La Niña. The cold PDO favors La Niña over El Niño with greater frequency, strength and longer duration (they are often multiyear).

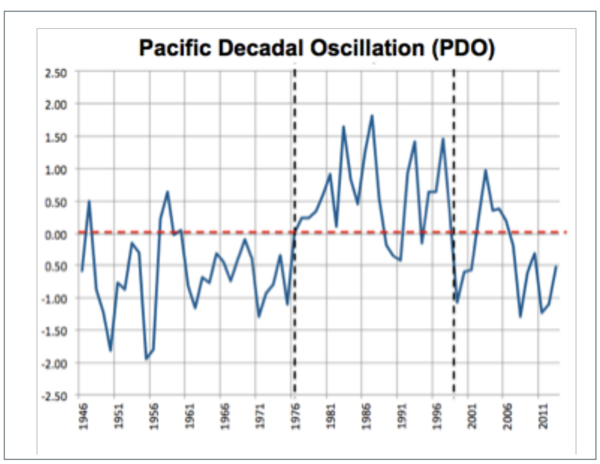


Figure 8. Annual standardized values of the Pacific Decadal Oscillation (PDO) from 1946 to 2013.

The Atlantic, like the Pacific, undergoes multidecadal changes in ocean temperature configurations related to the strength of the currents (the Thermohaline Circulation). It is a 60-70 year cycle, slightly out of phase with the PDO (Gray, 1997 and Goldenberg, 2001).

The Atlantic Ocean temperatures take on the same horseshoe-like pattern of warm surrounding cold or cold surrounding warm (that the PDO features). This pattern strongly correlates with Northern Hemisphere temperatures. It has an effect on many weather features including the Arctic Oscillation, frequency of hurricanes and importantly for agriculture, drought in the Lower 48 states.

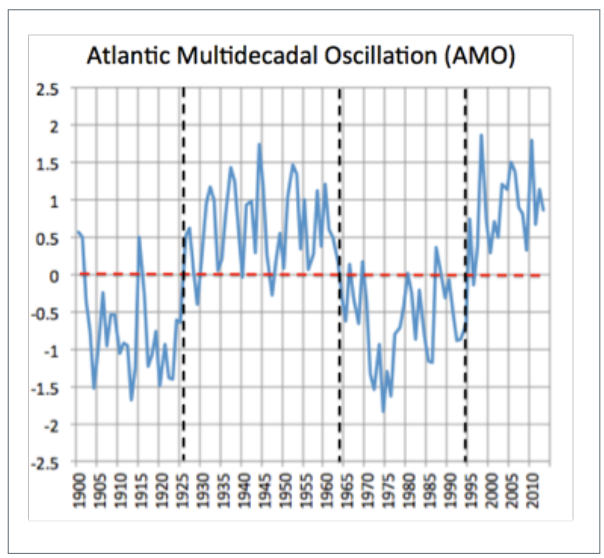


Figure 9. Annual standardized values of Atlantic Multidecadal Oscillation (AMO) from 1900 to 2013.

The warm mode (warm north and tropical Atlantic) was shown by McCabe et al. (2004) to enhance the frequency of drought.

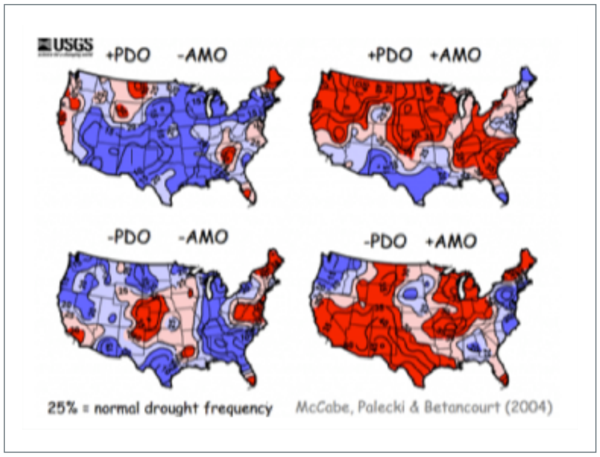


Figure 10. Matrix of the percentage of drought frequency during the phases of the PDO and AMO (McCabe et al., 2004).

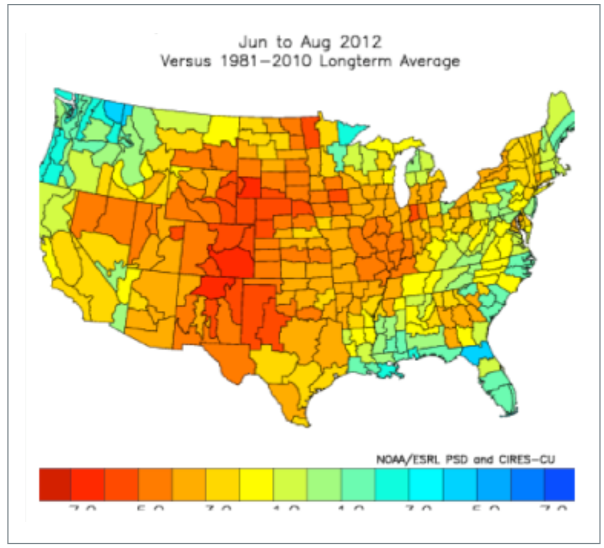


Figure 11. Summer 2012 Palmer Drought Severity Index (PDSI) versus the 1981-2010 long-term average.

They found that the PDO determined where the frequency of drought was greatest by affecting the strength, frequency and duration of the El Niños or La Niñas. A classic example of a +AMO/-PDO drought year (bottom right map in Figure 10) was 2012. The Palmer Drought Severity Index in 2012 (Figure 11) mirrored the McCabe, et al. (2004) finding (bottom right of Figure 10).

La Niñas are dry in the South, so it is no surprise that a southern drought is favored with feedback warming and drying into the Corn Belt (this was the pattern in the long drought of the 1950s and the droughts of recent years).

A positive PDO, with its enhanced frequency of El Niños (which are wet through the winter into the spring in the South but are drier in the North), has a greater likelihood of dryness in the northern growing areas (as in 1988, when there was a +PDO and +AMO in the summer and a strong La Niña).

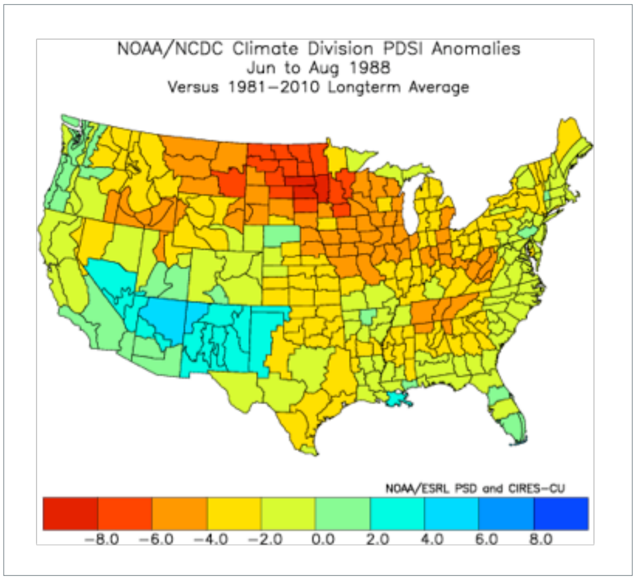


Figure 12. Summer 1988 Palmer Drought Severity Index (PDSI) versus the 1981-2010 long-term average.

The short term (El Niño and La Niña) drives year-to-year variability. The multidecadal cycles, the PDO and AMO, drive multidecadal changes on a well-established cycle that is approximately 60-years long. Note that the negative phases of both bring more cold than warmth and the positive more warmth than cold to the U.S. and globe. Figure 14 shows how there is a very strong correlation between the two multidecadal modes and U.S annual temperatures.

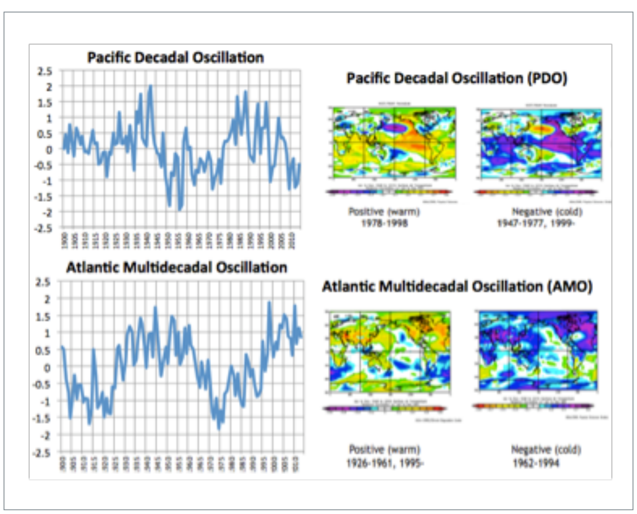


Figure 13. Time series (left) and spatial map (right) of global annual surface temperature anomalies in the positive and negative phases of the PDO (top) and AMO (bottom).

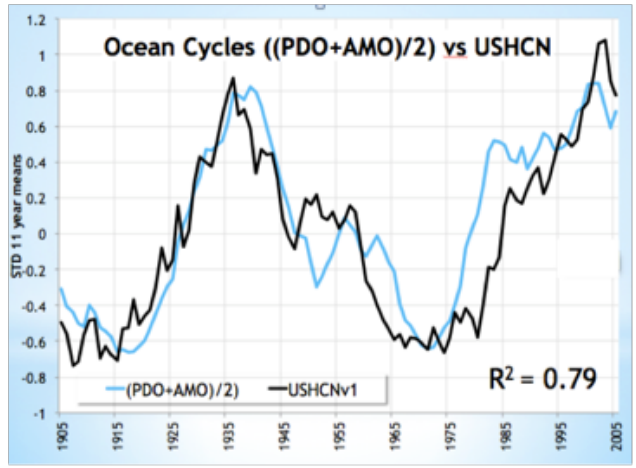


Figure 14. Smoothed (11-year) U.S. annual temperatures (NOAA NCDC USHCNv1) versus the average of the standardized values of the AMO and PDO from 1905-2005.

The long-term climate models are unable to reproduce consistently the short-term (El Niño/ La Niña) and multidecadal (PDO and AMO) variations. They, therefore, have insufficiently represented the observed 60-year combined cycles. It is not surprising that the models did not foresee a cessation of warming as one of the cycles, the PDO, turned negative in 1998. In the next few years, the AMO will soon join the PDO in its negative phase, which would imply that the observed flat-lining of global temperatures could turn into an overall cooling.

3c. The Sun As the Primary Driver
The IPCC downplays the sun's influence on the earth's climate because brightness (called irradiance) changes only 0.1% over the 11-year sunspot cycle. When sunspots are high, the sun is slightly brighter than when the count is low. Figure 15 depicts the last three sunspot cycles. Note how the activity during the peak of the last three cycles has declined by over 60%.

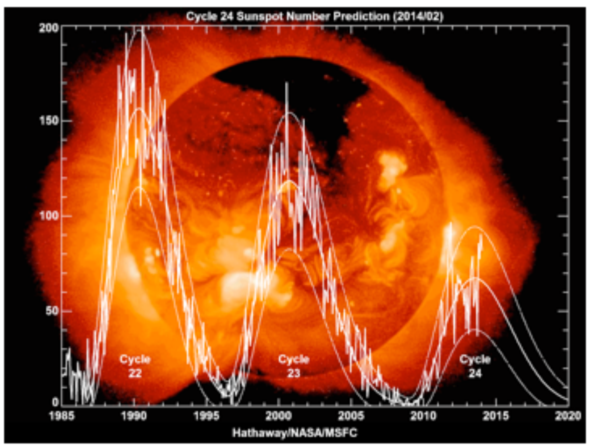


Figure 15. NASA/Marshall Space Flight Center's depiction of sunspot numbers for solar cycles 22 through 24.

The sun's role is more significant because irradiance is just a small part of the solar story. Yes, the brightness (irradiance) normally drops only 0.1% at solar minima, but it is a proxy for other magnifying factors. This decline in solar activity was not a surprise to solar scientists and experienced climatologists.

Each of these magnifiers does the work of warming and cooling the planet in different ways. During times when the sun is quiet, ultraviolet radiation drops between 6 and 8 percent, cooling low and mid latitudes through reduced ozone production in the stratosphere (a thinner ozone layer). The production of ozone is an exothermic (or heat-generating) reaction (Shindell, 1999 and Labitzke, 2001). This heat, also shown by Baldwin (2004), is dynamically coupled with the troposphere where weather patterns evolve.

Cosmic rays increase in quiet sun eras creating cloud forming ionized nuclei and, hence, more low clouds to reflect sunlight (Svensmark et al. 2013). Geomagnetic activity, when very low, favors cold polar air being pushed into middle latitudes in persistent and amplified weather patterns (D'Aleo 2011). Again, the IPCC climate models only look at brightness changes.

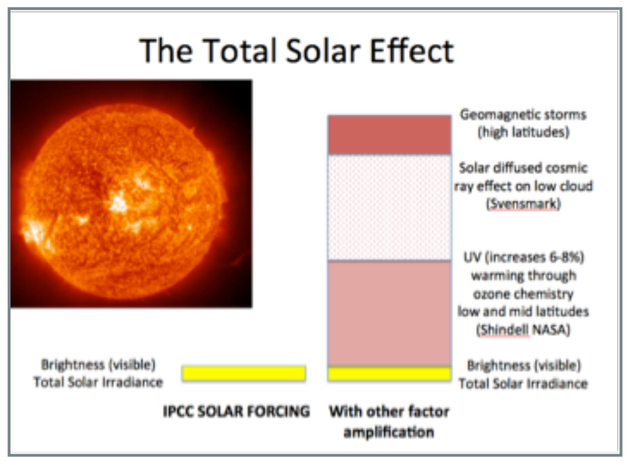


Figure 16. Depiction of the various solar factors that affect the earth's climate including brightness, ultraviolet, cosmic rays, and geomagnetic storms. The IPCC models only look at brightness changes.

When the Total Solar Irradiance is used as a proxy for the total solar effect (brightness plus the amplifiers), the solar activity and oceanic oscillations track well with the temperatures, while CO_2 (which rises steadily during the entire period) is positively correlated only about half of the time.

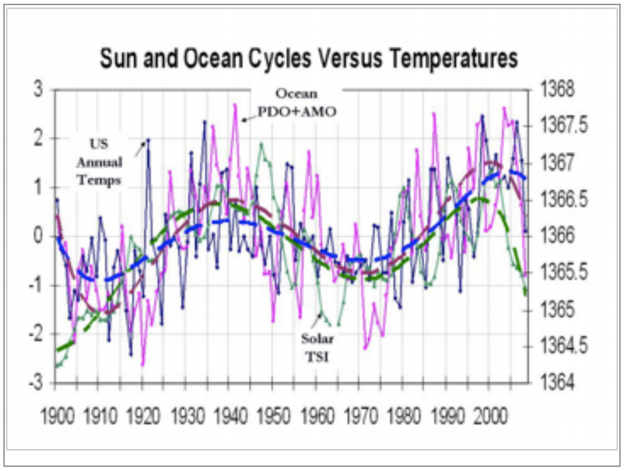


Figure 17. Total Solar Irradiance (Hoyt/Schatten TSI calibrated to Willson AMCRIMSAT TSI) and standardized PDO+AMO versus the United States Historical Climate Network (USHCN) annual temperatures plotted with polynomial smoothing (D'Aleo, 2011).

In addition to the 11 and 55-year cycles evident on the graph above, longer cycles can be seen on this plot of the past 11-year cycles since 1700. More specifically, 106-year and 212-year cycles can be observed.

Solar activity appears to be following the sequence observed around 1800, the Dalton Minimum, the last time the 106 and 212-year cycles coincided. Average European temperatures fell by 2° Celsius during the "Dalton minimum" cycle between 1790 and 1830.

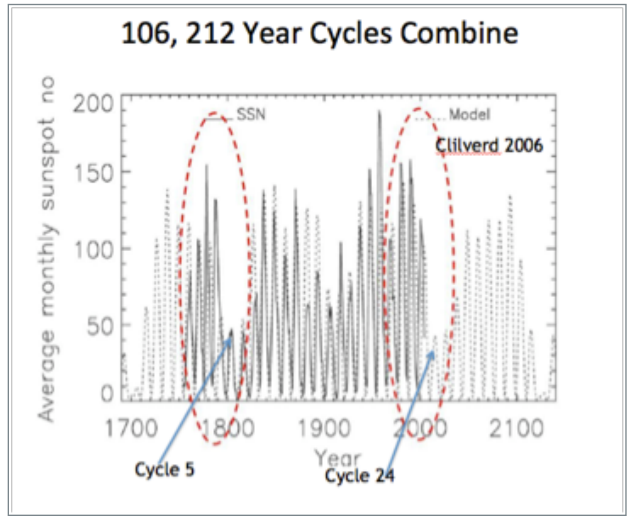


Figure 18. A model for sunspot numbers superimposed on past sunspot cycles from 1700 to the present and extended into the future past 2100 (Clilverd, 2006).

Dr. Habibullo Abdussamatov, who heads Russia's Pulkovo Observatory in St. Petersburg, predicts that after the maximum of solar cycle 24 in early 2014, the Earth can expect the start of the next bicentennial cycle of deep cooling with a "Little Ice Age" in 2055 (plus or minus 11 years), the 19th to occur in the past 7,500 years (Abdussamatov, 2013).

Dr. Abdussamatov points out that over the last 1,000 years deep cold periods have occurred five times. Each is correlated with declines in solar irradiance, much like the globe is experiencing now, with no human influence. He states:

> A global freeze will come about regardless of whether or not industrialized countries put a cap on their greenhouse gas emissions. The common view of Man's industrial activity as a deciding factor in global warming has emerged from a misinterpretation of cause and effect.

The new 'Dalton-like Minimum will be called the Eddy Minimum. Jack Eddy was a solar scientist who discovered the sunspot period known as the "Maunder Minimum" in the 1970s, and despite intense academic pressure of the consensus then, argued that this demonstrated that the sun was not constant, but indeed a slightly variable star.

Fellow solar astronomer and friend Dr. Leif Svalgaard from Stanford at the Solar Physics Division [of the American Astronomical Society in Boulder, Colorado] formally requested that if a significant solar minimum materializes that it be called the "Eddy Minimum." Following his suggestion, the astrophysics community has agreed to name the current period of low solar activity the Eddy Minimum. The Eddy Minimum will include at least solar cycles 24 and 25, and could continue until late in the 21st Century.

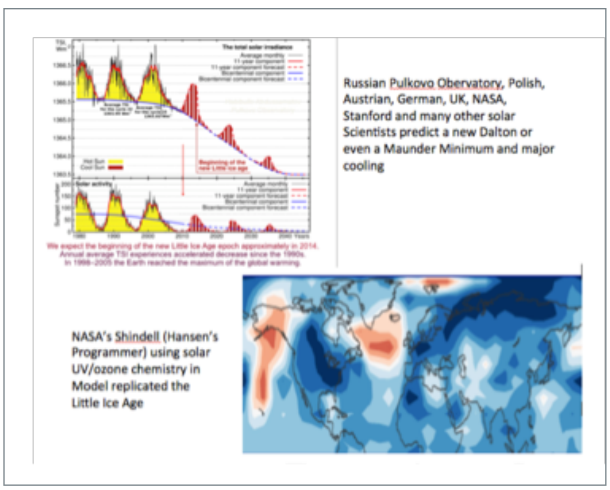
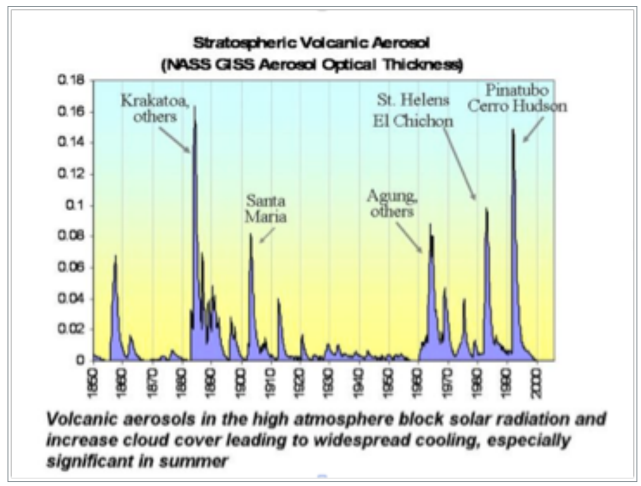


Figure 19. Total Solar Irradiance as predicted by the Russian Pulkovo Observatory through 2050 (top) and NASA's reconstruction of temperatures during the Little Ice Age based on ultraviolet radiation (bottom).

3d. Volcanism: The Wild Card

Major eruptions are relatively rare events but have at times occurred in clusters, affecting climate in some eras more than others. Figure 20 shows stratospheric aerosols, as measured by NASA GISS Aerosol Optical Thickness, which is proportional to the amount of resident volcanic materials. The late 1800s to the early 1900s was a very active period, with Krakatoa (Indonesia between Java and Sumatra in 1883) as the major event. Along with a quiet sun, it is no surprise this era was very cold. Recall from section 3c that a quiet sun is associated with lower solar irradiance (energy emission) and less heat input into the atmosphere.



stratosphere (Sato et al., 1993) and updated through 2012. High aerosols follow major volcanic eruptions and can have a significant impact on global average temperature.

The 1920s to the 1940s was a period of very little volcanic activity that coincided with a rapid increase in solar irradiance and multi-decadal warming in both oceans. This resulted in a warming of global temperatures. The sun and oceans are believed to be the primary drivers, but lack of volcanic ash may have augmented the warming.

The 1960s became very active, with Mt. Agung as the first of several significant eruptions that kept aerosol levels high through much of the decade. This coincided with a quieter sun and cooler cycles in both the Atlantic and Pacific. That decade, not surprisingly, was the coldest of the last 50 years.

After 1979, even as temperatures began to rise again, with an increasingly active sun and a warming in the Pacific (now known as the PDO warm phase, although it was then referred to as the "Great Pacific Climate Shift"), cooler global temperatures followed the major eruptions of Mt. St. Helens (Washington State in 1981), El Chichon (1982), and Mts. Pinatubo and Cerro Hudson (Chile) in 1991.

This is evident in Figure 21, which relates the stratospheric aerosol loading, represented as aerosol optical thickness (Sato et al 1998), to the satellite-derived lower tropospheric temperatures.

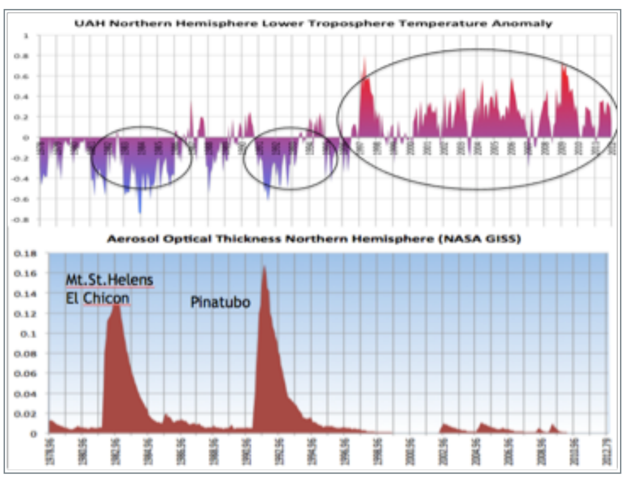


Figure 21. University of Alabama Huntsville measurement of lower tropospheric temperature anomalies from 1979 to the present (top) and NASA (GISS) stratospheric aerosol measurements (bottom) for the same time. Major volcanic eruptions can cool the globe while a lack of major eruptions can warm the globe.

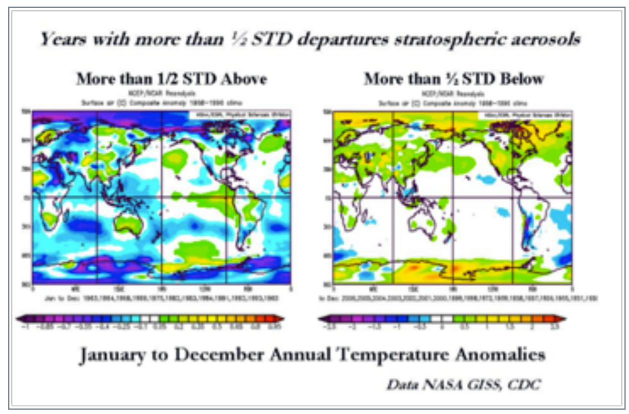
The eruption of Mt. Pinatubo in the Philippines in June 1991 ejected 10 cubic kilometers of magma and 20 million tons of sulfur dioxide. The aerosols it injected into the stratosphere lowered the annual global temperature by 0.5°C in 1992, with a peak intra-year effect of 0.7°C.

The impact on agriculture, though, was not significant. However, Archibald (2014) reported,

"Some wheat farmers in the northern part of the Canadian wheat belt found that the cool growing conditions didn't allow their crops to mature in time before winter set in."

Notice the warming in recent years, after the aerosol levels diminished to early and mid 20th century levels. Some percentage of the warmth in the past few decades has been due to fewer aerosols, allowing more solar radiation through. Figure 22 shows the importance of volcanism to the climate on the sub-decadal scale.

Figure 22. Annual surface temperature composite of all years with high stratospheric aerosol content (left) versus years with low aerosol content (right). Years after high



volcanic activity are significantly cooler.

When major eruptions are overprinted on a period of cold climate, the effect is far more severe. The Mt. Tambora super-eruption during the Dalton Minimum in 1816 led to what was called "The Year Without a Summer" with growing seasons cut in half in the Northeast U.S. and widespread crop failure. A repeat of the climate experience of 1816 in the world's temperate region grain belts would most likely result in almost all of the grain exporting countries to cease exports in order to conserve grain for domestic consumption. The effect on countries currently importing grain would go beyond calamity to catastrophe. The resultant mass starvation event would become one of the largest events in human history.

4. Consequences of a warming planet

4a. What if Warming Resumes?

As seen in Figure 23, global temperatures, after a step change upward in the 1990s after the super El Niño of 1997-98, have flat-lined in the last 12 to 18 years (varies with data source). The most reliable data comes from satellites, which provide full global coverage including the oceans, which cover 71% of the earth's surface.

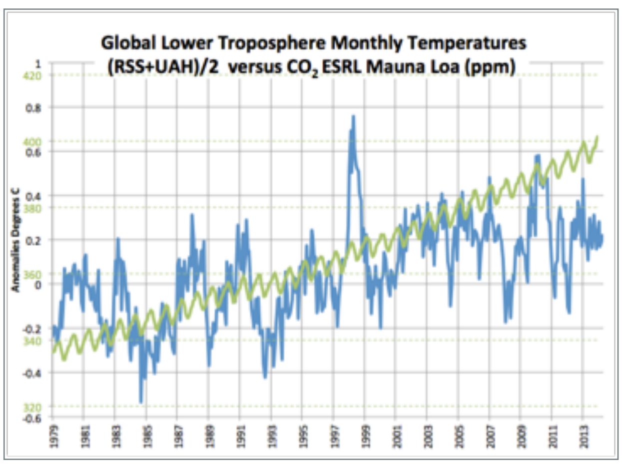


Figure 23. Satellite-derived global lower tropospheric monthly temperatures (blue) and Carbon Dioxide measurement at Mauna Loa, Hawaii (green) from 1979 to present. Note how the temperatures have been fairly steady since the turn of the century, despite a linear increase in CO2.

The IPCC climate models have not accounted for the pause, nor can they reproduce short term (El Niño and La Niña) or longer term (PDO, AMO) cycles. The models also assume that solar input is a constant and modeled effects from changes in solar activity are arbitrarily low because the models assume only brightness (or irradiance) forcing and not the amplifiers (as discussed in section 3c).

If it is assumed that greenhouse gases begin to dominate over natural variability (as they further increase) and if the low-solar activity scenarios do not materialize, there would be ramifications for climate and agriculture.

4b. Expanded Growing Regions

The minor warming over the last century and increases in CO2 have resulted in a greening and polar expansion of the prime growing regions.

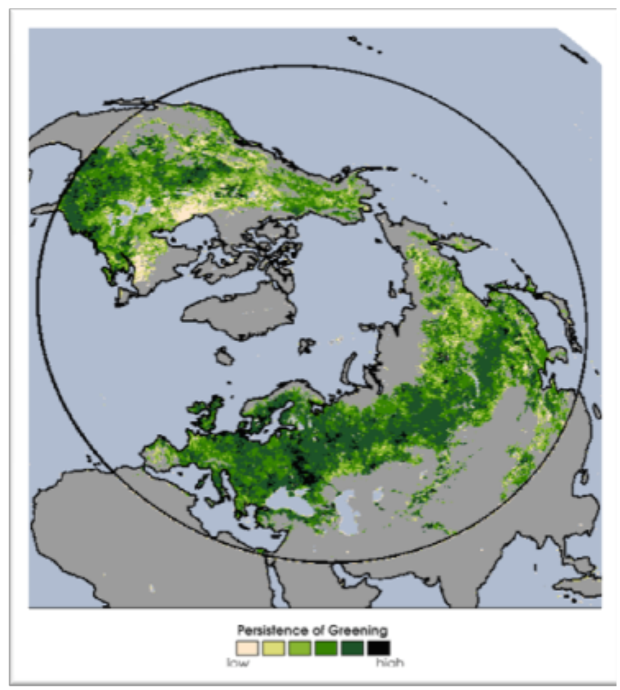


Figure 24. Greening persistence based on vegetation indices from 1981-1999. Image from the NASA Earth Observatory (Zhou, et al., 2001).

NASA reported that researchers confirm that plant life seen above 40 degrees north latitude, which represents a line stretching from New York to Madrid to Beijing, has been growing more vigorously since 1981. One suspected cause is rising temperatures, possibly linked to the buildup of greenhouse gases in the atmosphere (Zhou, 2001).

Over this same time period, parts of the Northern Hemisphere have become greener and the growing season has increased by several days (Zhou, 2001). Furthermore, Eurasia appears to be greening more than North America (see Figure 24), with more lush vegetation for longer periods of time.

4c. Expanded Growing Seasons

A resumption of warming would lead to an expanded growing season. This is observed near metropolitan areas, where the urban heat island effect results in earlier dates of the last freeze in the spring and delayed fall freezes.

Zhang (2004) found that vegetation "greenup" in cities started seven days earlier, and lasted eight days longer, than it did in adjacent rural sites. A large-scale warming would extend this benefit into growing areas.

It should be noted that increased humidity, as projected by the models, would elevate nighttime temperatures and serve as a brake on daytime warming. This is observed in areas where irrigation is practiced such as the valleys in California and the semiarid regions of the central U.S. (Christy, 2006), shown in Figure 25.

4d. More Double-Cropping

Expanded growing seasons might lead to increased double-cropping, as is common in some parts of the U.S. and is routine in places like Brazil. This may require shorter season hybrids that are more resistant to early and late freezes and frosts.

4e. Side Effects of CO_2

Hundreds of laboratory and field studies have demonstrated that elevated levels of atmospheric CO_2 stimulate plant productivity and growth and foster certain water-conserving and stress-alleviating benefits. These benefits likely persist throughout the plants' lifetimes (Idso & Isdo, 2011 and Idso et al., 2014).

Until the recent turn to colder patterns, the growing areas have expanded and have not been displaced, with more production from Canada and Russia.

In the U.S., corn, wheat, soybeans and milk production have increased from a combination of better hybrids, improved farming practices, beneficial precipitation patterns in the Corn Belt and the increased availability of CO_2 for photosynthesis.

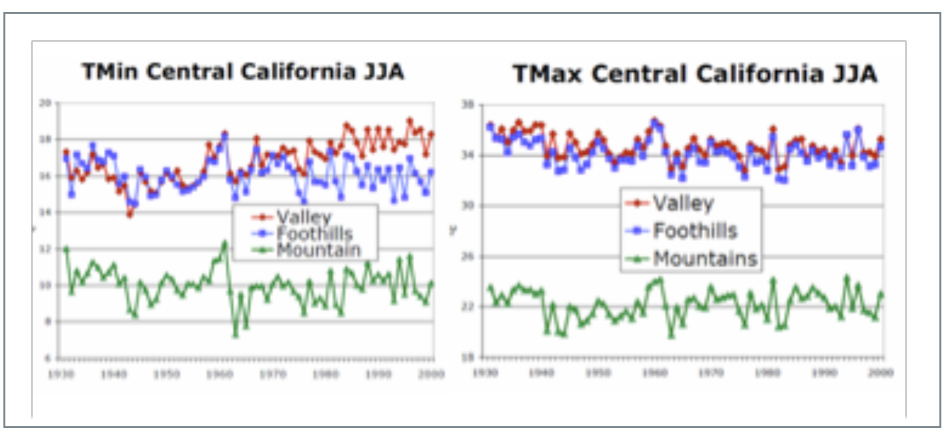


Figure 25. Central California Valley minimum (TMin) and maximum (TMax) temperatures as compared to the surrounding foothills and mountains. At night, added moisture in the valleys keeps temperatures elevated, but daytime temperatures are similar.

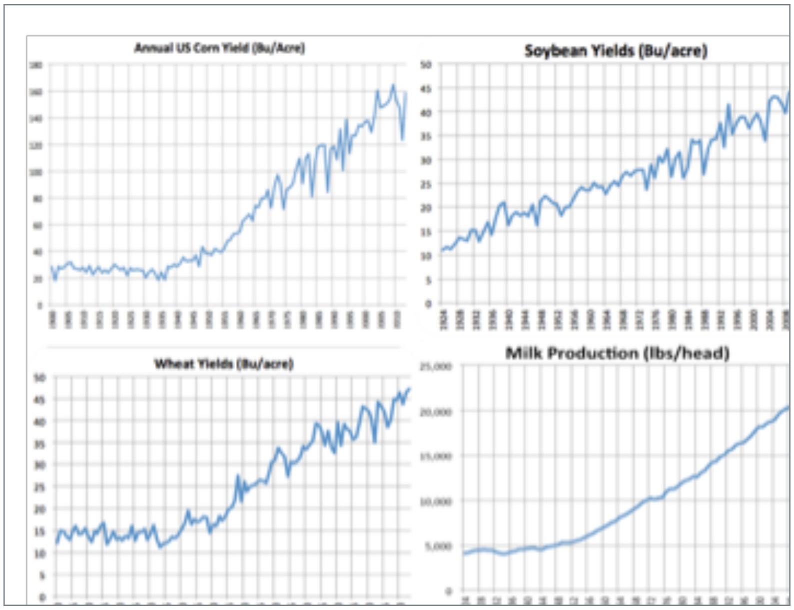


Figure 26. USDA yields for corn from 1900 to present (top left), soybeans from 1924 to present (top right), wheat from 1900 to present (bottom left) and milk production from 1924 to present (bottom right). Yields for the three grain-crops are in bushels per acre and milk production is in pounds per head of cattle.

Since the 1930's, corn yields have increased six-fold and are expected to double by 2030 according to Mark J. Perry (2011), a professor of economics and finance at the University of Michigan.

Another major benefit of atmospheric CO2 enrichment is that plants exposed to elevated levels of CO2 have a greatly increased ability to withstand drought.

As described in Wittwer (1997), in many cases a doubling of the atmospheric CO2 concentration actually doubles leaf-water use efficiency. More extensive plant canopies also shield the soil and limit soil moisture loss.

In 2012, despite a heat wave and drought as serious or worse than in 1988, production of corn was 50% higher than in 1988 thanks, at least in part, to the reduction of drought stress through elevated levels of CO2 and advancements in technology.

4f. More Serious Issues Arise Only If Outlier Scenarios Verify

With just a modest warming, the growing season would get longer, which would provide opportunities for farmers to grow new crops or, as noted in section 4d, do more double cropping. Along with CO2's enrichment and drought-mitigating benefits, crop yields likely would continue to improve.

Yield losses most likely would occur at the highest (outlier) end of the range of warming, associated with an increased frequency of high temperature stress, especially at critical crop phases such as flowering or filling. Additionally, an increase in soil erosion and crop failure may result from potential extreme precipitation events, while some growing areas may experience an inadequate winter chill period for optimum fruiting or insect control and increased pressure from invasive weeds, insects, or disease. Some studies, however, indicate that CO2 increases may ameliorate some of these issues for some areas and crops (Idso, et al., 2014).

5. Consequences of a cooling planet

5a. Shorter Growing Seasons Require New Hybrids

With a cooling of 2°C, as projected by the Eddy Minimum, the growing season at both ends would change by about 2 weeks. This is the difference between the last 32°F occurrence and the dates of a killing frost with 28°F (see Figures 27-30). This shortens the growing season by about 4 weeks. Not every year would have a problem, but short-season hybrids would be preferable to reduce the risk.

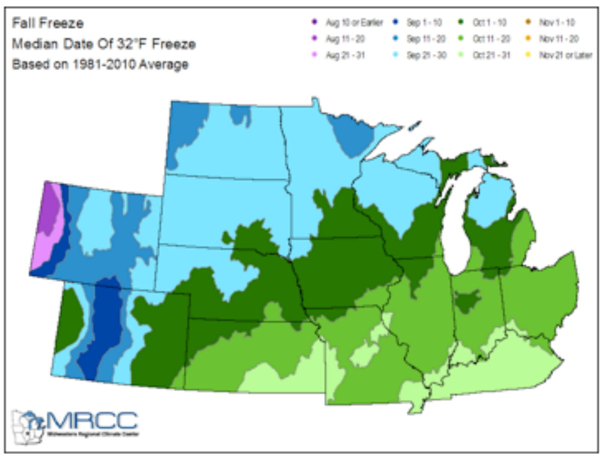


Figure 27. Median first date of a 32°F freeze in the autumn (Midwestern Regional Climate Center).

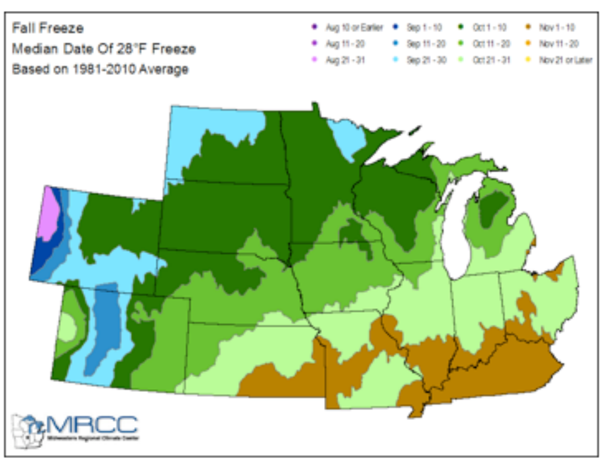


Figure 28. Median first date of a 28°F freeze in the autumn (Midwestern Regional Climate Center).

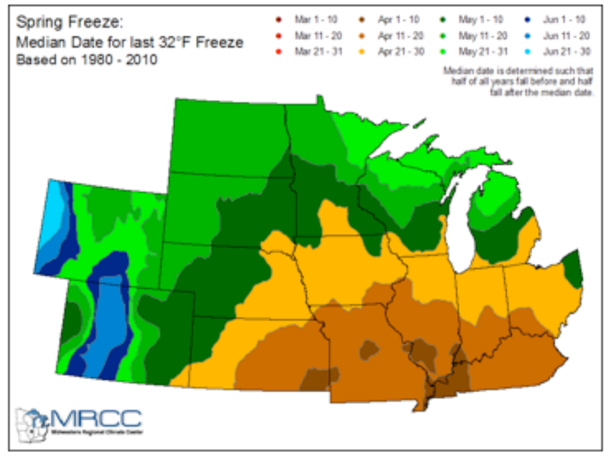


Figure 29. Median last date of a 32°F freeze in the spring (Midwestern Regional Climate Center).

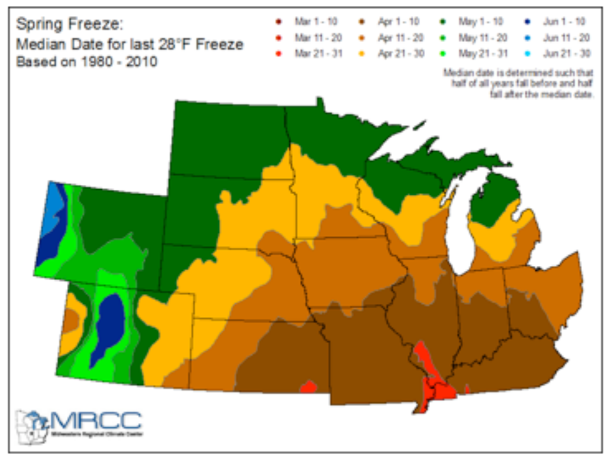


Figure 30. Median last date of a 28°F freeze in the spring (Midwestern Regional Climate Center).

5b. Replanting and Crop Failures

A crop damaged by early killing freezes can, of course, be replanted. A late planting and an early killing frost would lead to more significant losses.

Crops like citrus and vineyard grapes are often protected from the cold by smudge pots, water irrigation/spraying or, in the case of shallow radiational freezes or frosts, the use of large fans or even helicopters to mix the air. These can be expensive remedies that most grain farmers cannot afford to employ.

5c. Persistence and Amplification of Weather Patterns: More Summer Droughts

The prospects of a more amplified pattern that is more persistent will mean more extreme cold and areas of heavy precipitation in certain regions, but also mean more warmth and summer heat and dryness in other locations. This is often augmented by antecedent conditions.

For example, after a dry winter, areas like the southern Plains and Southwest are at increased risk of being under a heat ridge in the summer. This is how the droughts of 2010 to 2012, the 1930s and 1950s evolved in the United States and also how the summer heat waves of 2003 (Europe) and 2010 (Russia) developed. When the jet stream is less amplified and progressive, warm, dry periods are followed by showers and cooling. More normal growing seasons result.

5d. Expected Impacts of a Cooler Earth

Crop	Region	Impacts
Corn	Canada	Losses increase in Ontario and Quebec
	United States	Harder to grow in ND, MN, WI & MI. Improves in central and southern areas
	Eurasia	Problems in Germany, northern France, UK, Poland, Ukraine, eastern Europe/western FSU and Manchuria
	South America	Improved in northern Brazil. Early & late freezes some years in southern & central Brazil & Argentina
Soybeans	United States	Harder to grow in ND, MN, WI, MI. Improves in the Delta & Mid-south
	China	Early & late season freezes in Manchuria
	South America	Improved in northern Brazil, but early & late season freezes (some years) in southern & central Brazil and Argentina.

Crop	Region	Impacts
Wheat	Canada	
	United States	Drought losses south with more La Ninãs & cold losses north
	Eurasia	Losses in non-snow areas with early and late season freezes
	Australia	More La Niñas mean wetter years, but more cold south
	India & Pakistan	Cold and snow in northern sections with wetter winters
Citrus	United States	More freezes into central Florida, southern Texas and California
	South America	Colder farther north in Brazil
Coffee	South America	Freeze threat increases in Parana, Sao Paulo & SW Minas Gerais
	Central America & Mexico	Improved conditions
	Vietnam	Some cold damage in central Highlands

Figure 31. Expected impacts of a cooler climate in the main agricultural regions of the world.

David Archibald (2011 & 2014) conjectured on the response of Canadian wheat and U.S. Corn to an Eddy Minimum cooling (see Figure 32).

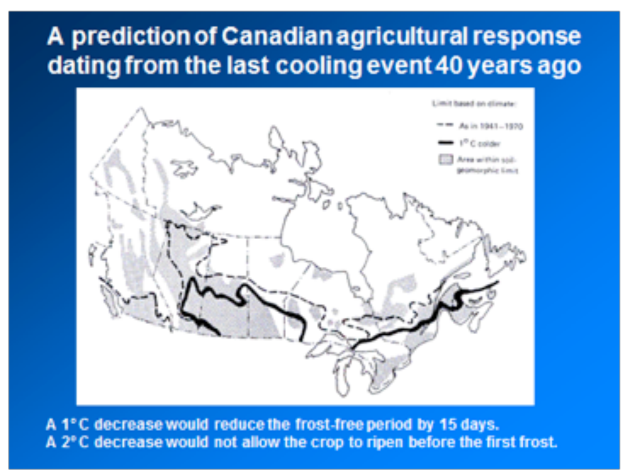


Figure 32. The shaded area represents topographical limits to agriculture. The dashed line depicts the northernmost agriculture limits of the 1941-1970 period and the solid line shows what would happen if the climate cooled another 1°C (Archibald 2014).

Newman (1980) provided an outlook to where the U.S. Corn Belt would shift with one degree of warming (Figure 33). His calculation of 144 km per degree C would lead to a 300km shift farther south, close to what Archibald (2011) calculated.

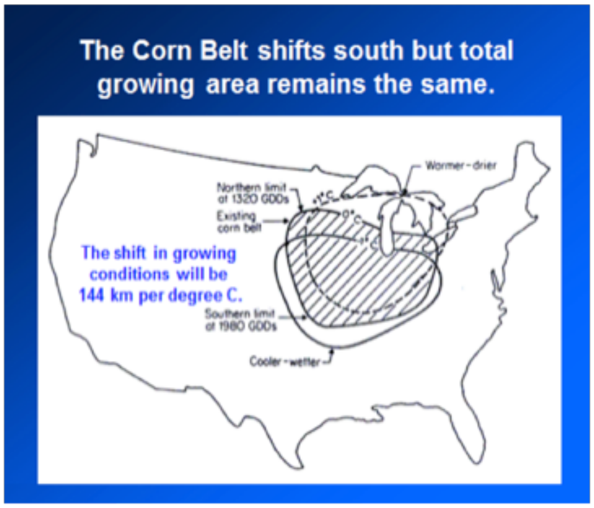


Figure 33. Ideal growing areas of the corn belt would shift north with warming and south with cooling by approximately 144 kilometers per 1°C (Newman, 1980). The current corn growing area is shaded.

Some Canadian Climatologists also see the start of a temperature decline that is tied to a reduction in solar activity. Babb et al. (2014) shows there has been about a 1°C cooling over the Canadian prairies between 1985 and 2013 during the months of June and July, when the spring wheat crop passes through the critical stem extension and heading phase (Peterson, 1965). This trend appears to driven by the deepest solar minimum since 1913 when the agricultural (September - August) years of 2007, 2008, 2009 and 2010 brought an average of 11.2, 3.3, 2.0 and 11.4 sunspots per month. Babb (2014) found a 2°C decline when the month of May is added for the period 1980-2011.

Hseih & Garnett (1999) and Babb et al. (2014) also have used the short-term (ENSO) and decadal (PDO) cycles in forecasting and analyzing Canadian wheat production. They have found spring wheat yields have increased over the last 35 years but are concerned with the impact that a further cooling would have on the growing season in Canada.

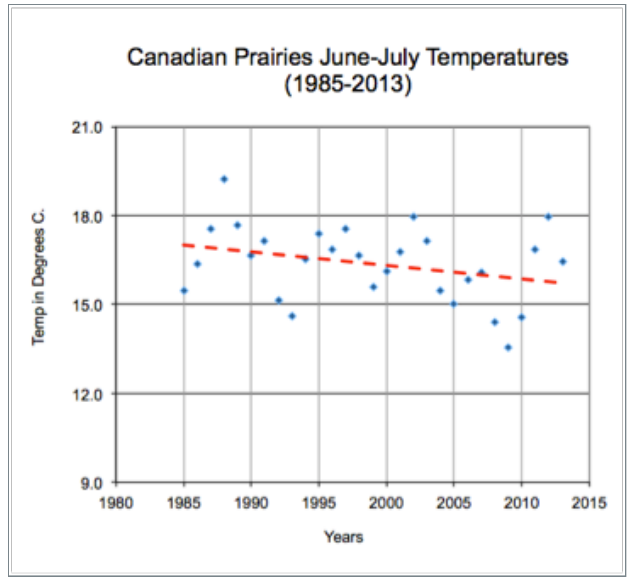


Figure 34. Average June and July temperatures in the Canadian Prairies from 1985 to 2013. Data sources: Ontario Climate Center 1985-2007 (400 stations), National Agro-Climatic Information Service (NAIS), Regina, Saskatchewan 2008-2010 (155 stations Environment Canada (EC) 2011-2013 (30 stations).

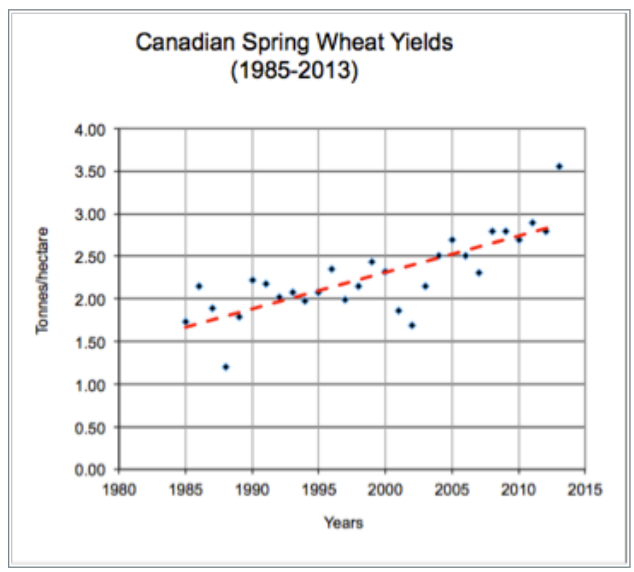


Figure 35. Canada's spring wheat yields from 1985 to 2013 (in tonnes per hectare). Data source: Statistics Canada.

David Archibald (2014) also wrote:

> In terms of the effect on agricultural productivity, productivity of corn production in the Corn Belt falls by 10% for each 1°C fall in annual average temperature. The Corn Belt also moves south by 144 km for each 1°C fall in annual average temperature.
>
> Soil quality declines to the south of the Corn Belt, though, so farms won't be as productive. Drought might reduce production further, on the order of 30%, producing a total decrease in production in the range of 50% to 60%. Two big corn states, Illinois and Indiana, had corn production falls of 30% in the 2012 drought year.

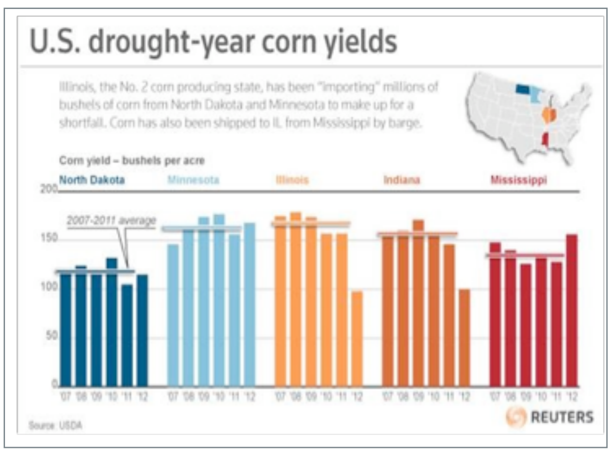


Figure 36. The impact of the 2012 drought on the heart of the Corn Belt (Illinois and Indiana) is shown.

Historically, deep solar minima and cooler climates have a tendency to produce megadroughts as Asmeron (2013) found. Steinhilber and Beer (2013) predict a deep minimum in solar activity starting in the present and continuing for 150 years. In effect, a megadrought for North America is predicted from at least 2050 to 2200.

Soft commodities, like coffee, cocoa and citrus are more sensitive to climate changes. In the mid 1990s, freezes in Brazil did major damage to coffee, causing approximately 18% of the coffee to be moved to less vulnerable areas farther north. In the middle 1980s, citrus in the United States was hit hard by freezes, moving citrus southward. In both cases, the freezes occurred at solar minima but were augmented by major volcanism a few years earlier.

With the new Eddy Minimum, these regions, and areas even farther north in Brazil and south in Florida, should be vulnerable to damaging freezes. There were a few in the recent solar minimum in the 2008 to 2010 time frame and even in Brazil last winter.

With the solar activity likely staying low, there will also be lower rainfall in Colombia, India and Indonesia, especially during the periodic El Niños (La Niñas will be favored in the cold PDO).

History tells us as the sun goes into its slumber, coffee prices will rise as they have dependably in recent cycles. Note the prices rose after 2004 as the sun went into a deep slumber. Prices peaked in 2011.

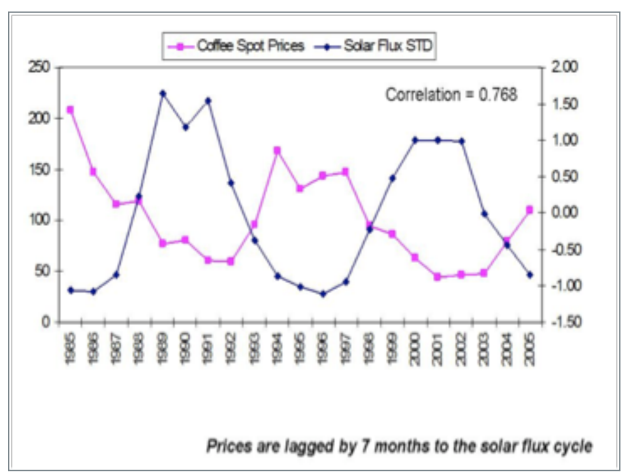


Figure 37. Coffee prices from 1985 to 2005. The graphs depict an inverse relationship between coffee prices and solar activity.

6. Future climate projections

6a. Temperatures

The U.N. IPCC reports relied on computer models that are struggling to capture recent temperature patterns. From an industry perspective, it is vital that traders and growers consider the alternate, and seemingly more plausible, impact on crops.

The trends of the last few years indicate that computer models have been oblivious to the flat-lining of global temperatures. On a regional level, a cool down has been occurring.

Figure 38. Satellite-derived lower tropospheric temperatures from 1997 to 2014. Global temperatures have not changed over the period.

The models used to project the change in crop yields have failed to capture the temperature patterns of the last two decades.

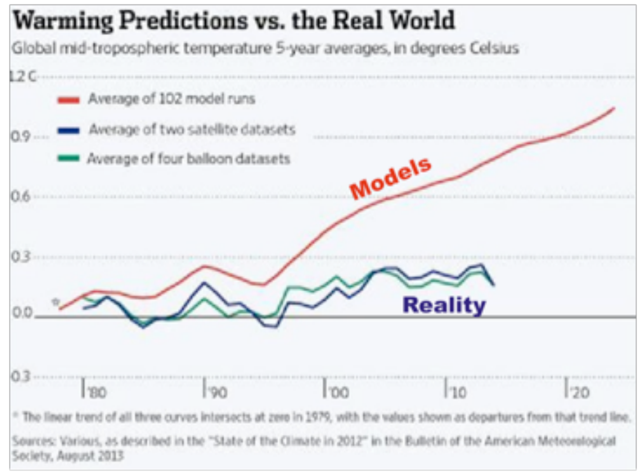


Figure 39. Global temperatures in the middle troposphere as predicted by climate models (red) compared to satellite measurements (blue) and weather balloon measurements (green). Temperatures are smoothed to a 5-year average.

As temperatures continually diverged further from the projections made in the four previous IPCC Assessments, the confidence in the warming forecast instead rose from 66% (2000) to 90% (2007) and then to 95% in AR5 (2013).

In the U.S. Corn Belt in particular, the temperatures have been steady during the last century despite model (42 CMIPS model average shown) projections of a significant, steady warming (Spencer, 2014).

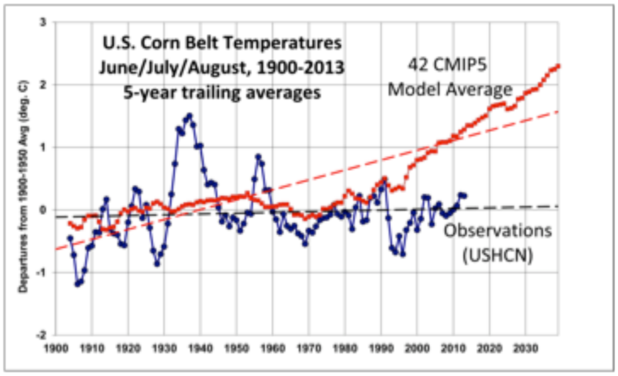


Figure 40. Summer temperatures in the U.S. Corn Belt from 1900 to 2013 (5-year trailing averages). The model prediction (solid red) is well above the observed temperatures (solid blue). The forecasted model trend (dashed red line) was for an approximately 1.5°C increase. Actual measurements (dashed blue line) show an approximately 0.2°C increase.

The projected warming in the tropical atmosphere was considered to be the most 'robust signal of greenhouse warming' of the models in the first four IPCC reports. That warming has been absent since 1979 in the tropical atmosphere and in the tropical Pacific Ocean to a depth of 300 meters (Humlum, 2014).

6b. Extreme Events

The IPCC model projections for sea level rise and hurricanes have also diverged from observations. The claims of increasing frequency of droughts and floods and hurricanes in prior reports were challenged by NOAA and the IPCC in AR5.

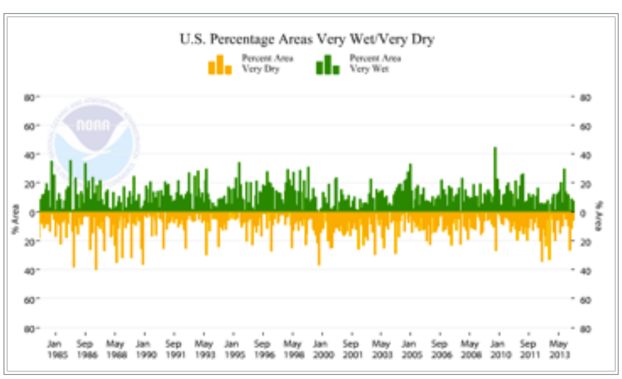


Figure 41. Percent area of the United States considered very wet (green) and very dry (yellow) from 1984 to 2013. (NOAA)

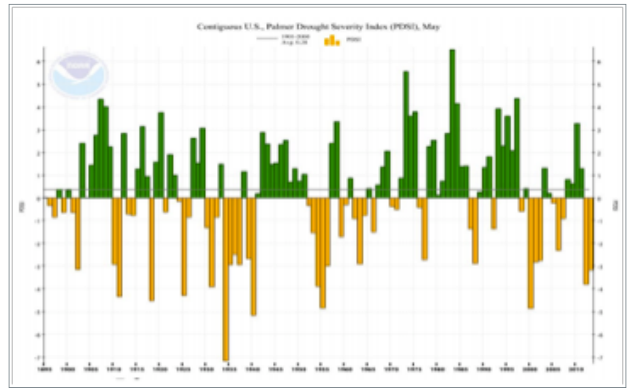


Figure 42. Palmer Drought Severity Index from 1985 to 2013 (NOAA).

Chapter 2 of the IPCC's AR5 stated:

> Con¬fidence is low for a global-scale observed trend in drought or dryness (lack of rainfall) since the middle of the 20th century owing to the lack of direct observations and geographical inconsistencies in the trends. Based on updated studies, AR4 conclusions regarding global increasing trends in drought since the 1970s were probably overstated. However, this masks important regional changes: the frequency and intensity of drought have likely increased in the Mediterranean and West Africa and likely decreased in central North America and north-west Australia since 1950 {AR4 2.6.2.2}.

NOAA found (Peterson, 2013):

> Confounding the analysis of trends in flooding is multiyear and even multidecadal variability, likely caused by both large-scale atmospheric circulation changes as well as basin-scale "memory" in the form of soil moisture.
>
> Droughts too have multiyear and longer variability. Instrumental data indicate that the Dust Bowl of the 1930s and the 1950s drought were the most widespread

twentieth-century droughts in the United States, while tree ring data indicate that the megadroughts over the 12th Century exceeded anything in the 20th Century in both spatial extent and duration.

Globally, tropical cyclone (hurricane) frequency has been at a 34 year low, although the warm mode of the Atlantic Multidecadal Oscillation (AMO) resulted in an increase in Atlantic Basin storms since 1995.

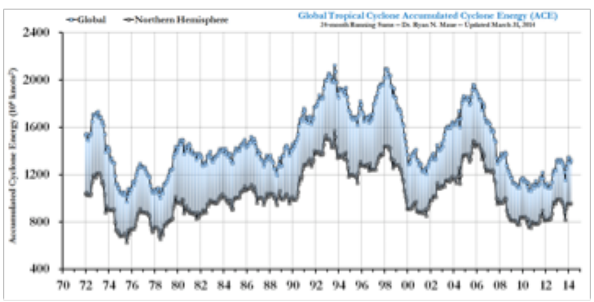


Figure 43. Last 4-decades of Global and Northern Hemisphere Accumulated Cyclone Energy: 24 month running sums. Note that the year indicated represents the value of ACE through the previous 24-months for the Northern Hemisphere (bottom line/gray boxes) and the entire globe (top line/blue boxes). The area in between represents the Southern Hemisphere total ACE.

El Niño, which is expected in 2014, has a tendency to see fewer Atlantic hurricanes (shown in red in the figure).

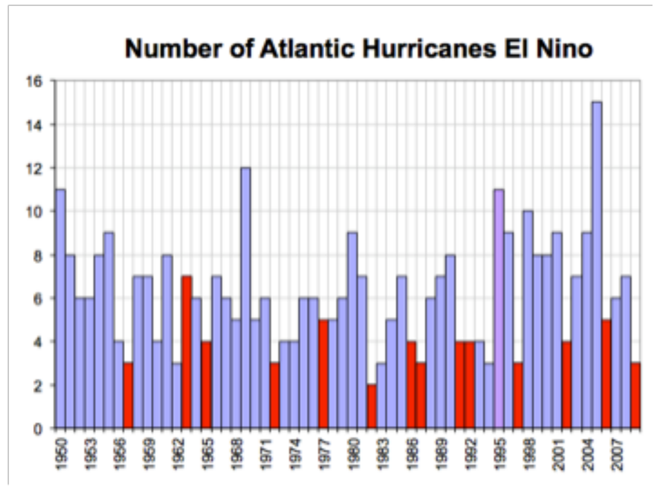


Figure 44. Number of Atlantic Basin Hurricanes from 1950 to 2009. El Niño years, which generally feature reduced activity, are shown in red. (NOAA)

7. Summary

The IPPC AR5 Working Group II report warned of future crop problems in the world's current mid-latitude grain belts due to warming and the deleterious effects of increased CO2.

These assumptions are based on computer models that are predicting warming and weather extremes that lead to a Poleward shift of the prime growing conditions. Section 6a showed how these models have had poor skill over the last two decades, during which a stasis or even cooling has occurred. In addition, IPCC scientists and data from the National Oceanographic and Atmospheric Administration (NOAA) have shown that there are no statistically significant global tendencies for increased drought and flooding and hurricanes.

This paper has also provided evidence for how the combination of ocean cycles and solar activity correlate well with temperatures and can explain shorter and longer-term cycles that the climate models have not reproduced. Both short term (El Niño/La Niña) and multidecadal (PDO, AMO) ocean cycles have important effects on crops both in the United States and globally

The current situation is most similar to the 1950s, when multi-year droughts occurred in the Plains. Given that the two ocean cycles will soon both be in the negative phases and the sun may be going into a deep slumber (similar to the Dalton Minimum in the early 1800s), it suggests that instead of warming and a shift north of the main grain belts, a shift south with shorter growing seasons cannot be dismissed and should be given serious considerations in medium to long-term planning. This could impact the grains and soft commodities like citrus and coffee.

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About the Author

Joseph D'Aleo is currently Co-Chief Meteorologist at WeatherBELL Analytics, LLC (weatherbell.com) where he issues global agricultural forecasts and long-range outlooks for grains and soft commodities, along with daily blogs on weather and climate events.

Mr. D'Aleo has over 40 years of experience in professional meteorology and was a cofounder and first Director of Meteorology at The Weather Channel. He was Chief Meteorologist at WSI Corporation, where he focused on product development, including multivariate statistical modeling for long range forecasting that was used operationally in energy and agriculture services. He was Senior Editor and "Dr. Dewpoint" for WSI's Intellicast.com website. He is a former college professor of Meteorology and Climatology at Lyndon State College. For four years, he was partner and chief meteorologist at Hudson Seven, LLC a hedge fund that focused on energy and agriculture.

Mr. D'Aleo authored a Resource Guide on El Niño and La Niña for Greenwood Publishing in 2002. Mr. D'Aleo has also authored articles and peer reviewed papers and made numerous presentations on integrity issues in surface temperature measurements and the roles that cycles in the sun and oceans play in climate change. He was also a contributor to the NIPCC series, the ISPM reports and Elsevier's Evidence Based Climate Change. He is the founder and Director of the ICECAP organization and website. Mr. D'Aleo is a Certified Consulting Meteorologist and was elected a Fellow of the American Meteorological Society (AMS). He has served as chairman of the American Meteorological Society's Committee on Weather Analysis and Forecasting and has co-chaired national conferences for both the American Meteorological Society and the National Weather Association. By his peers, Mr. D'Aleo was elected to the AMS Council.

Joseph D'Aleo is a graduate of the University of Wisconsin (BS, MS) and was in the doctoral studies program in Air Resources at NYU for three years. He has been awarded an honorary doctorate in science from The Vermont State Colleges.

About WeatherBELL Analytics, LLC

WeatherBELL Analytics is a meteorological consulting firm that provides customized weather forecasts, data services, and weather intelligence tools to entities exposed to the weather. The forecasting team is led by two meteorologists, Joe Bastardi and Joe D'Aleo, both of whom are widely acknowledged for their skill in short, medium, and long-term weather forecasting. Their proprietary techniques and combined experience of more than 80 years provide a distinct competitive advantage to WeatherBELL Analytics' clients.