The Game is Afoot

"Come, Watson, come! The game is afoot. Not a word! Into your clothes and come!"

Background

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 entering the next solar cycle, Solar Cycle 24, so named because it is the 24th consecutive cycle that astronomers have observed and listed. The first cycle began in March 1755.

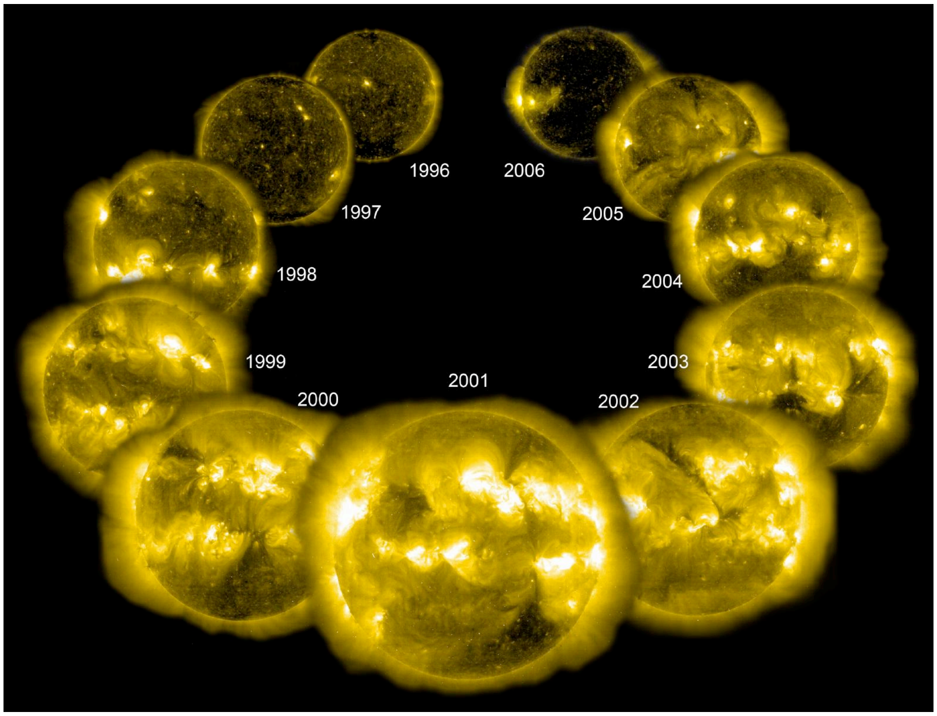

Figure 1. Image of Solar Cycle 23 from the Solar and Heliospheric Observatory (SOHO) by Steele Hill (NASA GSFC)

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.)

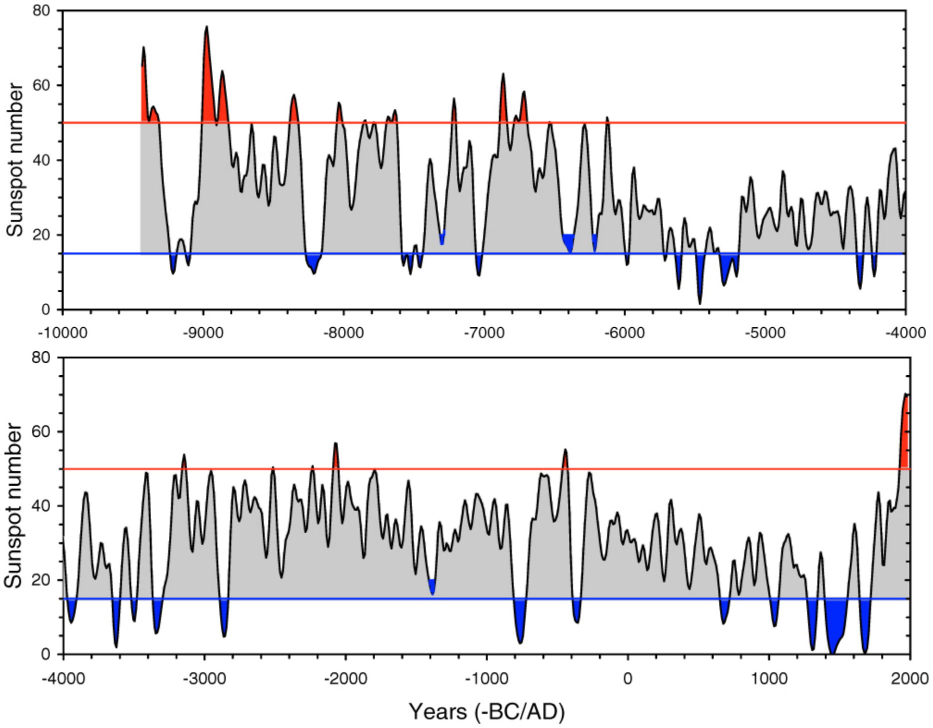

Figure 2. Sunspot activity throughout the Holocene. Blue and red areas denote *grand minima and maxima*, respectively. The entire series is spread out over two panels for better visibility.[1]

Our Milky Way galaxy is awash with high-energy galactic cosmic rays (GCRs). These are charged particles (protons, ions) that originate from exploding stars (supernovas). Many of these particles are traveling near the speed of light. Because they 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. 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 have increased 19% beyond anything we've seen since satellite measurements began 50 years ago.[2]

If we slip into a quiet solar *Grand Minima* state, we can expect GCR flux rates to increase 200% to 300% above current levels.

The Quiet Sun

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 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.

Earth's ocean cloud cover is strongly correlated with GCR flux modulated by solar cycle variations. Refer to Figure 3.

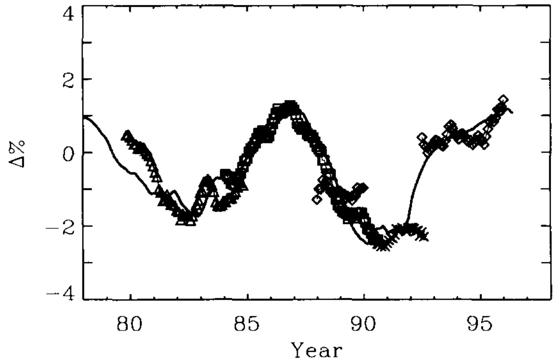

Figure 3. A strong correlation between Galactic Cosmic Rays (GCRs) and Earth's cloud cover over the oceans. This figure shows cosmic rays fluxes from Climax (thick curve) plotted against four satellite cloud data sets. Triangles are the Nimbus-7 satellite data, squares are the ISCCP-C2 data, diamonds are the DMSP data, and crosses are the ISCCP-D2 data.[3]

In 2006, the Danish National Space Center in Copenhagen 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 experiments confirmed the causal mechanism by which cosmic rays facilitate the production of clouds in Earth's atmosphere.[4] 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).

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. The

Maunder Minimum corresponded to the depths of the Little Ice Age. Before that was the Spörer Minimum (about 1420 to 1570 A.D.). That *Grand Minima* was also noted for bone-chilling cold temperatures and was referred to as a *Little Ice Age*.

Historically past solar *Grand Minima's* produced a global drop in world temperatures. This is because clouds reflect sunlight back into deep space, effectively increasing the albedo of our planet. Food production declined due to shortened growing seasons, unpredictable early frost, a dramatic increase of days with overcast skies and a resulting decline in the intensity of sunlight. With diminished food production, a string of famines occurred. Added cloud cover also produced greater rainfall, massive storms and floods. For example during the Spörer Minimum, approximately 400,000 people perished in the A.D. 1570 "All Saints Day storm" in northwestern Europe. And two catastrophic storms hit England and the Netherlands in A.D. 1421 and A.D. 1446, each storm killing 100,000. Flooding created swamplands that became mosquito breeding grounds and introduced tropical diseases such as malaria throughout Europe.[5] During the Little Ice Age, glaciers expanded rapidly in Greenland, Iceland, Scandinavia and North America. This 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. Finland's population fell by one-third, Iceland's by a half, the Viking colonies in Greenland were abandoned altogether, as were many Inuit communities.[6]

This threat from a *Grand Minima* is not a short-term threat but extends over several decades. Of the 27 *Grand Minima's* that have occurred over the past 12,000 years: 30% lasted less than 50 years, 52% lasted between 50 and 100 years, and 18% lasted over 100 years. Of these, the longest was Spörer Minimum, which lasted approximately 150 years.

Current Trends

The sun is currently coming out of one of the longest solar minimums in many decades and transitioning into Solar Cycle 24.

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*.

This solar minimum is rather unusual. If we define a period of quiet sun as those months that produced an *Ap index* of 6 or less and compare the total number of quiet months within each solar minimum, then the results would be:

Minimum Preceding Solar Cycle	**Number of Months with *Ap Index* of 6 or less**
SC17	11 months
SC18	2 months
SC19	2 months
SC20	5 months
SC21	0 months
SC22	0 months
SC23	3 months
SC24	31 months and counting

November 2010 produced an *Ap index* of 5. The sun still remains relatively quiet. At the same time, the winter weather has produced unusually large snowfalls and cold weather in both the Northern and Southern hemispheres for approximately four years now (counting this winter in the mix).

The northern hemisphere polar jet flows over the middle to northern latitudes of North America, Europe, and Asia and their intervening oceans. Almost all big storms develop, mature, and dissipate in the vicinity of this main jet stream. It appears that during the past few winters, the jet stream has become sharper, producing a stronger wind flows that reaches further north and bring very cold weather and monster winter storms into mid-latitude environments.

This phenomenon is different than the galactic cosmic rays / cloud theory which causes natural global cooling. Something else is afoot. So the question that needs to be asked is "Can large amplitude atmospheric circulations changes be caused by prolonged low solar activity?"

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 many decades. It might be beneficial to explore the records from Grand Minima events to determine if this atmospheric pattern was present. During the Spörer Minimum, early explorers made significant progress in probing and surveying the New World. They described North America as a

> *"land of frozen seas, horrid, barren and scarcely habitable for cold". "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. 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."* [7]

The observations of these early explorers indicate that not only was this large amplitude atmospheric circulation pattern present during the Spörer Minimum 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.

After comparing 350 winters in the United Kingdom, M. Lockwood et al. has also observed a strong correlation between the coldest U.K. winters and periods of quiet sun. Michael goes on to write about a possible causal mechanism: "tropospheric jet streams have been shown to be sensitive to the solar forcing of stratospheric temperatures. This could occur through disturbances to the stratospheric polar vortex which can be propagated downwards to affect the tropospheric jets, or through the effects of tropical stratospheric temperature changes on the refraction of tropospheric eddies." [8]

Causal Mechanism

Why would a quiet sun cause the atmospheric circulation patterns to change?

Just as there are natural causes for climate change; there are natural causes for ozone depletion. These tend to be overlooked by the proponents of Anthropogenic [Man-Made] Global Warming theory and by the proponents of the Anthropogenic [Man-Made] Ozone Hole Theory. In both instances, these natural causal mechanisms are related to the sun.

The Earth is surrounded by a thin layer of ozone in the middle atmosphere (stratosphere) about 25 kilometers above the Earth's surface. Ozone is a minor constituent of the stratosphere (1-10 ppm). 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 depletion varies both by season and geographically. Ozone holes are areas where the reduction of ozone is dramatic; leaving voids in the ozone layer. The ozone holes occur in the Polar Regions (70% over Antarctica and 30% over the Arctic). The ozone losses occur annually each spring in the Polar Regions but recover by the summer.

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%. [9]

In this natural process, ozone levels are in a state of quasi-equilibrium. Ozone is destroyed by solar proton events, a component of solar storms but slowly restored by UV radiation, a component of sunlight. When the sun goes quiet, there is an absence of sunspots and concurrently *an absence of massive solar storms*. Thus there is a shift in this natural equilibrium. The destruction of the ozone layer is minimized. But the UV radiation from the sun slowly continues on - restoring the levels of ozone in the stratosphere. As a result, ozone levels in the upper atmosphere rise.

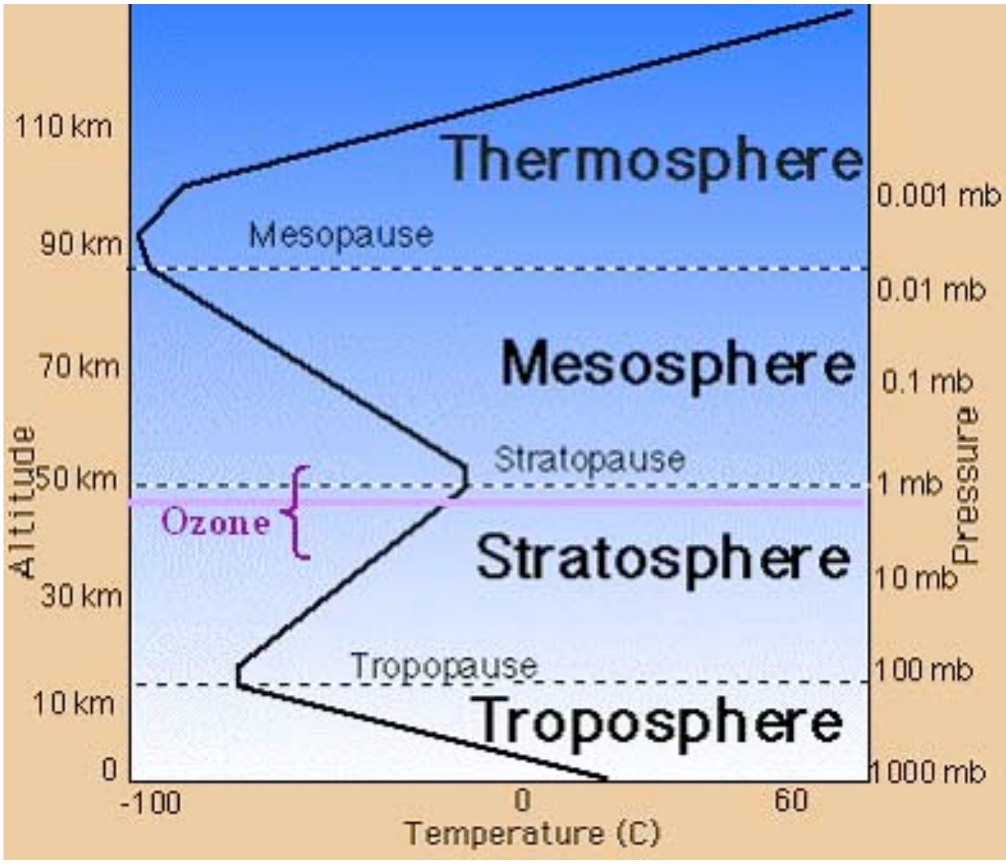

Figure 4. Ozone heating between Mesosphere and Stratosphere.

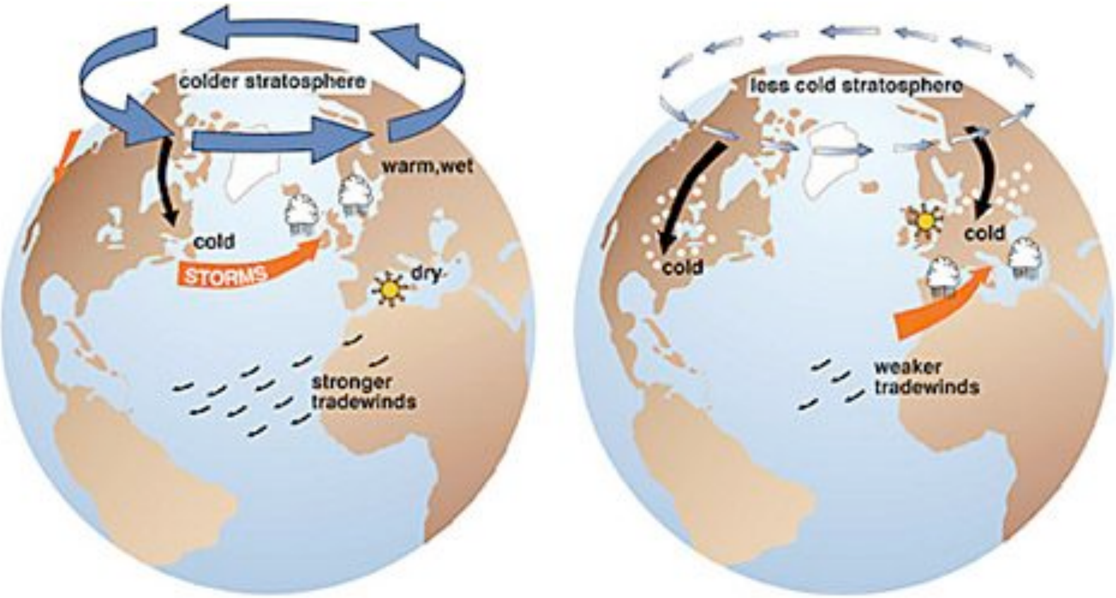

Figure 5. Impact of the strength of the polar vortex on the main jet stream.

Let's take a break for a few seconds and look at the research related to massive solar storms. The sun produced very powerful solar storms between 18 October and 5 November 2003. 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.[10] 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.[11] In the southern polar cap region, ozone losses of 75% were measured in the mesosphere and upper stratosphere from a 28 October 2003 solar storm.[12]

The next question is "How does ozone levels influence atmospheric circulation patterns?

Because little, if any, sunlight reaches the Polar Regions during the winter, air in the upper stratosphere is able to cool to low temperatures. By comparison, in equatorial regions, sunlight prevails all year long, allowing stratospheric ozone to absorb solar energy and warm the air. Since ozone can absorb UV radiation especially the most energetic ultraviolet light (UV), known as UV-C (220-290 nm) and UV-B (290-320 nm), ozone can capture this heat at high elevations. The horizontal temperature gradients between the cold poles and the warm tropics create steep horizontal pressure gradients, and a strong westerly jet forms in Polar Regions at an elevation near 50 km (30 mi). Because the wind maximum occurs in the stratosphere during the dark polar winter, it is known as the stratospheric polar night jet stream.[13] Inside the polar night jet is the polar vortex. The warmer air can only move along the edge of the polar vortex, but not enter it. Within the vortex, the cold polar air becomes even colder. Neither warm air from lower latitudes nor energy from the sun enters the vortex during the polar night.

A polar vortex is a persistent, large-scale cyclone located near Earth's geographical poles in the middle and upper troposphere and the stratosphere. They surround the polar highs and are part of the polar front. The vortex is most powerful in the hemisphere's winter, when the temperature gradient is steepest, and diminishes or can even disappear in the summer. The polar vortex shields the Polar Regions by deflecting the main jet stream away from the poles. 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.

During periods of quiet sun, there is an absence of major solar storms that destroy mesospheric ozone. As a result, the mesospheric ozone levels in the Polar Regions will slowly rebound and thicken due to an interaction with UV radiation. Greater ozone in the mesosphere will cause Polar Regions to warm slightly, which in turn reduces the temperature gradients between the polar and equatorial regions. This in turn weakens the polar vortex allowing the main jet stream to periodically punch through and pull extremely frigid polar air into mid-latitude environments during winter.

I suggest there exists a direct linkage between solar cycles and atmospheric circulation patterns on Earth and the pathway is mesospheric ozone.

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