Probability estimation of a catastrophic Carrington−like geomagnetic storm: Re−evaluated in new light of upcoming Maunder Minimum and recent decreases in geomagnetic field, after recent studies came to conflicting conclusions; Proposed solutions for citizens and lawmakers

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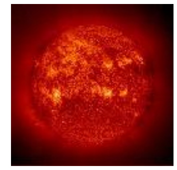

Image 1.
Earth's sun[75]

Abstract **[Abstract is written mainly for fellow-scientists/researchers; Summary is more 'broad'.]**

In September 1859, the famous "Carrington Event" occurred (with estimated Dst readings of **−850 nT** to **−900 nT**), the largest recorded solar geomagnetic event since accurate records were made, causing widespread failures to contemporary telegraph systems and producing brilliant polar aurorae. In July 2012, a solar storm of much greater strength almost hit earth, narrowly missing because we'd moved about nine (9) days [about **2.46%** of earth's **365¼−day** orbit] from its trajectory[70], with a peak Dst value of **−1,182 nT,** as reported by ***Space Weather***[31]. As a result, astronomers & scientists worldwide began calculating the probability estimation of another catastrophic Carrington−like geomagnetic event, since current technology (communications, GPS, power grids, satellites, etc.) are much more vulnerable to a severe solar storms than in the past when the only 'electronics' available were long−wire telegraphs —before even the telephone had been invented. Prior published research gave widely varying probability estimations of another such event. Moreover, prior research did not take into account the upcoming Maunder Minimum or acceleration in the geomagnetic pole movement, and the acceleration in the collapse of earth's protective magnetic field; nor, did they account for "lesser" magnetic storms which were very destructive, in their own right, causing many failures of communications and the power grid in various parts of the world. Historically, earth's magnetic north pole has wandered at a rate of about 0–15 km/year, but beginning in 1990, it accelerated to its current velocity of about 60 km/year[64][65][66], which affects compasses, GPS, & other navigation. Moreover, the last time earth's protective magnetic field dropped by 30%, it needed fully 3,000 years[56], but, at the rapid rate it's decreasing now, it's projected to need only about 338.5 or 363.2 years (or 364.3 years or 333.9583 years), to drop by another 30%, depending of which set of data is used. While the data aren't in complete agreement, they're all very close, and suggest that a "geomagnetic flip," with concurrent field collapse to almost zero strength, is imminent. This is relevant because the weaker earth's protective magnetic field gets, the less it protects earth from severe geomagnetic storms. We review solar/geomagnetic data of all storms from the Carrington Event until present and estimate the probability of another similar catastrophic solar storm **in the next decade:** Prior prominent research of another Carrington Event are, at one extreme, Riley's estimates of about **12%** probability[50], and Moriña's estimates[40] about **1.17%** (taking the average of "0.46% and 1.88%," from his research paper). We find an **8.57%** chance of another Carrington−class solar storm **in the next decade.** While we may overestimate the probabilities of another similar storm, the dangers posed to modern−day technology (much more vulnerable to geomagnetic solar storms or EMP detonations) suggest that it's better to use cautious & conservative estimates—especially given new unknowns and variables, such as the impending geomagnetic flip and concomitant collapse of earth's protective magnetic field—which, of course, make us even more vulnerable to a "direct hit." I stand by my estimate as it's methods are sound, with results between both extremes in the reported literature—and put forth proposed solutions for lawmakers and citizens.

Plain Language Summary [Written for 'broad' audience: Lawmakers, press, scientists, citizens]

There have been several recent severe geomagnetic storms which caused severe disruption to telecommunications and electrical grids, HF (high−frequency) radio communications, and Global Positioning System (GPS) navigation: The infamous solar storm of **March 1989** inflicted major damage to Quebec, Canada's power grid, causing a 9−hour blackout when transformers were overloaded and failed, leaving more than 6 million Canadians without power, and crashing computer hard−drives later that year **(August 1989),** resulting in halted trading in the Toronto stock market. In fact, astronauts aboard the space shuttle Atlantis, during this solar storm, in **October 1989,** "reported burning in their eyes, a reaction of their retinas to the solar particles," according to the book "Storms From The Sun."[7][23]

Another solar storm hit Canada, as well as the northeast United States, in **August 2003,** causing wide−spread blackouts, this time jamming the short−wave radio frequencies used by commercial pilots, prompting contemporary observers to speculate that the Kremlin was jamming radio signals. "In space, some satellites actually tumbled out of control for several hours," NASA said. Malmö also suffered wide−spread failure of their power grids later that year **(October and November 2003)** in what was dubbed the **"Halloween solar storm" of 2003:** The SOHO (Solar and Heliospheric Observatory) satellite even failed temporarily, and the Advanced Composition Explorer (ACE) was also damaged by this solar storm.[20][27][28][51]

More recently, the **"Solar Storm of 2012,"** a Carrington−class solar storm, widely−believed to be even larger than the largest recorded solar storm in recorded history, almost made a "direct hit" on earth, narrowly missing only because earth had moved about nine (9) days in solar orbit from its trajectory.[70] As a result, researchers across the globe began calculating statistical probabilities of a "direct hit" of another catastrophic Carrington−class solar storm. Prior published research came up with widely varying estimates, prompting this researcher to revisit the subject anew.

I will address three (3) aspects of the dangers of solar storms: **<u>(1)</u>** I will present the dangers and threats of catastrophic damage to electrical and communications systems**;** **<u>(2)</u>** I will attempt to assess the probabilities of estimation of a catastrophic event; and, lastly**,** **<u>(3)</u>** I will offer proposed solutions for both citizens and lawmakers. My findings suggest that prior research **<u>over−estimated</u>** the probabilities of another catastrophic storm, but that subsequent research **<u>under−estimated</u>,** and suggest that the actual probabilities of a possible "**global blackout"** to be in−between both extremes. As a result, citizens are advised to "prepare," and lawmakers must "harden the grid." Furthermore, prior research did not take into account (or discuss) the fact that even "lesser" storms have been documented to have produced widespread damage to the communications and electrical grid, as documented above, which is misleading, because even "lesser" events have had inflicted very great damage, with heavy repair costs impacting the economy, including one instance when the Canadian stock market was shutdown. Lastly, prior research did not account for the upcoming Maunder Minimum and recent decreases in earth's protective geomagnetic field, both of which have an effect on any solar geomagnetic events—not to mention the increased acceleration of the movement of the geomagnetic poles, which affect compasses, GPS, and other navigation. Even if this researcher over-estimates the probability of another catastrophic event, given the dire consequences of documented damage that would be done, it's best to have a cautious and conservative estimate—especially given new unknowns and variables, such as the impending geomagnetic flip & concomitant collapse of earth's protective magnetic field—which, of course, make us even more vulnerable to a "direct hit."

1. Introduction [PART I. Threats / dangers posed by Solar Events]

The well−known "Carrington Event" (also known as "The Solar Storm of 1859"), occurring on September 1–2, 1859, was a very powerful geomagnetic storm during solar cycle 10 (1855–1867), and one of the largest recorded geomagnetic storms (as recorded by ground−based magnetometers). The storm produced some of the brightest and most amazing displays of The Northern Lights (*Aurora Borealis*) and The Southern Lights (*Aurora Australis*) around the world, so bright, in fact, that many people reported being able to read a newspaper, at night, by the brilliant "Polar Lights," even as far south as the northeastern United States.[1][2]

More−importantly, however, this "Carrington−class" solar storm, widely−believed to be the most powerful solar storm of modern times, only had a "Dst" (disturbance–storm time) measurement of about −850 to −900 nT (nanoTelsas), and even the very powerful "Quebec Storm of 1989" (which knocked about 6 million people into a blackout) registered only about −589 nT. (The Dst measurement is an index calculated from magnetometer readings around the equator, and, basically, it measures how hard Earth's magnetic field shakes when a solar storm hits: The more negative Dst, the more powerful the solar storm. Scientists were able to get accurate measurements on July 2012 super−storm because, although it angled away from Earth, nonetheless, it made a "direct hit" on the solar observation satellite, STEREO−A, which is especially "hardened" to withstand extreme magnetic disturbances.[31])

However, what frightens this researcher is the fact that "Solar Storm of 2012," had it actually hit earth (it missed us, very narrowly), would have had a Dst−reading of up to **−1,200 nT,** making it much worse than even the infamous Carrington Event.[71] (It had a peak Dst value of −**1,182 nT,** as reported by ***Space Weather***[31]) Historians recall that the Carrington Event, which produced brilliant auroral displays, and also wrought havoc with telegraph systems, induced such fierce magnetic flux into telegraph pylons that they sparked violently, even giving some telegraph operators electric shocks.

The only thing that saved the planet from wide−spread economic catastrophe was the fact that most of the electrical equipment in 1859 was very basic. (Telephones were not even invented until 1876.) Thus, the geomagnetic storm did not have any sensitive "targets" to damage. In modern times, however, with all of the sensitive electronics, GPS, telecommunications, power grids, cellular phone towers, and communications & military satellites, even something as "small" as the −589 nT "Quebec Storm of 1989" was able to do wide−spread damage. In fact, a declassified report shows that a strong solar storm in 1972 may have led to the detonation of mines[18] during the Vietnam War: Many of the "destructor mines" were designed to explode if they sensed changes in magnetic fields associated with moving ships—due to the large metallic content in the target ships, and the solar storms were apparently strong enough to disturb the earth's magnetic field, sufficient to trigger the more−than 4,000 sea mines which mysteriously went off with no other obvious cause. Besides random Solar Storms (which I've shown to be very capable of sudden damage to "The Grid"– critically important for providing power to Police, Fire, Ambulance, Hospitals, gas stations, supermarkets— even 911 & GPS), rogue nations with nuclear capabilities are also able to detonate an EMP (Electromagnetic Pulse), a burst of electromagnetic radiation created by a nuclear explosion, which would have basically the same effect in the local area where it's detonated—potentially knocking out all electrical equipment.[68]

In part I, here, I have (hopefully) shown the grave dangers and threats of catastrophic damage to electrical and communications systems posed by solar storms and EMP's. **In part II,** below, I will address the key part of my new findings**:** a new (and, hopefully, more accurate) assessment the statistical probabilities of estimation of a catastrophic event, **and, then, in part III,** below, I will offer proposed solutions for both citizens and lawmakers. While the 11−year solar cycle is well−known, I do not see any scientific research of probability estimates that take into account the upcoming Maunder Minimum, or the recent (and accelerating) decreases in the strength of earth's **geomagnetic field** or the "rapidly moving" geomagnetic poles**:** Scientists have long known that **earth's magnetosphere** protects against lethal cosmic radiation.

<u>2.</u> Materials & Methods [<u>PART I.</u> Threats/dangers posed...(continued)]

For part <u>I</u>, here (1. Introduction, 2. Materials & Methods, 3. Results listed in Table 1, and 4. References cited throughout this paper, along with Table 2., a copy/paste of selected data from other peer−reviewed research along these lines), I merely gleaned the published peer−reviewed scientific research papers and credible news reports of solar storms and the dangers they pose**. For part <u>III</u>,** below, I propose practical solutions for both citizens and lawmakers: What can citizens do to protect themselves in the event of a "Failure of the Grid?" What can lawmakers (City, County, State, Federal, & International lawmakers—but particularly Federal lawmakers in America & other countries) do to prepare for such an inevitable event, and protect key critical infrastructure? **However, for Part <u>II</u>,** my key findings on the estimations of probability of another catastrophic solar storm, I will do something "different" than my esteemed colleagues (who published widely−varying estimates of whether we would face another Carrington−class event in the upcoming decade or so): I "cheated" by going directly to the published reports of such events, beginning with the Carrington Event (when our recording methods were sufficient to get accurate measurements on the geomagnetic strength of the storms—a key requirement for classifying "how strong" a storm must be to do catastrophic damage), and itemising them individually. Then, by doing a direct division of quantity of catastrophic storms, divided by elapsed time, I directly derive the average number of storms in a given time−period. While this does not take into account the fact that solar flares, CME's (Coronal Mass Ejections), and catastrophic solar storms are greater during the peak of each 11−year "Solar Cycle," it will, nonetheless, give readers a rough estimate of long−term probabilities. Then, once this "baseline" is established, we can hope to make a more precise and accurate estimation of the probabilities, when considering additional factors, particularly <u>the 11−year solar cycle</u>, and the new, and frankly frightening, trend of the <u>rapidly−decreasing geomagnetic field</u>, which is associated with (happening at the same time as) <u>the accelerating velocity of the movement of the geomagnetic poles</u>: Many GPS navigational and satellite systems depend on the geomagnetic north and south poles, and these become increasingly inaccurate when the poles move, another threat to "The Grid." Also, as previously mentioned, the earth's magnetosphere protects against cosmic radiation from <u>all</u> sources—including CME's and solar flares from earth's sun—which pose an ever−increasing threat as earth's magnetosphere starts to collapse, as we head towards another "geomagnetic reversal"—that is, when Earth's magnetic poles start to flip again, as they have done many times in the history of our planet. **<u>EDITOR'S NOTE:</u> When quoting papers, my use of double brackets [] indicates a line−break, omitted for the sake of space.**

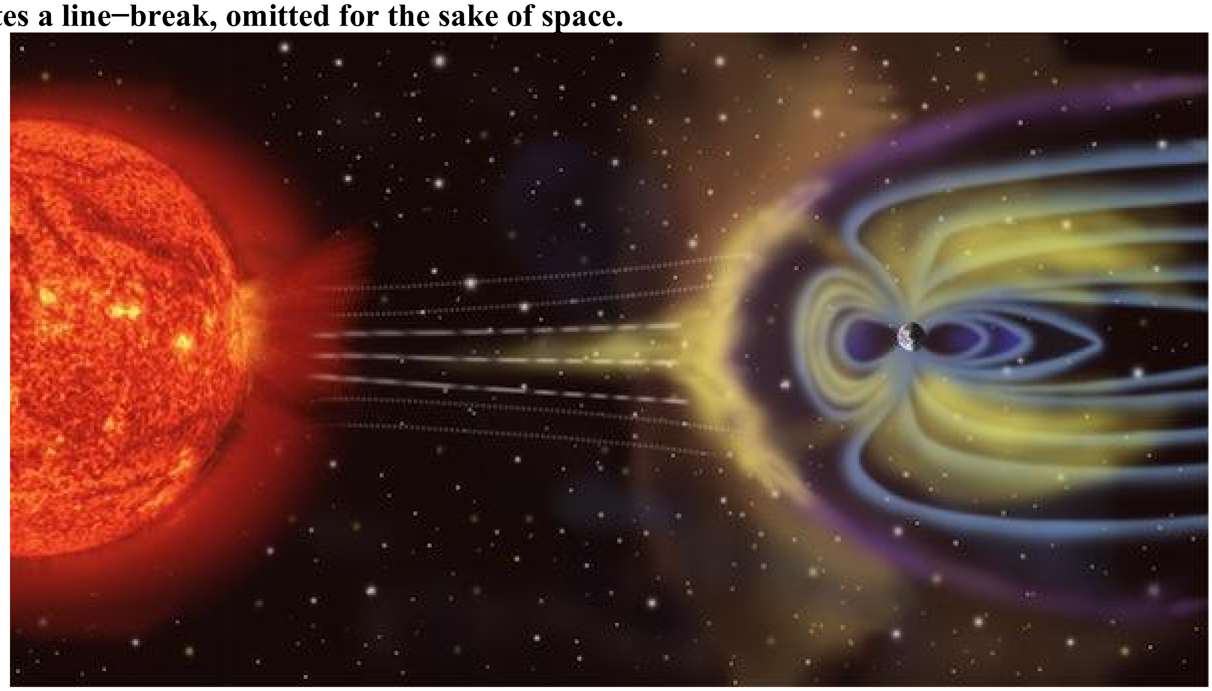

Image 2. The sun hits earth's protective magnetic field with a CME (coronal mass ejection), and/or a solar flare; artist's rendition[76]

TABLE 1.

List of solar storms and related events, starting with the infamous "Carrington Event"

Date(s)	**Number (on this list) – and Name (if any) – and Dst value**	*(Numbered citations to references appear below the table)* **Description, with citations to verify**
Early September 1859	**1.** Solar storm of 1859, aka: "The Carrington Event"; had an estimated peak Dst value of **−850 nT,** as reported by Moriña[39][40]; had an estimated peak Dst value of **−900 (+50, −150) nT,** as reported by Cliver[37]	Overall most extreme storm ever documented; telegraph machines reportedly shocked operators and caused small fires; aurora visible in tropical areas; first solidly established connection of flares to geomagnetic disturbances. Extreme storming directly preceded this event in late August.[1][2][3][4][5][6][7] Please note that this storm (which is often used as the "baseline" or "standard" for comparing new solar events) was the absolute most powerful solar storm to hit planet earth (by several measures, most particularly the Dst readings and the damage done to electrical equipment—not to mention the brilliant, **very bright,** and very beautiful nighttime auroral displays). However, The Carrington Event only registered between **−850 nT and −1,050 nT,** as reported in the scientific literature. The "Near miss of 2012," by contrast, had a peak Dst value of **−1,182 nT,** as reported by ***Space Weather***[31], or even a peak Dst value of **−1,200 nT,** as reported by ***REUTERS***[71], and, had it hit earth (we were about 9 days in orbit past where it hit)[70], we would have probably experienced a much stronger electromagnetic flux. Worse yet, much of the modern−day electronics & communication, on which we depend, is much more sensitive to such flux than the "primitive" telegraph equipment that took a brutal bearing in late 1859 when the Carrington Solar Storm hit earth.
17−20 November 1882	**2.** Geomagnetic Storm of 17−20 November 1882; had an estimated peak Dst value of **−386 nT,** as reported by ***Space Weather***[8]	"In November 1882, an intense magnetic storm related to a large sunspot group caused widespread interference to telegraph and telephone systems and provided spectacular and unusual auroral displays. The (ring current) storm time disturbance index for this storm reached maximum −Dst ≈ 386 nT, comparable to Halloween storm of 29−31 October 2003..."[8]
25−26 September 1909	**3.** Geomagnetic storm of September 1909; had an estimated peak Dst value of **−595 nT,** as reported by ***Space Weather***[9]	"For this storm, Dst attained a minimum of −595 nT, comparable to that of the great magnetic storm of March 1989 (−589 nT; the most intense storm in terms of Dst of the space age)...The 1909 storm was one of the most intense of the twentieth century. It exhibited violent levels of geomagnetic disturbance (with a minimum Dst value of −595 nT), caused widespread interference to telegraph systems, and brought spectacular

		aurorae to the nighttime sky."[9]
13–15 May 1921	**<u>4.</u>** May 1921 geomagnetic storm; had an estimated peak Dst value of −**825 to −900 nT,** as reported by Cliver[37]	Among most extreme known geomagnetic storms; farthest equatorward (lowest latitude) aurora ever documented; burned out fuses, electrical apparatus, and telephone station; caused fires at signal tower and telegraph station; total communications blackouts lasting several hours "We review solar//geophysical data relating to the great magnetic storm of 14−15 May 1921, with emphasis on observations of the low−latitude visual aurora...for the 1921 event, there is a report of aurora from Apia, Samoa, in the southern hemisphere, within /13° of the geomagnetic equator." Such low latitude observations support the claims above that this is among the most extreme ever recorded.[10]
22 January 1938	**<u>5.</u>** Unnamed storm; had a peak Dst value of −**344 nT,** as reported by Cliver[36]	Odd that this storm is unnamed, as its **−344 nT** reading[36] is quite strong. Probably, it was 'conflated' with the "Fátima storm," which occurred a few days later, and was only slightly more powerful (clocking in at −**352 nT**): See below for the "Fátima storm."
25−26 January 1938	**<u>6.</u>** 25−26 January 1938 geomagnetic storm aka the "Fátima storm"; had a peak Dst value of −**352 nT,** as reported by Cliver[36]	"The most brilliant display of an aurora borealis in fifty years held Britons spellbound over a wide area of this country tonight...During this period all transatlantic communication was interrupted, and it was not until 11:30 A.M. That normal service was resumed." [11] "A magnetic storm was recorded at Abinger [Surrey, England] commencing on January 16 at 22·6h."[12]
24 March 1940	**<u>7.</u>** Unnamed storm; had a peak Dst value of −**366 nT,** as reported by Cliver[36]	Odd that this storm is unnamed, as its **−366 nT** reading is even stronger than the massive and severe September 1941 storm, the following year, which only dipped to a −359 nT reading −yet still managed to create havoc with power grids, radio communications, and brilliant nighttime auroral displays.
01 March 1941	**<u>8.</u>** Unnamed storm; had a peak Dst value of −**382 nT,** as reported by Cliver[36]	Odd that this storm is unnamed, as its **−382 nT** reading is even stronger than the massive and severe September 1941 storm, just months later, which only dipped to a −359 nT reading −yet still managed to create havoc with power grids, radio communications, and brilliant nighttime auroral displays.

05 July 1941	**9.** Unnamed storm; had a peak Dst value of **−453 nT,** as reported by Cliver[36]	Odd that this storm is unnamed, as its **−453 nT** reading is even stronger than the massive and severe September 1941 storm, just months later, which only dipped to a −359 nT reading −yet still managed to create havoc with power grids, radio communications, and brilliant nighttime auroral displays.
17–19 September 1941	**10.** "The Geomagnetic Blitz of September 1941"; had a peak Dst value of **−359 nT,** as reported by Cliver[36]	"Seventy−five years ago next week, a massive geomagnetic storm disrupted electrical power, interrupted radio broadcasts, and illuminated the night sky in a World War II battle theater."[13] This was strong, but not as strong as the unnamed storms in March and July of that year, as shown above.
28 March 1946	**11.** Unnamed storm; had a peak Dst value of **−440 nT,** as reported by Cliver[36]	Odd that this storm is unnamed, as its **−440 nT** reading is even stronger than the September 1941 storm, just a few years earlier, which only dipped to a −359 nT reading −yet still managed to create havoc with power grids, radio communications, and brilliant nighttime auroral displays.
26 January 1949	**12.** Unnamed storm; had a peak Dst value of **−350 nT,** as reported by Cliver[36]	Odd that this storm is unnamed, as its **−350 nT** reading is almost as strong as the September 1941 storm, just a few years earlier, which only dipped to a −359 nT reading −yet still managed to create havoc with power grids, radio communications, and brilliant nighttime auroral displays.
23 February 1956	**13.** "Solar Cosmic Rays of February, 1956"; No data available for the Dst values of this event, but it was probably pretty strong, as it fell close to the 05 September 1957 event, which had a Dst value of **−324 nT,** as reported by Cliver[36]	"The solar flare event was superposed by chance upon a large but typical intensity decrease of nonsolar cosmic rays which began several days prior to February 23."[14] "The 23 February 1956 ground level enhancement of the solar cosmic ray intensity (GLE05) is the most famous among the proton events observed since 1942...It is shown that the most outstanding features of this proton enhancement were a narrow and extremely intense beam of ultra−relativistic particles arriving at Earth just after the onset and the unusually high maximum solar particle energy."[15]
05 September 1957	**14.** Unnamed storm; had a peak Dst value of **−324 nT,** as reported by Cliver[36]	Odd that this storm is unnamed, as its **−324 nT** reading[36] is almost as strong as the solar storm eight days later (13 September 1957), which only dipped to a **−426 nT** reading −yet still managed to be categorised as one of the "most intense superstorms observed."[16] Probably these two solar storms were 'conflated' with one another because they were only about a week apart.
13	**15.** Geomagnetic	"This paper presents results of reconstruction of the ionospheric weather

September 1957	storm of September 1957; had a peak Dst value of −**426 nT,** as reported by Cliver[36]; had a peak Dst value of −**427 nT,** as reported by ***NOAA***[28]	**during five <u>of the most intense superstorms</u> observed** since International Geophysical Year, IGY (**<u>1957</u>**, 1958, 1959, 1989, and 2003) with the instantaneous global maps of the F2 layer critical frequency, GIM−foF2, and the ionospheric weather index maps, GIM−Wf. "(Emphasis added for clarity and to differentiate; not in original)[16]
23 September 1957	**<u>16.</u>** Unnamed storm; had a peak Dst value of −**302 nT,** as reported by Cliver[36]	Odd that this storm is unnamed, as its **−302 nT** reading[36] is almost as strong as the solar storm on 13 September 1957, just 10 days earlier, which only dipped to a **−426 nT** reading −yet still managed to be categorised as one of the "most intense superstorms observed."[16] Perhaps these two solar storms got 'conflated' together since they were only about a week apart.
11 February 1958	**<u>17.</u>** Geomagnetic storm of February 1958; had a peak Dst value of −**428 nT,** as reported by Cliver[36]; had a peak Dst value of −**426 nT,** as reported by ***NOAA***[28]	"This paper presents results of reconstruction of the ionospheric weather **during five <u>of the most intense superstorms</u> observed** since International Geophysical Year, IGY (1957, **<u>1958</u>**, 1959, 1989, and 2003) with the instantaneous global maps of the F2 layer critical frequency, GIM−foF2, and the ionospheric weather index maps, GIM−Wf. "(Emphasis added for clarity and to differentiate; not in original)[16]
08 July 1958	**<u>18.</u>** Unnamed storm; had a peak Dst value of −**334 nT,** as reported by Cliver[36]	Odd that this storm is unnamed, as its **−334 nT** reading[36] is almost as strong as the solar storm on 13 September 1957, which only dipped to a **−426 nT** reading −yet still managed to be categorised as one of the "most intense superstorms observed."[16]
04 September 1958	**<u>19.</u>** Unnamed storm; had a peak Dst value of −**305 nT,** as reported by Cliver[36]	Odd that this storm is unnamed, as its **−305 nT** reading[36] is almost as strong as the solar storm on 13 September 1957, which only dipped to a **−426 nT** reading −yet still managed to be categorised as one of the "most intense superstorms observed."[16]
15 July 1959	**<u>20.</u>** Geomagnetic storm of July 1959; had a peak Dst value of −**434 nT,** as reported by Cliver[36]; had a peak Dst value of −**429 nT,** as reported by ***NOAA***[28]	"This paper presents results of reconstruction of the ionospheric weather **during five <u>of the most intense superstorms</u> observed** since International Geophysical Year, IGY (1957, 1958, **<u>1959</u>**, 1989, and 2003) with the instantaneous global maps of the F2 layer critical frequency, GIM−foF2, and the ionospheric weather index maps, GIM−Wf."(Emphasis added for clarity and to differentiate; not in original)[16]
01 April	**<u>21.</u>** Unnamed storm;	Odd that this storm is unnamed, as its **−325 nT** reading[36] is almost as

1960	had a peak Dst value of −**325 nT,** as reported by Cliver[36]	strong as the solar storm on 13 September 1957, which only dipped to a **−426 nT** reading −yet still managed to be categorised as one of the "most intense superstorms observed."[16]
30 April 1960	**22.** Unnamed storm; had a peak Dst value of −**325 nT,** as reported by Cliver[36]	Odd that this storm is unnamed, as its **−325 nT** reading[36] is almost as strong as the solar storm on 13 September 1957, which only dipped to a **−426 nT** reading −yet still managed to be categorised as one of the "most intense superstorms observed."[16]
13 November 1960	**23.** Unnamed storm; had a peak Dst value of −**333 nT,** as reported by Cliver[36]; had a peak Dst value of −**339 nT,** as reported by ***NOAA***[36]	Odd that this storm is unnamed, as its **−333 nT** reading[36] is almost as strong as the solar storm on 13 September 1957, which only dipped to a **−426 nT** reading −yet still managed to be categorised as one of the "most intense superstorms observed."[16]
26 May 1967	**24.** The "Space weather storm of late May 1967"; had a peak Dst value of −**391 nT,** as reported by Cliver[36]; had a peak Dst value of −**387 nT,** as reported by ***NOAA***[28]	Blackout of polar surveillance radars during Cold War led U.S. military to scramble for nuclear war until solar origin confirmed "Although listed as one of the most significant events of the last 80 years, the space weather storm of late May 1967 has been of mostly fading academic interest. The storm made its initial mark with a colossal solar radio burst causing radio interference at frequencies between 0.01 and 9.0 GHz and near−simultaneous disruptions of dayside radio communication by intense fluxes of ionizing solar X−rays. Aspects of military control and communication were immediately challenged."[17]
Early August 1972	**25.** Solar storm of August 1972; had a peak Dst value of −**125 nT,** as reported by ***Space Weather***[18]	Fastest CME transit time recorded; most extreme solar particle event (SPE) by some measures and the most hazardous to human spaceflight during the Space Age; severe technological disruptions, caused accidental detonation of numerous magnetic−influence sea mines. "Although the magnetic storm index, Dst, dipped to only −125 nT, the magnetopause was observed within 5.2 RE and the plasmapause within 2 RE. Widespread electric− and communication−grid disturbances plagued North America late on 4 August. There was an additional effect, long buried in the Vietnam War archives that add credence to the severity of the storm impact: a nearly instantaneous, unintended detonation of dozens of sea mines south of Hai Phong, North Vietnam on 4 August 1972. The U.S. Navy attributed the dramatic event to *magnetic perturbations of solar storms*."[18]
14 July 1982	**26.** Unnamed storm; had a peak Dst value of −**322 nT,** as	Odd that this storm is unnamed, as its **−322 nT** reading[36] is almost as strong as the solar storm on 13 September 1957, which only dipped to a **−426 nT** reading −yet still managed to be categorised as one of the "most

	reported by Cliver[36]	intense superstorms observed."[16]
8−9 February 1986	**<u>27.</u>** The Geomagnetic Storm of 8−9 February 1986; had a peak Dst value of **−301 nT,** as reported by the ***Royal Academy of Engineering***[41]; had a peak Dst value of **−307 nT,** as reported by the ***Research in Astronomy and Astrophysics***[42]	Even during a "solar minimum," you can experience very powerful solar flares, such as this example: "Another significant event was the geomagnetic storm of 8−9 February 1986, which saw Dst drop to −301 nT. This event is significant because of its timing very close to sunspot minimum, which nominally occurred in September 1986, but which would have been in March 1986 if the February storm had not occurred. This storm shows that extreme events can occur at any phase of the solar cycle and it is unwise to focus mitigation efforts only around solar maximum." (pp.17—18){small quote used under Fair Use}[41] "We have plotted all seven storm events together in Figure 1. The first case of super storm was recorded on February 09, 1986 and was associated with a number of solar flares of low intensities occurred. The peak of the storm was observed at 01:00 UT on February 09. By chance this storm was the largest recorded storm, since 1960 and the eighth largest since 1932 (Allen 1986). Two other factors made this storm particularly unusual (i) it occurred near the minimum of the Sun's activity cycle; and (ii) it was apparently caused by flares that could be described as moderate to large. The initial phase of this storm was started on 06 Feb at 21:00 UT and continued till Feb 07 till 07:00 UT and the main phase occurred with its minimum value (Dst index −307 nT) on Feb 09 at 01:00 UT, then it reached to its recovery phase and this phase continued till Feb 13 at 23:00 UT."[42]
13−14 March 1989	**<u>28.</u>** March 1989 geomagnetic storm; aka the "Quebec Storm of 1989"; had a peak Dst value of **−589 nT,** as reported by ***NOAA***[28] and by Cliver[37] and by Kane[43]; had a peak Dst value of **−595 nT,** as reported by ***Space Weather***[9]; had a peak Dst value of **−548 nT,** as previously reported by Cliver[36]	The infamous solar storm of March 1989 was the most extreme storm of the Space Age by several measures: It outed power grid of Canadian province of Quebec, causing a 9−hour blackout when transformers were overloaded and failed, leaving more than 6 million Canadians without power. "The CME associated with the X15 flare in March 1989 caused major power failures in Canada, and subsequent smaller events have disrupted communication and navigation satellites. Also, had the flare occured [sic] over the weekend we could have seen a major proton storm such as the one observed last July, when a number of SOHO's imaging instruments were temporarily blinded."(Misspelling in original, denoted by 'sic' in brackets.)[19]
August 1989	**<u>29.</u>** August 1989 geomagnetic storm; No data available for	"The Toronto stock market in Canada halted trading after solar activity crashed a series of computer hard drives in August 1989. [] Trading was stopped for three hours. [] "I don't know what the gods were doing to us,"

	the Dst values of this event. (Probably around the −**589 nT,** value for the "Quebec Storm of 1989," above, as reported by ***NOAA***[28], as it was pretty strong: It crashed the Canadian stock market—quite literally.)	said exchange vice−president John Kane."[20] "SCIENTISTS blame an intense burst of solar activity for events which halted all trading on Toronto's stock market last month. Officials watched in disbelief as three disc drives failed in succession on what is supposed to be a 'fault−tolerant' computer system. The crash stopped trading for three hours."[21] "A significant geomagnetic storm caused by a very large X20 solar flare affected microchips and lead to the halt of Toronto's stock market trading on August 16, 1989. [] The solar flare was stronger than the X15 flare recorded in March of the same year. That flare caused extremely intense auroras and a geomagnetic storm that lead to the collapse of Hydro−Québec's electricity transmission system."[22]
10 October 1989	<u>**30.**</u> The solar storm of October 1989; had a peak Dst value of −**268 nT,** as reported by Kane[36]	Even a so−called "mild" storm of Dst level −**268 nT** was able to inflict serious threat upon our astronauts: "Astronauts aboard the space shuttle Atlantis, during this solar storm, in October 1989, "reported burning in their eyes, a reaction of their retinas to the solar particles", according to the book Storms From The Sun. [] "The crew was ordered to go to the 'storm shelter' in the farthest interior of the shuttle, the most shielded position. But even when hunkered down inside the spacecraft, some astronauts reported seeing flashes of light even with their eyes closed," **the book notes, adding that if the astronauts had been on a deep−space mission or working on the Moon, <u>there was a 10 per cent chance they would have died</u>."**(Emphasis added, in bold−face & underline, for clarity; not in original)[20][23]
17 November 1989	<u>**31.**</u> The solar storm of November 1989; had a peak Dst value of −**266 nT,** as reported by Kane[36]	Odd that this storm is unnamed: While Kane does not discuss this solar storm in his paper, it's almost the same intensity as the one the month before that caused major discomfort for our astronauts, and almost placed their lived in danger. See "Table 1" of this citation for data.[36]
25 March 1991	<u>**32.**</u> Unnamed storm; had a peak Dst value of −**297 nT,** as reported by Cliver[36]	Odd that this storm is unnamed, as its **−297 nT** reading[36] is almost as strong as the solar storm on 13 September 1957, which only dipped to a **−426 nT** reading −yet still managed to be categorised as one of the "most intense superstorms observed."[16]
09 November 1991	<u>**33.**</u> Unnamed storm; had a peak Dst value of −**375 nT,** as reported by Cliver[36]; had a peak Dst value of −**354 nT,**	Odd that this storm is unnamed, as its **−375 nT** reading is even stronger than the massive and severe September 1941 storm, just decades earlier, which only dipped to a −359 nT reading −yet still managed to create havoc with power grids, radio communications, and brilliant nighttime auroral displays.

	as reported by ***NOAA***[28]	
06 April 2000	**34.** April geomagnetic storm of 2000; had a peak Dst value [at 01:00 UT, on 04/07/2000, which was really the same storm, as it was within a 24−hour period of 06 April 2000] of **−287 nT,** as reported by ***Geophysical Research Letters***[38]	Geomagnetic storm was so strong that it was felt even down to about 42° in geographic latitude: “This paper reports on the first observations of postsunset/evening midlatitude plasma bubbles in the European sector during the main phase of severe storms (Dst≤−200 nT) on **6 April 2000** and 11 April 2001. Plasma depletions observed in Global Navigation Satellite System total electron content measurements are confirmed with those observed from in situ Defense Meteorological Satellite Program ion density measurements. The results show that the plasma bubbles were migrating north at virtual speeds of 400 m/s and on each of the storm days they extended as far north as ˜42° (geographic latitude).”(Emphasis added, in bold−face & underline, for clarity; not in original)[24]
14 July 2000	**35.** The “Bastille Day Flare” aka the “Bastille Day Event”; No data available for the Dst values of this event, but it was probably pretty strong, as interfered with radio communications, could be seen even by the distant Voyager 1 and 2 space probes, and put on impressive auroral displays, and was the largest solar radiation event since 1989; UPDATE: had a peak Dst value of **−69 nT,** as reported by Halo CME[36]	A powerful solar flare on Bastille Day (July 14, 2000), the national day of France and was the biggest solar radiation event since 1989, which scientists were describing as the space equivalent of a Category 4 hurricane on the 5−point Saffir−Simpson scale, and even, despite their great distance from the Sun, observed by the Voyager 1 & Voyager 2 deep−space probes: “The eruption of a powerful flare on the surface of the sun Friday has triggered what scientists are calling the biggest solar radiation event since the fall of 1989. [] The flare was followed by a coronal mass ejection a blast of billions of tons of electrically charged atomic particles and magnetic energy hurled in the Earth's direction at 3 million mph. [] The blast was expected to trigger "strong" to "severe" geomagnetic disturbances this weekend affecting power grids, pipelines, navigation systems, shortwave radio communications and satellite operations. [] And skywatchers were advised to look for displays of the Northern Lights about midnight tonight at latitudes spanning much of the United States. [] Space weather forecasters were describing the solar storm as the space equivalent of a Category 4 hurricane on the 5−point Saffir−Simpson scale. [] "I think it's probably the second−largest (storm) in the last 20 years," said Bill Murtaugh, a space weather forecaster at the federal Space Environment Center in Boulder, Colo.”[25] “This energetic particle decrease is thus slightly smaller in magnitude at the Earth than the two earlier transient events occurring in July 1982 and June 1991 that later produced large increases of very low frequency radio emission seen by instruments on Voyager 1 and Voyager 2 when the interaction regions from these events eventually encountered the heliopause some 410 days later [Gurnett et al., 1993].”[26]
16 July	**36.** Unnamed storm;	Odd that this storm is unnamed, as its −301 nT reading[36] is quite

2000	had a peak Dst value of −**301 nT,** as reported by Cliver[36]; had a peak Dst value of −**301 nT,** as reported by ***Geophysical Research Letters***[38]; had a peak Dst value of −**301 nT,** as reported by ***Earth, Planets and Space***[46]	strong. Probably, it was 'conflated' with the "Bastille Day Event," which was only two days earlier. (See immediately above in this table.) Moreover, it is also odd that Cliver[36] does not give a Dst reading for the "Bastille Day Flare," which was two days earlier, on 14 July 2000. But it is assumed that these are two different solar flares, because the dates are different, and moreover, the solar flare and CME's a few days earlier would probably have had a stronger value. [Note to self: Look up a Dst reading for the "Bastille Day Event."] Note: ***Earth, Planets and Space*** reported: " In the case of the solar sources of the Bastille geomagnetic storm that occurred on July 15–17, 2000, with a Dst minimum of −301 nT...,"[46] but we take this to refer to the 16 Jul 2000 entry, taking the average of 15 and 17, so as to differentiate this event from the event 2 days prior. Their readings agree with others, so all is well, here.
31 March 2001	**<u>37.</u>** Unnamed storm; had a peak Dst value of −**383 nT,** as reported by Cliver[36]; had a peak Dst value of −**387 nT,** as reported by ***NOAA***[28]; had a peak Dst value of −**383 nT,** as reported by ***Geophysical Research Letters***[38]	Odd that this storm is unnamed, as its −383 nT reading[36] is quite strong. Probably, it was 'conflated' with the continuing solar flares, CME's, and continuation of the solar storm which went on into the following month, as shown below. Indeed, very odd, since the following readings, while severe, were only reported by ***Space Weather*** to be Dst≤−200 nT, or so, not nearly as severe as the peak −383 nT readings, here.[24]
11 April 2001	**<u>38.</u>** April geomagnetic storm of 2001; had a peak Dst value [at 00:00 UT, on 04/12/2000, which was really the same storm, as it was within a 24−hour period of 11 April 2000] of **−271 nT,** as reported by ***Geophysical Research Letters***[38]	Geomagnetic storm was so strong that it was felt even down to about 42° in geographic latitude: "This paper reports on the first observations of postsunset/evening midlatitude plasma bubbles in the European sector during the main phase of severe storms (Dst≤−200 nT) on 6 April 2000 and **<u>11 April 2001.</u>** Plasma depletions observed in Global Navigation Satellite System total electron content measurements are confirmed with those observed from in situ Defense Meteorological Satellite Program ion density measurements. The results show that the plasma bubbles were migrating north at virtual speeds of 400 m/s and on each of the storm days they extended as far north as ˜42° (geographic latitude)."(Emphasis added, in bold−face & underline, for clarity; not in original)[24]
06 November 2001	**<u>39.</u>** Unnamed storm; had a peak Dst value of −**292 nT,** as reported by ***Geophysical***	Odd that this storm is unnamed, as its **−292 nT** reading[38] is almost as strong as the solar storm on 13 September 1957, which only dipped to a **−426 nT** reading −yet still managed to be categorised as one of the "most intense superstorms observed."[16]

	Research Letters[38]	
29−30 October 2003	**<u>40.</u>** Halloween solar storms, 2003; had a 'provisional' peak Dst value of −**401 nT,** as reported by ***NOAA*** in June 2004[28] and Kane [43]; had a final peak Dst value [at 01:00] of −**353 nT,** as reported by ***Geophysical Research Letters*** in Feb. 2008[38]; had a final peak Dst value [at 23:00] of −**383 nT,** as reported by ***Geophysical Research Letters*** in Feb. 2008[38]	**Among the top few most intense storms of the Space Age:** "In **<u>October</u>** and November of 2003, well into the declining phase of Solar Cycle 23, the Sun produced a significant display of solar activity, including one of the most intense solar flares ever recorded."(Emphasis added in bold−faced underline to differentiate; not in original.)[28] "The **<u>October</u>**−November 2003 solar storms rank as one of the largest outbreaks of solar activity in recent history. The global effects were wide ranging, impacting power grids, airline flights, spacecraft operations, and much more. Media interest and public awareness of this activity was at the highest levels ever...With little warning, large and intense sunspot groups developed on the solar surface, and by the end of October 2003, NOAA Space Weather Forecasters were engaged in the most active and demanding solar activity epoch in years...Seventeen major flares erupted on the sun between **<u>October 19</u>** – November 05, 2003, including perhaps the most intense flare ever seen by a GOES XRS instrument – a huge X28 flare (NOAA scale R5 – see Appendix A and B) on November 04. Many of these flares had associated radiation storms, including an S4 (severe) storm on October 29."(Emphasis added in bold−faced underline to differentiate; not in original.) [27]
20−21 November 2003	**<u>41.</u>** Solar storms of November 2003; had a 'provisional' peak Dst value of −**465 nT,** as reported by ***NOAA*** in June 2004[36]; had a peak Dst value of −**383 nT,** as reported by Cliver in Oct. 2004[36]; had a final peak Dst value of −**472 nT,** as reported by Kane in Feb. 2005[43]; had a final peak Dst value of −**422 nT,** as reported by ***Geophysical Research Letters*** in Feb. 2008[38]; had a final peak Dst value of −**422 nT,** as reported by ***Earth, Planets and Spacs*** in Feb. 2008[46]	**Among the top few most intense storms of the Space Age:** "In October and **<u>November of 2003</u>**, well into the declining phase of Solar Cycle 23, the Sun produced a significant display of solar activity, including one of the most intense solar flares ever recorded."(Emphasis added in bold−faced underline to differentiate; not in original.)[28] "The October−**<u>November 2003</u>** solar storms rank as one of the largest outbreaks of solar activity in recent history. The global effects were wide ranging, impacting power grids, airline flights, spacecraft operations, and much more. Media interest and public awareness of this activity was at the highest levels ever...With little warning, large and intense sunspot groups developed on the solar surface, and by the end of October 2003, NOAA Space Weather Forecasters were engaged in the most active and demanding solar activity epoch in years...Seventeen major flares erupted on the sun between October 19 – **<u>November 05, 2003</u>**, including perhaps the most intense flare ever seen by a GOES XRS instrument – a huge X28 flare (NOAA scale R5 – see Appendix A and B) on November 04. Many of these flares had associated radiation storms, including an S4 (severe) storm on October 29."(Emphasis added in bold−faced underline to differentiate; not in original.)[27] "Previous studies have suggested that solar flares of modest intensity and duration can produce severe geomagnetic storms. In the case of the solar sources of the Bastille geomagnetic storm that occurred on July 15–17,

		2000, with a Dst minimum of −301 nT, the duration of the solar flare was 40 min (Andrews 2001). In case of the solar sources of the Halloween geomagnetic storm that occurred **<u>November 20–21</u>, 2003,** with a Dst minimum of −422 nT, three long−durational event (LDE) flares with intensities less than M5.0 were reported (e.g., Gopalswamy et al. 2005). This demonstrates that a strong geoeffective solar wind driver can be produced from a solar flare modest of intensity and duration."(Emphasis added in bold−faced underline to differentiate; not in original.)[46]
08 November 2004	**<u>42.</u>** Unnamed storm; had a peak Dst value [at 07:00 UT] of **−373 nT,** as reported by ***Geophysical Research Letters***[38]	Odd that this storm is unnamed, as its **−373 nT** reading[38] is almost as strong as the solar storm on 13 September 1957, which only dipped to a **−426 nT** reading −yet still managed to be categorised as one of the "most intense superstorms observed."[16] This is a separate solar storm than the one below, on 11/10/2004: They are more than 48 hours apart.
10 November 2004	**<u>43.</u>** Unnamed storm; had a peak Dst value [at 10:00 UT] of −**289 nT,** as reported by ***Geophysical Research Letters***[38]	Odd that this storm is unnamed, as its **−289 nT** reading[38] is almost as strong as the solar storm on 13 September 1957, which only dipped to a **−426 nT** reading −yet still managed to be categorised as one of the "most intense superstorms observed."[16] This is a separate solar storm than the one above, on 11/08/2005: They are more than 48 hours apart.
20−22 January 2005	**<u>44.</u>** The "Giant Solar Storm of January 2005" aka the "Anomalous geomagnetic storm of January 2005"; had a peak Dst value of **−105 nT,** as reported by ***Journal of Geophysical Research***[44]	Even though this solar storm only clocked in at −105 nT [44], it was able to present a major threat, and the "giant GLE of 2005 January 20 was the second largest on record (and largest since 1956), with up to 4200% count rate enhancement at sea level.,"[30] as documented below: "One of the largest recorded solar radiation storms, on 20 January 2005, resulted in up to 55−fold increases in the count rates of ground−based particle detectors in polar regions."[29] "A ground level enhancement (GLE) is a solar event that accelerates ions (mostly protons) to GeV range energies in such great numbers that ground−based detectors, such as neutron monitors, observe their showers in Earth's atmosphere above the Galactic cosmic ray background. GLEs are of practical interest because an enhanced relativistic ion flux poses a hazard to astronauts, air crews, and aircraft electronics, and provides the earliest direct indication of an impending space radiation storm. The giant GLE of 2005 January 20 was the second largest on record (and largest since 1956), with up to 4200% count rate enhancement at sea level. "[30] "The major (minimum Dst = −105 nT) magnetic storm which occurred on 21–22 January 2005 is highly anomalous because the storm main

		phase (identified by the SYM−H indices) developed during northward interplanetary magnetic fields (IMFs). We believe this to be the first event of its type to be reported in the literature.”[44]
15 May 2005	**<u>45.</u>** Unnamed storm; had a peak Dst value of −**263 nT,** as reported by ***Geophysical Research Letters***[38]	Odd that this storm is unnamed, as its **−263 nT** reading[38] is almost as strong as the solar storm on 13 September 1957, which only dipped to a **−426 nT** reading −yet still managed to be categorised as one of the “most intense superstorms observed.”[16]
23−24 July 2012	**<u>46.</u>** The “Near Miss of 2012” aka the “Solar Superstorm of 2012”[32][33]; had a peak Dst value of **−1,182 nT,** as reported by ***Space Weather***[31]; had a peak Dst value of **−1,200 nT,** as reported by ***REUTERS***[71]	“On 23 July 2012, solar active region 1520 (~141°W heliographic longitude) gave rise to a powerful coronal mass ejection (CME) with an initial speed that was determined to be 2500 ± 500 km/s. The eruption was directed away from Earth toward 125°W longitude. STEREO−A sensors detected the CME arrival only about 19 h later and made in situ measurements of the solar wind and interplanetary magnetic field. In this paper, we address the question of what would have happened if this powerful interplanetary event had been Earthward directed. Using a well−proven geomagnetic storm forecast model, we find that the 23−24 July event would certainly have produced a geomagnetic storm that was comparable to the largest events of the twentieth century (Dst ~ −500 nT). **Using plausible assumptions about seasonal and time−of−day orientation of the Earth's magnetic dipole, the most extreme modeled value of storm−time disturbance would have been Dst = −1182 nT. This is <u>considerably larger than estimates for the famous Carrington storm</u> of 1859.** This finding has far reaching implications because it demonstrates that extreme space weather conditions such as those during March of 1989 or September of 1859 can happen even during a modest solar activity cycle such as the one presently underway. We argue that this extreme event should immediately be employed by the space weather community to model severe space weather effects on technological systems such as the electric power grid.”(Emphasis added in bold−faced underline for clarity; not in original.)[31] “Last month (April 8−11), scientists, government officials, emergency planners and others converged on Boulder, Colorado, for NOAA's Space Weather Workshop—an annual gathering to discuss the perils and probabilities of solar storms. [] The current solar cycle is weaker than usual, so you might expect a correspondingly low−key meeting. On the contrary, the halls and meeting rooms were abuzz with excitement about an intense solar storm that narrowly missed Earth. [] "If it had hit, we would still be picking up the pieces," says Daniel Baker of the University of Colorado, who presented a talk entitled *The Major Solar Eruptive Event in July 2012: Defining Extreme Space Weather Scenarios.*”[34] “If an asteroid big enough to knock modern civilization back to the 18th century appeared out of deep space and buzzed the Earth−Moon system, the near−miss would be instant worldwide headline news. [] Two years

		ago, Earth experienced a close shave just as perilous, but most newspapers didn't mention it. The "impactor" was an extreme solar storm, the most powerful in as much as 150+ years. [] "If it had hit, we would still be picking up the pieces," says Daniel Baker of the University of Colorado. ”[35] Were there any others which aren't listed here? Like the 2012 storm, near miss...Justify paragraph margins.
2012—present	**47.** Miscellaneous	Although we're apparently in a solar minimum at the time of this writing, I have no doubt overlooked many solar geomagnetic events, due to the human limitations of this researcher. As such, I have probably underestimated the probability estimate of another “Carrington−class” geomagnetic event.

Image 6. *Aurora Borealis,* at night: The Northern Lights[80]

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Tel: 301−286−4098, Dr. Joe Gurman, gurman@eitv.nascom.nasa.gov ; Tel : 301−286−4767
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[36] "The 1859 Solar−Terrestrial Disturbance And the Current Limits of Extreme Space Weather Activity," by Cliver, E.W.; Svalgaard, L., ***Solar Physics,*** Volume 224, Issue 1−2, pp. 407−422, 08 October 2004, DOI: 10.1007/s11207−005−4980−z, Bibcode: 2004SoPh..224..407C,
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LINK: https://doi.org/10.1007%2Fs11207−005−4980−z
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EDITOR'S NOTE: "TABLE V" of Cliver's paper, here, e.g., "The 25 largest geomagnetic storms based on the Aa∗m index, 1868–1998.," lists about 25 storms, a few of which may be missing above, so I'm using Cliver's data to supplement my own research.
["Abstract. It is generally appreciated that the September 1859 solar–terrestrial disturbance, the first recognized space weather event, was exceptionally large. How large and how exceptional? To answer these questions, we compiled rank order lists of the various measures of solar−induced disturbance for events from 1859 to the present. The parameters considered included: magnetic crochet amplitude, solar energetic proton fluence (McCracken *et al.,* 2001a), Sun–Earth disturbance transit time, geomagnetic storm intensity, and low−latitude auroral extent. While the 1859 event has close rivals or superiors in each of the above categories of space weather activity, it is the only documented event of the last ~150 years that appears at or near the top of all of the lists. Taken together, the top−ranking events in each of the disturbance categories comprise a set of benchmarks for extreme space weather activity**."]**

[37] "The 1859 space weather event revisited: limits of extreme activity," by Edward W. Cliver and William F. Dietrich, ***Journal of Space Weather and Space Climate,*** Volume 3, Article Number: A31, 21 October 2013, DOI: 10.1051/swsc/2013053, LINK: https://doi.org/10.1051/swsc/2013053
LINK: https://www.swsc−journal.org/articles/swsc/full_html/2013/01/swsc130015/swsc130015.html
Small 'Fair Use' Quote: "The solar flare on 1 September 1859 and its associated geomagnetic storm remain the standard for an extreme solar−terrestrial event. The most recent estimates of the flare soft X−ray (SXR) peak intensity and Dst magnetic storm index for this event are: SXR class = X45 (±5) (vs. X35 (±5) for the 4 November 2003 flare) and minimum Dst = −900 (+50, −150) nT (vs. −825 to −900 nT for the great storm of May 1921)."

[38] "Interplanetary conditions leading to superintense geomagnetic storms (Dst ≤ −250 nT) during solar cycle 23," by E. Echer, W.D. Gonzalez, B.T. Tsurutani, ***Geophysical Research Letters,*** Volume 35, Issue 6,

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[39] "Probability of catastrophic geomagnetic storm lower than estimated," ***ScienceDaily,*** March 12, 2019,
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[40] "Probability estimation of a Carrington−like geomagnetic storm," by David Moriña, Isabel Serra, Pedro Puig & Álvaro Corral, ***Scientific Reports***, volume 9, Article number: 2393, 20 February 2019, DOI: 10.1038/s41598−019−38918−8, LINK: https://doi.org/10.1038/s41598−019−38918−8
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Small 'Fair Use' Quote: "The Carrington event is the largest known example of geomagnetic storm, occurred by the end of August and early September 1859 and is associated to a minimum Dst under −850−nT."

[41] "Extreme space weather: impacts on engineered systems and infrastructure," © ***Royal Academy of Engineering*** [small quote used under Fair Use], ISBN 1−903496−95−0, February 2013, Published by:
Royal Academy of Engineering, Prince Philip House, 3 Carlton House Terrace, London SW1Y 5DG,
LINK: https://www.raeng.org.uk/spaceweather
LINK: https://www.raeng.org.uk/publications/reports/space−weather−full−report
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http://www.ProteccionCivil.org/catalogo/naturales/climaespacial/jt_clima_espacial_2013/presentaciones/p42.pdf
LINK:
https://web.Archive.org/web/20130210183311/http://www.raeng.org.uk/news/publications/list/reports/space_weather_full_report_final.pdf
Small 'Fair Use' Quote: "Another significant event was the geomagnetic storm of 8−9 February 1986, which saw Dst drop to −301 nT. This event is significant because of its timing very close to sunspot minimum, which nominally occurred in September 1986, but which would have been in March 1986 if the February storm had not occurred. This storm shows that extreme events can occur at any phase of the solar cycle and it is unwise to focus mitigation efforts only around solar maximum." (pp.17—18)

[42] "Repercussions of Solar High Energy Protons on Ozone Layer during Super Storms," by Asheesh Bhargawa, M. Yakub, and A. K. Singh, ***Research in Astronomy and Astrophysics,***
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LINK: https://iopscience.iop.org/article/10.1088/1674−4527/19/1/2/pdf
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https://www.ResearchGate.net/publication/326345647_Repercussions_of_Solar_High_Energy_Protons_on_Ozone_Layer_during_Super_Storms
Small 'Fair Use' Quote: "We have plotted all seven storm events together in Figure 1. The first case of super storm was recorded on February 09, 1986 and was associated with a number of solar flares of low intensities occurred. The peak of the storm was observed at 01:00 UT on February 09. By chance this storm was the largest recorded storm, since 1960 and the eighth largest since 1932 (Allen 1986). Two other factors made this storm particularly unusual (i) it occurred near the minimum of the Sun's activity cycle; and (ii) it was apparently caused by flares that could be described as moderate to large. The initial phase of this storm was started on 06 Feb at 21:00 UT and continued till Feb 07 till 07:00 UT and the main phase occurred with its minimum value (Dst index −307 nT) on Feb 09 at 01:00 UT, then it reached to its recovery phase and this phase continued till Feb 13 at 23:00 UT."

[43] “How good is the relationship of solar and interplanetary plasma parameters with geomagnetic storms?,” by R.P. Kane, ***JOURNAL OF GEOPHYSICAL RESEARCH,*** VOL. 110, A02213, 25 February 2005, DOI:10.1029/2004JA010799,
LINK: http://dx.doi.org/10.1029/2004JA010799
LINK: https://agupubs.OnlineLibrary.wiley.com/doi/full/10.1029/2004JA010799
LINK:
https://www.ResearchGate.net/publication/41388470_How_good_is_the_relationship_of_solar_and_interplanetary_plasma_parameters_with_geomagnetic_storms
Selected Data from Table 1:
Date: Dst, −nT:
13.03.1989 589
20.10.1989 268
17.11.1989 266
Small 'Fair Use' Quote: “There were two giant events in recent times (Halloween events A: 29 October 2003, Dst −401 nT, and B: 20 November 2003, Dst −472 nT, marked in Figure 1 as solid big circles) and the earlier largest event of 13 March 1989 (Dst −589 nT).”

[44] “Anomalous geomagnetic storm of 21–22 January 2005: A storm main phase during northward IMFs,” by A.M. Du, B.T. Tsurutani, W. Sun, ***Journal of Geophysical Research: Space Physics,*** 28 October 2008 DOI: 10.1029/2008JA013284, LINK: https://doi.org/10.1029/2008JA013284
LINK: https://agupubs.OnlineLibrary.wiley.com/doi/full/10.1029/2008JA013284
Small 'Fair Use' Quote: “The major (minimum Dst = −105 nT) magnetic storm which occurred on 21–22 January 2005 is highly anomalous because the storm main phase (identified by the SYM−H indices) developed during northward interplanetary magnetic fields (IMFs). We believe this to be the first event of its type to be reported in the literature.”

[45] ***Halo CME [Twitter account: @halocme] “Solar physicist (alum UtkyAst),”*** 19 July 2017
Link: https://pic.twitter.com/cpbmn2ro0q
Link: https://Twitter.com/halocme/status/887825185373421568
Link: https://Twitter.com/halocme/status/887825185373421568/photo/1
Small 'Fair Use' Quote: “Summary of the consequences of the Bastille Day (14 July) eruption, which also produced a M2.4 solar flare. Min Dst −69 nT, Max Kp 6.0 (G2).pic.twitter.com/cpbmn2ro0q”

[46] “Estimating the solar wind conditions during an extreme geomagnetic storm: a case study of the event that occurred on March 13–14, 1989,” by Tsutomu Nagatsuma, Ryuho Kataoka, & Manabu Kunitake, ***Earth, Planets and Space,*** volume 67, Article number: 78, 27 May 2015,
DOI: org/10.1186/s40623−015−0249−4, **LINK:** https://doi.org/10.1186/s40623−015−0249−4
LINK: https://Earth−Planets−Space.SpringerOpen.com/articles/10.1186/s40623−015−0249−4
Small 'Fair Use' Quote: “Previous studies have suggested that solar flares of modest intensity and duration can produce severe geomagnetic storms. In the case of the solar sources of the Bastille geomagnetic storm that occurred on July 15–17, 2000, with a Dst minimum of −301 nT, the duration of the solar flare was 40 min (Andrews 2001). In case of the solar sources of the Halloween geomagnetic storm that occurred November 20–21, 2003, with a Dst minimum of −422 nT, three long−durational event (LDE) flares with intensities less than M5.0 were reported (e.g., Gopalswamy et al. 2005). This demonstrates that a strong geoeffective solar wind driver can be produced from a solar flare modest of intensity and duration.”

[47] “SUN−TO−EARTH MHD SIMULATION OF THE 14 JULY 2000 “BASTILLE DAY” ERUPTION,” by Tibor Török, Cooper Downs, Jon A. Linker, R. Lionello, Viacheslav S. Titov, Zoran Mikić, Pete Riley, Ronald M. Caplan, and Janvier Wijaya, ***The Astrophysical Journal,*** Volume 856, Number 1, 20 March 2019, Published online: 27 March 2018, DOI: 10.3847/1538−4357/aab36d,

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LINK: https://iopscience.iop.org/article/10.3847/1538−4357/aab36d
LINK: https://iopscience.iop.org/article/10.3847/1538−4357/aab36d/pdf
Small 'Fair Use' Quote: "The Bastille Day eruption occurred on 14 July 2000 in active region (AR) NOAA 9077. It was one of the largest events during the solar cycle 23. The eruption has been extensively studied, and many articles have been published, including a special volume of Solar Physics (2001, Vol. 204, Issue 1–2)...The MC [magnetic cloud], carrying a strong southward magnetic field component ("negative Bz"), produced a very strong geomagnetic storm with a minimum geomagnetic storm index, Dst, lower than −300 nT (Lepping et al. 2001)."

[48] "The Bastille day Magnetic Clouds and Upstream Shocks: Near−Earth Interplanetary Observations," by R.P. Lepping, D.B. Berdichevsky, L.F. Burlaga, A.J. Lazarus, J. Kasper, M.D. Desch, C.−C. Wu, D.V. Reames, H.J. Singer, C.W. Smith, K.L. Ackerson, ***Solar Physics,*** December 2001, Volume 204, Issue 1–2, pp 285–303, DOI: org/10.1023/A:1014264327855,
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LINK: https://Link.Springer.com/article/10.1023/A:1014264327855
Small 'Fair Use' Quote: "The energetic charged particle, interplanetary magnetic field, and plasma characteristics of the `Bastille Day' shock and ejecta/magnetic cloud events at 1 AU occurring over the days 14–16 July 2000 are described...Overall this dramatic series of interplanetary events caused a large multi−phase magnetic storm with min Dst lower than −300 nT."

[49] "1 in 8 Chance of Catastrophic Solar Megastorm by 2020," by Adam Mann, ***WIRED,*** 29 February 2012, **LINK:** https://www.Wired.com/2012/02/massive−solar−flare

[50] "On the probability of occurrence of extreme space weather," by Pete Riley, ***Space Weather,*** 10(2):2012, 02 February 2012, DOI: 10.1029/2011SW000734,
LINK: https://doi.org/10.1029/2011SW000734
LINK:
https://www.ResearchGate.net/publication/258723347_On_the_probability_of_occurrence_of_extreme_space_weather
Small 'Fair Use' Quote: "By virtue of their rarity, extreme space weather events, such as the Carrington event of 1859, are difficult to study, their rates of occurrence are difficult to estimate, and prediction of a specific future event is virtually impossible. Additionally, events may be extreme relative to one parameter but normal relative to others. In this study, we analyze several measures of the severity of space weather events (flare intensity, coronal mass ejection speeds, Dst, and >30 MeV proton fluences as inferred from nitrate records) to estimate the probability of occurrence of extreme events. By showing that the frequency of occurrence scales as an inverse power of the severity of the event, and assuming that this relationship holds at higher magnitudes, we are able to estimate the probability that an event larger than some criteria will occur within a certain interval of time in the future. **For example, the probability of another Carrington event (based on Dst < −850 nT) occurring within the next decade is ~12%.** We also identify and address several limitations with this approach. In particular, we assume time stationarity, and thus, the effects of long−term space climate change are not considered. While this technique cannot be used to predict specific events, it may ultimately be useful for probabilistic forecasting."

[51] "The Day the Sun Brought Darkness," by Dr. Sten Odenwald, NASA Astronomer, ***NASA,*** March 13, 2009, Last Updated: Aug. 7, 2017 (Editor: Holly Zell),
LINK: https://www.NASA.gov/topics/earth/features/sun_darkness.html
Small 'Fair Use' Quote: "On March 13, 1989 the entire province of Quebec, Canada suffered an electrical power blackout. Hundreds of blackouts occur in some part of North America every year. The Quebec Blackout was different, because this one was caused by a solar storm! [] On Friday March 10, 1989

astronomers witnessed a powerful explosion on the sun. Within minutes, tangled magnetic forces on the sun had released a billion−ton cloud of gas. It was like the energy of thousands of nuclear bombs exploding at the same time. The storm cloud rushed out from the sun, straight towards Earth, at a million miles an hour. The solar flare that accompanied the outburst immediately caused short−wave radio interference, including the jamming of radio signals from Radio Free Europe into Russia. It was thought that the signals had been jammed by the Kremlin, but it was only the sun acting up!”

[52] “The Maunder Minimum and Climate Change: Have Historical Records Aided Current Research?,” by John E. Beckman, and Terence J. Mahoney, (Instituto de Astrofísica de Canarias, E−38200 La Laguna, Tenerife, Spain) ***Astronomical Society of the Pacific,*** ASP Conference Series, Vol. 153 (Library and Information Services in Astronomy III, Editors: U. Grothkopf, H. Andernach, S. Stevens−Rayburn, and M. Gomez, Electronic Editor: H. E. Payne), Date: 1998,
LINK: http://www.stsci.edu/stsci/meetings/lisa3/beckmanj.html

[53] “Are We Headed Towards Another Deep Solar Minimum?,” by David Dickinson,
UNIVERSE TODAY: Space and astronomy news, 22 May 2018,
LINK: https://www.UniverseToday.com/139189/are−we−headed−towards−another−deep−solar−minimum

[54] “Is the Sun heading for another Maunder Minimum? − Precursors of the grand solar minima,” by Miyahara, H.; Kitazawa, K.; Nagaya, K.; Yokoyama, Y.; Matsuzaki, H.; Masuda, K.; Nakamura, T.; Muraki, Y., ***Journal of Cosmology,*** vol. 8, p. 1970−1982, June 2010, Bibliographic Code: 2010JCos....8.1970M,
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[55] “Is Earth's Magnetic Field Flipping Soon?,” by Elizabeth Howell, ***SPACE.com,*** 30 January 2019,
LINK: https://www.Space.com/43173−earth−magnetic−field−flips−when.html
Small 'Fair Use' Quote: “Earth's north magnetic pole is so out of whack that scientists need to update the global magnetic−field model they released only four years ago. Could that be a sign that the magnetic pole will flip soon? [] The World Magnetic Model (WMM) — the name of the updated representation of the magnetic field of Earth — is expected to be released no earlier than Jan. 30. That's about two weeks later than planned, with the delay due to the government shutdown, according to a report in Nature. [] The magnetic pole is moving erratically out of the Canadian Arctic and toward Siberia so unpredictably that it took scientists by surprise. That 2015 update was supposed to remain valid until 2020, Arnaud Chulliat, a geomagnetist at the University of Colorado Boulder and the National Oceanic and Atmospheric Administration's (NOAA) National Centers for Environmental Information, told Nature.”

[56] “Earth's magnetic poles could start to flip. What happens then?,” by Jonathan O'callaghan,
PHYS.ORG, 07 December 2018, **LINK:** https://Phys.org/news/2018−12−earth−magnetic−poles−flip.html
Small 'Fair Use' Quote: “As Earth's magnetic shield fails, so do its satellites. First, our communications satellites in the highest orbits go down. Next, astronauts in low−Earth orbit can no longer phone home. And finally, cosmic rays start to bombard every human on Earth. [] This is a possibility that we may start to face not in the next million years, not in the next thousand, but in the next hundred. If Earth's magnetic field were to decay significantly, it could collapse altogether and flip polarity – changing magnetic north to south and vice versa. The consequences of this process could be dire for our planet. [] Most worryingly, we may be headed right for this scenario. [] 'The geomagnetic field has been decaying for the last 3,000 years,' said Dr. Nicolas Thouveny from the European Centre for Research and Teaching of Environmental Geosciences (CEREGE) in Aix−en−Provence, France. 'If it continues to fall down at this rate, in less than one millennium we will be in a critical (period).'...'The geomagnetic field has been losing 30 percent of its intensity in the last 3,000 years,' said Dr. Thouveny. 'From this value, we predict it will drop to near zero in a few centuries or a millennia.'...'This is a region where we see that satellites consistently (experience) electronic failures,' said Prof. Finlay. 'And we don't understand where this weak field region is coming from, what's producing it, and

how it might change in the future.' [] Scientists first noticed the SAA [the “South Atlantic Anomaly”] in the 1950s, and since then it has decreased in strength by a further 6%, as well as moving closer to the west.'”(Comments in bracket to define “SAA”; not in original)

[57] “Why Space Radiation Matters,” Page Editor: Kelli Mars, NASA Official: Brian Dunbar,
NASA (National Aeronautics and Space Administration), Page Last Updated: June 11, 2018,
LINK: https://www.NASA.gov/analogs/nsrl/why−space−radiation−matters
Small 'Fair Use' Quote: “Outside the protective cocoon of the Earth’s atmosphere is a universe full of radiation – it is all around us...Space radiation is made up of three kinds of radiation: particles trapped in the Earth’s magnetic field; particles shot into space during solar flares (solar particle events); and galactic cosmic rays, which are high−energy protons and heavy ions from outside our solar system. All of these kinds of space radiation represent ionizing radiation...Beyond Low Earth Orbit, space radiation may place astronauts at significant risk for radiation sickness, and increased lifetime risk for cancer, central nervous system effects, and degenerative diseases. Research studies of exposure in various doses and strengths of radiation provide strong evidence that cancer and degenerative diseases are to be expected from exposures to galactic cosmic rays (GCR) or solar particle events (SPE)...In addition to a protective atmosphere, we are also lucky that Earth has a magnetic field. It shields us from the full effects of the solar wind and GCR. Without this protection, Earth’s biosphere might not exist as it does today, or would at least be limited to the subsurface.”

[58] “Is it true that the strength of the Earth's magnetic field is decreasing? What's the effect?,” ***SCIENTIFIC AMERICAN,*** 05 October 1998,
LINK: https://www.ScientificAmerican.com/article/is−it−true−that−the−stren
Small 'Fair Use' Quote: “The Earth's magnetic field is constantly changing, and the way which it changes also changes. When describing the magnetic field of the Earth we must specify both the direction and the intensity of the field...At most places there has been a general decrease in the strength over the past century, typically ten percent or so.”

[59] “Magnetic north just changed. Here's what that means.,” by Maya Wei−Haas,
NATIONAL GEOGRAPHIC, 04 February 2019,
LINK: https://www.NationalGeographic.com/science/2019/02/magnetic−north−update−navigation−maps
Small 'Fair Use' Quote: “Magnetic north has never sat still. In the last hundred years or so, the direction in which our compasses steadfastly point has lumbered ever northward, driven by Earth's churning liquid outer core some 1,800 miles beneath the surface. Yet in recent years, scientists noticed something unusual: Magnetic north's routine plod has shifted into high gear, sending it galloping across the Northern Hemisphere —and no one can entirely explain why. [] The changes have been so large that scientists began working on an emergency update for the World Magnetic Model, the mathematical system that lays the foundations for navigation, from cell phones and ships to commercial airlines...“We know that the pole now is moving faster than it has for decades, but how often does that happen in the long historical record?” inquires Geoff Reeves, a space scientist at Los Alamos National Lab. [] “We don't have any idea. What we know is what it's doing now is different, and that's always exciting scientifically.””

[60] “Earth’s Magnetic North Pole Moving Towards Siberia,” ***21stCenturyWire.com,*** 11 January 2019,
LINK: https://21stCenturyWire.com/2019/01/11/earths−magnetic−north−pole−moving−towards−siberia
Small 'Fair Use' Quote: “The north magnetic pole sped across the International Date Line last year at a rate of 55 km per year, more than three times as fast as it moved before the mid−1990s. Now located in the Eastern Hemisphere, it’s moving away from Canada and approaching Siberia.”

[61] “Earth's Magnetic Pole Is Wandering, Lurching Toward Siberia,” by Laura Geggel, ***LiveScience,***
14 January 2019, **LINK:** https://www.LiveScience.com/64486−earth−magnetic−pole−moving.html
Small 'Fair Use' Quote: “News of the magnetic north's meanderings isn't exactly new. Researchers figured

out in the 1800s that magnetic north tended to drift. Then, in the mid−1990s, it began moving faster, from just over 9 miles (15 kilometers) a year to about 34 miles (55 km) annually, Nature reported. In 2018, magnetic north skipped over the International Date Line and entered the Eastern Hemisphere."

[62] "What would happen if the magnetic field of the Earth suddenly changed?," ***NASA,***
LINK: https://image.gsfc.NASA.gov/poetry/ask/q279.html
Small 'Fair Use' Quote: "If the magnetic field of the Earth suddenly changed, and this DOES happen naturally every 250,000 years or so, the consequences would be fascinating. For life, we can see from the fossil record that the past field changes had no significant effect on living organisms. This is most curious because the field reversal (North magnetic pole shifting to antarctica and the South magnetic pole shifting to the arctic region in the Northern Hemisphere) **one might expect the field to go to zero strength for a century or so.** This would let cosmic rays freely penetrate to the Earth's surface and cause mutations. This seems not to have had much effect in the past, so we probably don't really know what is going on during these field reversals. There have been a dozen of them over the last few million years, documented in the rock which has emerged and solidified along the mid−Atlantic Ridge where continental plates are slowly separating. These epochs form parallel bands all long the ridge where the rock has stored a fossilized image of the local orientation of the Earth's magnetic field for the last few million years." [Emphasis added in bold for clarity, not in original.]

[63] "Earth's Magnetic Field Could Take Longer to Flip Than Previously Thought: New research suggests a polarity reversal of the planet takes about 22,000 years, significantly longer than former estimates,"
by Emily Toomey, ***SMITHSONIAN.COM aka the Smithsonian Institution,*** 07 August 2019, **LINK:** https://www.SmithsonianMag.com/science−nature/earths−magnetic−field−could−take−longer−flip−previously−thought−180972843
Small 'Fair Use' Quote: ""When the [magnetic] field is weak, which is during reversals, **the main dipole field collapses to something on the order of <u>ten percent of its normal strength</u>,"** Singer says. This collapse could spell trouble for life on Earth, since the magnetic field stabilizes ozone molecules, shielding the planet from ultraviolet radiation."(Emphasis added in bold and underline for clarity, not in original.)

[64] "Tug−of−war drives magnetic north sprint,"***EUROPEAN SPACE AGENCY,*** 15 May 2019, **LINK:** https://www.esa.int/Our_Activities/Observing_the_Earth/Swarm/Tug−of−war_drives_magnetic_north_sprint
Small 'Fair Use' Quote: "Between 1990 and 2005 magnetic north accelerated from its historic speed of 0–15 km a year, to its present speed of 50–**<u>60 km a year.</u>** In late October 2017, it crossed the international date line, passing within 390 km of the geographic pole, and is now heading south." [Emphasis in bold−faced underline for clarity; not in original]

[65] "The whole atmosphere response to changes in the Earth's magnetic field from 1900 to 2000: An example of "top−down" vertical coupling," by Ingrid Cnossen, Hanli Liu, Hua Lu, ***American Geophysical Union,*** 27 June 2016, DOI: 10.1002/2016JD024890, **LINK:** https://doi.org/10.1002/2016JD024890
LINK: https://agupubs.OnlineLibrary.wiley.com/doi/full/10.1002/2016JD024890
Small 'Fair Use' Quote: "The northern magnetic pole motion has even been speeding up since the 1970s to a speed of 40–**<u>60−km/yr</u>** [*Newitt et al.,* 2002; *Olsen and Mandea*, 2007]. At the same time, the magnetic dipole moment has been decreasing by about 5–7% per century since 1840 [*Gubbins et al.,* 2006; *Mandea and Purucker,* 2005]. The strongest changes in the Earth's magnetic field over the past few centuries have taken place over South America and the southern Atlantic Ocean, approximately corresponding to the South Atlantic Anomaly region."[Emphasis in bold−faced underline for clarity; not in original]

[66] "MAGNETIC NORTH POLE IS MOVING AT AN ACCELERATED RATE,"
Magazine of Engineering Dyna, "Official Organ of Science and Technology of the Federation of Spansih [sic] Associations for Industrial Engineers," 01 April 2019, [Editor's Note: "Spansih" in original, misspelled, and probably meant to say: "Spanish."]

LINK: https://www.DynaPubli.com/news−4/the−magnetic−north−pole−is−moving−at−an−accelerated−rate
Small 'Fair Use' Quote: "The movement of the earth's north magnetic pole, the reference to which the compasses point, is well known and controlled, at least since it was fixed by Ross in 1831. Every five years its exact position is determined and the trajectory model is checked, the last time being in 2015. [] The year of its first determination was in the arctic islands off the north coast of Canada and since then it has moved slowly and oscillatingly, but for most of the 20th century, it has followed a path towards the north pole at a speed of around 10 km/year. [] From 1990 onwards things changed significantly, with a determined northern trajectory being detected, which would take it to the coasts of Siberia and a considerable increase in its speed up to 50 or **60 km/year at present.**" [Emphasis in bold−faced underline for clarity; not in original]

[67] "Magnetic north is shifting fast. What'll happen to the northern lights?: As magnetic north shifts increasingly away from the geologic north pole – towards Siberia – studies suggest the northern lights could move with it.," Posted by EarthSky Voices in ***EARTH,*** May 22, 2019,
LINK: https://EarthSky.org/earth/magnetic−north−pole−shift−northern−lights
Small 'Fair Use' Quote: "Our planetary magnetic field has many advantages. For over 2,000 years, travellers have been able to use it to navigate across the globe. Some animals even seem to be able to find their way thanks to the magnetic field. But, more importantly than that, our geomagnetic field helps protect all life on Earth."

[68] "Scientists Are Zapping Fake Electrical Grids to Help Us Survive an EMP Attack," by Jennifer Walter, ***Discover Magazine,*** 08 August 2019,
LINK:
http://blogs.DiscoverMagazine.com/crux/2019/08/08/emp−electromagnetic−pulse−attack−electrical−grid−solar−flare
Small 'Fair Use' Quote: "Surprise! Your Power is Out [] It wasn't a coincidence that 36 strings of streetlights suddenly went dead in Honolulu on July 9, 1962. That same day, the United States tested Starfish Prime, a nuclear bomb detonated above the Pacific Ocean that sent out high−altitude electromagnetic pulses – or HEMPs, as they're known – and accidentally took Honolulu's power out with it. [] The bomb test was part of Operation Fishbowl, the United States' Cold War−era program to develop high−altitude nuclear weapons that could detonate above the atmosphere and emit high radiation to compromise electronics on the ground. And even though the test site was about 900 miles from Honolulu, the blast was strong enough to be seen from the island and take out a transmission station." (Bold face in original; not edited except by use of brackets to indicate paragraph breaks)

[69] "Trump Acts on Critical Infrastructure Resiliency Against EMP Threats,"
by Sonal Patel, ***POWER,*** 26 March 2019,
LINK: https://www.PowerMag.com/trump−acts−on−critical−infrastructure−resiliency−against−emp−threats
Small 'Fair Use' Quote: "President Trump has signed an executive order (EO) to boost coordination for and national resilience against electromagnetic pulse (EMP) threats—both from nuclear warfare and natural events like solar superstorms. The action suggests new federal mandates to protect critical infrastructure against EMP events and attacks may be on the horizon...Industry and academia have warned for years—and the DHS has internally recognized that—EMP events, and especially high−altitude EMP (HEMP) events resulting from detonation of a nuclear device, could severely damage critical electrical infrastructure...If the E3 pulse is high enough and long enough, it can result in grid collapse and potentially damage transformers, experts warn. [] Solar weather events of sufficient intensity can cause E3−type electromagnetic impacts. In 1989, for example, a geomagnetic disturbance (GMD) caused a regional grid collapse within 92 seconds in the Hydro−Quebec power system that left six million customers without power for up to nine hours. The threat of GMDs has been played up with good reason: Space weather researchers currently estimate a 6% to 12% chance that a Carrington−class storm—a solar storm comparable in size to the largest on record—is likely to hit the earth within the next 10 years."
[70] "Powerful solar storm narrowly missed Earth in 2012," by Scott Sutherland, Meteorologist/Science

Writer, ***The Weather Network,*** 02 May 2014, **LINK:** https://www.TheWeatherNetwork.com/news/articles/powerful−solar−storm−narrowly−missed−earth−in−2012/26473

Small "Fair Use" Quote: "The current 'K−index' used to rate solar flares wasn't in use then, but studies have estimated the strength of the Carrington super flare at somewhere around X40 or higher, which is well off the maximum practical end of the scale (which only goes up to X9.9). [] However, as it turns out, it doesn't take one of these scale−shattering solar flares to produce this kind of powerful CME, and this means that we could be at a higher risk from solar flares than we previously thought...Given that this CME missed us by roughly 9 days, the use of the word 'narrowly' when describing how close it came to us may seem a bit excessive. However, when you look at those 9 days compared to the length of our year (the time it takes Earth to travel once around the Sun), the distance between us and the CME was only about 3 per cent of our orbital path. That's a *pretty narrow miss."*

COMMENT: Actually, 9 days divided by 365¼ days is only **2.46%,** rounded to 3 significant figures.

[71] "Time to be afraid − preparing for the next big solar storm: Kemp," by John Kemp, ***REUTERS,*** 25 July 2014, **LINK:** https://www.Reuters.com/article/us−electricity−solarstorms−kemp/time−to−be−afraid−preparing−for−the−next−big−solar−storm−kemp−idUSKBN0FU20Q20140725

Small 'Fair Use' Quote: "What frightened the solar scientists was that the July 2012 storm would have had a Dst index of up to −1,200 nT if it had struck Earth, making it much worse than the Carrington Event."

[72] "Variations in the geomagnetic dipole moment over the last 12 000 years," by S. Yang, H. Odah, J. Shaw, ***Geophysical Journal International,*** Volume 140, Issue 1, January 2000, Pages 158–162,
01 January 2000, DOI: 10.1046/j.1365−246x.2000.00011.x,
LINK: https://doi.org/10.1046/j.1365−246x.2000.00011.x
LINK: https://Academic.oup.com/gji/article/140/1/158/707986

Small 'Fair Use' Quote: "To a first approximation, the magnetic field of the Earth is dipolar. The magnetic moment and orientation of the dipole are known to have changed with time from palaeomagnetic and archaeomagnetic measurements. An analysis of archaeointensity results (McElhinny & Senanayake 1982) has shown that t**he Earth's dipole moment was <u>twice the present−day value 2000 years ago</u>,** whilst between 5000 and 6000 years ago it was much weaker. Over the past 15 years, many new archaeointensity results have been published." [Emphasis added in underline and bold for clarity; not in original]

[73] "The earth's magnetic field: evidence that the earth is young," by Jonathan Sarfati, ***Creation Ministries International,*** March 1998; updated August 2014,
LINK: https://Creation.com/the−earths−magnetic−field−evidence−that−the−earth−is−young

Small 'Fair Use' Quote: "...archaeological measurements show that **<u>the field was 40% stronger in AD 1000 than today</u>**," [Emphasis added in underline bold for clarity; not in original], citing R.T. Merrill and M.W. McElhinney [sic: Misspelled. Is actually spelled: "McElhinny," without the trailing 'e'], The Earth's Magnetic Field, Academic Press, London, pp. 101–106, **<u>1983</u>,** one later edition of this book which is linked at: https://www.Amazon.com/Magnetic−Field−Earth−Paleomagnetism−International/dp/B01F82CVW4
and cited as: "The Magnetic Field of the Earth: Paleomagnetism, the Core, and the Deep Mantle (International Geophysics Series)," by Ronald T. Merrill **(<u>1996</u>−09−03)** Hardcover (ASIN: B01F82CVW4)
by Ronald T. Merrill; Michael W. McElhinny; Phillip L. McFadden (Author),
and another edition [Publisher: Academic Press; 1st edition **(August 14, <u>1998</u>)**] linked here:
LINK: https://www.Amazon.com/Magnetic−Field−Earth−Paleomagnetism−International/dp/012491246X
and cited as: "The Magnetic Field of the Earth, Volume 63: Paleomagnetism, the Core, and the Deep Mantle (International Geophysics)," 1st Edition (ISBN−13: 978−0124912465; ISBN−10: 012491246X),
by Ronald T. Merrill (Author), Michael W. McElhinny (Editor), Phillip L. McFadden (Editor)

[74] "The Erosion of Continents as a Creationist Clock," by Kevin Mellem, ***Department of Earth Sciences,***

University of South Dakota, Honors Seminar (UHON 390), Fall 2005,
LINK: http://apps.usd.edu/esci/creation/age/content/creationist_clocks/magnetic_field.html
Small 'Fair Use' Quote: "[Dr. Thomas] Barnes used the data of McDonald and Gunst to plot an exponential curve and, by extrapolating the observed data backward into time using his exponential decay equation, Barnes claimed that **the magnetic field was approximately 40 percent stronger in 1000 A.D. than it is today** (Sarfati 1998)." [Comments added in basket to clarify Dr. Barnes's first and last name; Emphasis added in underline and bold for clarity; not in original]

[75] Image 1., Photo of Earth's sun, titled: "He II (304 Å)" ; Taken at 19:19 UT, 28 February 2000,as depicted in the ***NSSDCA Photo Gallery*** (the "NASA Space Science Data Coordinated Archive," NASA's archive for space science mission data), and released into the public domain. Original image reduced **to 30% resolution** to squeeze it into this paper—and used for illustration purposes only. Author/curator: Dr. Edwin V. Bell, II ; NSSDCA, Mail Code 690.1, NASA Goddard Space Flight Center, Greenbelt, MD 20771, PHONE: +1−301−286−1187, Email: Ed.Bell@nasa.gov, NASA Official: Dr. David R. Williams , Version 2.5, 10 December 2012, Source URL for image: https://NSSDC.gsfc.nasa.gov/image/solar/eit_sl_304.jpg
Article URL for image: https://nssdc.gsfc.NASA.gov/photo_gallery/photogallery−solar.html
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[76] Image 2., The sun hits earth's protective magnetic field with a CME (coronal mass ejection), and/or a solar flare; artist's rendition, from "The Impact of Flares," ***NASA,*** NASA Official: Gordon Holman; Web Curator: Kim Tolbert; no known copyright, and assumed to be released into the public domain, as shown for other official governmental work, and cited in reference [75], above. If there is a copyright, then this author claims "Fair Use" for academic research, criticism, and commentary of copyrighted works. Image used for illustration purposes only, in this paper. Unaltered original image—and used for illustration purposes only.
Image LINK: https://hesperia.gsfc.NASA.gov/rhessi3/pics/NASAsunEarthConnection.jpg
Article LINK: https://hesperia.gsfc.NASA.gov/rhessi3/mission/science/the−impact−of−flares/index.html

[77] Image 3., GRAPH: The Maunder Minimum, a time in history, from 1645—1715, when sunspots were very rare, and where solar events (CME's, solar flares, solar storms, etc.) were at a low ebb, from "SDO Science," ***NASA,*** NASA Official: Dean Pesnell; Webmaster: Kevin Addison; no known copyright, and assumed to be released into the public domain, as shown for other official governmental work, and cited in reference [75], above. If there is a copyright, then this author claims "Fair Use" for academic research, criticism, and commentary of copyrighted works. Image used for illustration purposes only, in this paper. Original image reduced **to 65% resolution** to squeeze it into this paper—and used for illustration purposes only.
Image LINK: https://sdo.gsfc.NASA.gov/assets/img/site/sunspot_web.png
Article LINK: https://sdo.gsfc.NASA.gov/mission/science.php

[78] Image 4., Earth's protective geomagnetic field during normal activity, between pole flips / reversals (depicted on the left), and during geomagnetic reversals (depicted on the right).from "Reversing the Geomagnetic Field," by Aaron Gronstal (SOURCE: ***International Journal of Astrobiology***), published by ***NASA,*** NASA Official: Mary A. Voytek; Last Updated: September 26, 2019; no known copyright, and assumed to be released into the public domain, as shown for other official governmental work, and cited in reference [75], above. If there is a copyright, then this author claims "Fair Use" for academic research,

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[79] Image 5., from "The Aurora!," ***NASA,*** A NASA/IMAGE Resource in space science education; an image of the *Aurora Borealis,* the Northern Lights, and published by ***NASA,*** at the links below; no known copyright, and assumed to be released into the public domain, as shown for other official governmental work, and cited in reference [75], above. If there is a copyright, then this author claims "Fair Use" for academic research, criticism, and commentary of copyrighted works. Image used for illustration purposes only, in this paper. Unaltered original image—and used for illustration purposes only; IMAGE CREDIT: Jan Curtis, 2571 NW 3rd Terrace, Gresham, OR 97030, Email: JanCurtis.nl@gmail.com
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Article Link: https://image.gsfc.NASA.gov/poetry/educator/Aurora79.html
Author Page LINK: http://climate.gi.Alaska.edu/Curtis/curtis.html

[80] Image 6., from "The Aurora!," ***NASA,*** A NASA/IMAGE Resource in space science education; an image of the *Aurora Borealis,* the Northern Lights, and published by ***NASA,*** at the links below; no known copyright, and assumed to be released into the public domain, as shown for other official governmental work, and cited in reference [75], above. If there is a copyright, then this author claims "Fair Use" for academic research, criticism, and commentary of copyrighted works. Image used for illustration purposes only, in this paper. Unaltered original image—and used for illustration purposes only; IMAGE CREDIT: Dick Hutchinson; **Image LINK:** https://image.gsfc.NASA.gov/poetry/educator/hutch3.jpg
Article Link: https://image.gsfc.NASA.gov/poetry/educator/Aurora79.html

[81] Image 7., Photograph of Earth: View of the Eastern Pacific Ocean (just off the coast of South America) from Galileo, as depicted in the ***NSSDCA Photo Gallery*** (the "NASA Space Science Data Coordinated Archive," NASA's archive for space science mission data), and released into the public domain. Original image reduced **to 30% resolution** to squeeze it into this paper—and used for illustration purposes only. Author/curator: Dr. Edwin V. Bell, II ; NSSDCA, Mail Code 690.1, NASA Goddard Space Flight Center, Greenbelt, MD 20771, PHONE: +1−301−286−1187, Email: Ed.Bell@nasa.gov, NASA/GSFC Security and Privacy Statement, NASA Official: Dr. David R. Williams, Version 3.5, 09 September 2003
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[82] Image 8., Photo of one of the Voyager spacecraft, NASA's Mariner series,as depicted in the ***NSSDCA***

Photo Gallery (the “NASA Space Science Data Coordinated Archive,” NASA's archive for space science mission data), and released into the public domain. Original image reduced **to <u>65%</u> resolution** to squeeze it into this paper—and used for illustration purposes only. Author/Curator: Dr. Edwin V. Bell, II, Mail Code 690.1, NASA Goddard Space Flight Center, Greenbelt, MD 20771, PHONE: +1−301−286−1187, Email: Ed.Bell@NASA.gov, NASA Official: Dr. David R. Williams, Version 2.5, Last Updated: 26 November 2018, Source URL for image:
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Article URL for image: https://nssdc.gsfc.NASA.gov/planetary/voyager.html
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[83] Image 9., a “Linear Regression” graph created by this researcher (Gordon Wayne Watts), using Graph, Version 4.3, Build 384 (Copyright Ivan Johansen, 2007, Email: Graph@Padowan.dk ; Website: http://www.Padowan.dk), with trendlines representing both an Exponential trendline and selected orders of power of Polynomial trendlines. DATA used for this graph are the five (5) data points taken from Table 4. of this paper, and using **“49%”** for the 5th and last data point, where a choice is given. This graph is shown **<u>twice</u>** in this paper**: Once** as an “8½−x−11” portrait−view compliant image, embedded within this paper, and with “cutoff” artifacts of the image manually corrected, and with the formula legend arbitrarily enlarged for viewing convenience**; and, again,** as and “11−x−8½” landscape−view compliant image, as a separate PDF file, attached to the bottom of this paper, and manually appended using “PDF Split and Merge basic,” Version 2.2.4., Console version: 2.4.3e Developed by: Andrea Vacondio Build date: 25−Jun−2014 Java home: C:\Program Files\Java\jre6 Java version: Java(TM) SE Runtime Environment 1.6.0_16−b01 Max memory: 254Mb Configuration file: C:\Program Files\PDF Split And Merge Basic\pdfsam−config.xml Website: http://www.PdfSam.org

[84] Image 10., a “Linear Regression” graph created by this researcher (Gordon Wayne Watts), using Graph, Version 4.3, Build 384 (Copyright Ivan Johansen, 2007, Email: Graph@Padowan.dk ; Website: http://www.Padowan.dk), with trendlines representing both an Exponential trendline and selected orders of power of Polynomial trendlines. DATA used for this graph are the five (5) data points s taken from Table 4. of this paper, and using **“5%”** for the 5th and last data point, where a choice is given. This graph is shown **<u>twice</u>** in this paper**: Once** as an “8½−x−11” portrait−view compliant image, embedded within this paper, and with “cutoff” artifacts of the image manually corrected, and with the formula legend arbitrarily enlarged for viewing convenience**; and, again,** as and “11−x−8½” landscape−view compliant image, as a separate PDF file, attached to the bottom of this paper, and manually appended using “PDF Split and Merge basic,” Version 2.2.4., Console version: 2.4.3e Developed by: Andrea Vacondio Build date: 25−Jun−2014 Java home: C:\Program Files\Java\jre6 Java version: Java(TM) SE Runtime Environment 1.6.0_16−b01 Max memory: 254Mb Configuration file: C:\Program Files\PDF Split And Merge Basic\pdfsam−config.xml Website: http://www.PdfSam.org

Table 2.

5. Below is a copy & paste of selected data I used from prior research, and is identified as such by citation: **[PART I. Threats/dangers posed...(continued)]**

TABLE VI from Cliver, cited above in [36]: The 25 largest geomagnetic storms based on the Dst index, from 1932–2002 [Based on Dst index from Karinen and Mursula, 2004], copied/pasted below:

Date	Time (UT h)	Peak value (nT)
14 Mar.	1989 01	−548
05 Jul.	1941 13	−453
28 Mar.	1946 14	−440
15 Jul.	1959 19	−434
11 Feb.	1958 11	−428
13 Sep.	1957 10	−426
26 May	1967 04	−391
31 Mar.	2001 08	−383
01 Mar.	1941 18	−382
09 Nov.	1991 01	−375
24 Mar.	1940 20	−366
19 Sep.	1941 06	−359
25 Jan.	1938 23	−352
26 Jan.	1949 00	−350
22 Jan.	1938 11	−344
08 Jul.	1958 20	−334
13 Nov.	1960 09	−333
30 Apr.	1960 18	−325
01 Apr.	1960 18	−325
05 Sep.	1957 03	−324
14 Jul.	1982 03	−322
04 Sep.	1958 22	−305

23 Sep.	1957	07	−302
16 Jul.	2000	00	−301
25 Mar.	1991	00	−297

From: **“Table 5: Top 10 Dst Storms*” [from NOAA “Halloween” paper] – June 2004 paper. [28]**

Rank	Dst (nT)	Date
1	−589	03/14/1989
2.	−465**	11/20/2003
3.	−429	07/15/1959
4.	−427	09/13/1957
5.	−426	02/11/1958
6.	−401**	10/30/2003
7.	−387	03/31/2001
8.	−387	05/26/1967
9.	−354	11/09/1991
10.	−339	11/13/1960

*Dst data from Kyoto World Data Center−C2 in Kyoto, Japan.
**Provisional Dst – not the final value

From ***Geophysical Research Letters*** **[38]**

“Table 1. Geomagnetic and Interplanetary Parameters of Superstorms of Solar Cycle 23

Time/Date	Dstp, nT
01:00 04/07/2000	−287
01:00 07/16/2000	−301
09:00 03/31/2001	−387
00:00 04/12/2001	−271
07:00 11/06/2001	−292
01:00 10/30/2003	−353
23:00 10/30/2003	−383
21:00 11/20/2003	−422
07:00 11/08/2004	−373
10:00 11/10/2004	−289
09:00 05/15/2005	−263

3. Results...”

Image 7. Photograph of Earth: View of the Eastern Pacific Ocean (just off the coast of South America) from Galileo[81]

6. Discussion: [PART II: My key findings – discussion]

In this section, I will attempt to assess the probabilities of estimation of a catastrophic event. Initially, it is appropriate to see where prior research has taken us here. First off, Riley[49][50] estimated the probability of another Carrington−class storm to be "occurring within the next decade is ~12%," using the Power Law, and went on to explain it thus: "A final tool that will be useful for our analysis relies on the average time to the next event to compute a probability of occurrence. For Bernoulli distributions, that is, independent events that either happen or do not, with a constant probability of occurrence, it can be shown that the probability of occurrence is given by

$$P(x) = [1/(1+\tau)],$$

where τ is the average time to the event. Thus, an event that occurs once every 100 years would have a probability, P = 1/(1 + 100/10) = 0.09, or 9% of occurring during the next decade."[50] Looking at his formula, and comparing it with his example (in the text of his paper), it is clear that Riley didn't quite state the formula correctly: He accidentally used a denominator of **$(1+\tau)$, that is, (1+A),** e.g., "one plus the average time to event," and not accounting for the time−span under consideration—a decade here. But, ignoring Riley's typo, and correcting his formula, rather, it should be stated as follows:

P(x) = [1/(1+ A/t)], where:

P(x) = Probability of the event;
A = Average time to event; and,
t = time−span under consideration for probability of occurrence.

Analysis of the Riley exponential formula

That said, it's also clear that his formula is exponential in nature, and (more−importantly) it seems "sound" on both the extremes and the "center" of the curve—let's use 100−years as the "average" time between Carrington Event's in this example:

(1) Set "t = 1 year," and we get P(x) = [1/(1 + A/t)] = [1/(1 + 100/1)] = 1/101 = 0.099= **0.99%** (to 3 significant figures, when considering the final percent value), which seems reasonable, because the odds of a once−in−a−lifetime event are quite low for just the next year.

(2) Set "t = 1,000 years," and we get P(x) = [1/(1 + A/t)] = [1/(1+ 100/1,000)] = 1/(1 + 0.1) = 0.909= **90.9%** (to 3 significant figures, when considering the final percent value), which seems reasonable, because the odds of any event are quite high when looking at a very long time−frame.

(3) Set "t = 100 year," and we get P(x) = [1/(1 + A/t)] = [1/(1 + 100/100)] = 1/(1 + 1) = 0.5 = **50.0%** (to 3 significant figures, when considering the final percent value), which seems reasonable, because the odds of a once−in−a−lifetime event are probably about 50% when considering the entire "life−time" of, say, a person who lives to be a hundred years old. If we assume that Riley obtained 12% for his final figure for the next decade, then we can solve for the time−frame he assumed, using P(x) = [1/(1 + A/t)]

0.12 = [1 / (A / 10)] – rearranging this, we get:
0.12 * (A / 10) = 1.00 – rearranging this, we get:
0.12*A / 10 = 1.00 – multiplying out, we get:

0.012*A = 1.00 – and, solving for A, we get:
A = 1.00 / 0.012 (in years, of course) = 83.33 years. Not sure how he derived 83.3 years, but considering that Riley's paper was written in 2012, and the Carrington Event was in 1859, we have a time−lapse of 153 years, and two such “Carrington−class” events, both the namesake event in 1859, and then the “Solar Super Storm of 2012,” which prompted all the attention from scientists. Assuming he estimated 2 such events every 153 years, this would mean an “average” time of 76.5 years between events, close to my 83.33 derivation.

Using 76.5 as my baseline average, P(x) = [1/(1 + A/t)] = [1/(1 + 76.5/10.0)] = [1 / (1 + 7.65)] = **11.561%** to five significant figures, almost the 12% figure stated in the paper, and a 1−in−8.65 chance (close to the news article's interpretation in ***WIRED*** magazine.[49] In fact, Riley also had stated: “Additionally, since the event occurred only ~150 years ago, it is a constant reminder that a similar event could reoccur any day.”[50] Using 150−years as my average time between events, with an average time of once every 75−years, we get a P(x) = [1 / (1 + 75/10)] = **11.76%** chance. That seems right because the “average time to event” is half of either extreme: “Zero−time” and the average time to “next” event, since, on average, you would be in “the middle” of such a time−line.

However, Moriña[40], using a “counting process with Weibull inter−occurrence times in order to estimate the probability of extreme geomagnetic events,” came up with a much lower figure in a more−recent paper, which finds that: “the probability of occurrence on the next decade of an extreme event of a magnitude comparable or larger than the well−known Carrington event of 1859 is explored, and estimated to be between **0.46% and 1.88% (with a 95% confidence),** a much lower value than those reported in the existing literature.”(Bold face for clarity; not in original)[40] What are Weibull−based statistical analyses, you might ask? Moriña helps us by explaining that: “the scale parameter of the inter−occurrence time [in other words, the time between geomagnetic storms of a given intensity] distribution grows exponentially with the absolute value of the intensity threshold defining the storm, whereas the shape parameter keeps rather constant.”(My comments in brackets to clarify; not in original)[40] In other words, he is saying that a storm twice as powerful does not necessarily have “half” the chance of occurrence, but rather, less, because there's an exponential element to the probabilities. Thus, the data on smaller, more−recent, geomagnetic storms might lead researchers to underestimate the average time to a given storm of a larger magnitude, or, put another way, to overestimate the probabilities of occurrence.

So, Riley estimates about **12%** probability[50], and Moriña estimates[40] about **1.17%** (taking the average of “0.46% and 1.88%,” from his research paper). These results are very much in disagreement, opening the door to confusion, prompting this researcher to “look further.”

While statistics is an interesting avenue to pursue in analyzing data, this paper will not follow Moriña's path, but, rather, do something much more concrete: We will look at actual storms in recent decades, and make assumptions based on a direct time−averaging method so see “how often” storms of a given magnitude occur, that is, the average time between geomagnetic storms of known magnitude and danger levels. To obtain a “baseline” for 'which' storms to count, we look mainly as the published news media of damage associated with a given storm, but also make inferences based on the Dst values of the storms. With that model, here are my findings:

My data lists forty−six (46) verified storms from 1859 to 2012. (There may have been more that were overlooked due to the human limitations of this researcher, so this is a “low” estimate.) In every single entry, above, there was either wide−spread damage and interference, or at least the inference that it was possible, when looking at the Dst readings of storms which garnered lesser levels of press coverage. While not all of the storms were grave threats, nonetheless, all 46 of the geomagnetic storms I list in my research are documented to have the potential for wide−spread damage to the power grid, telecommunications, and such.

This researcher can't find any more recent severe geomagnetic events, in published news media reports, since the 2012 super storm, and will infer that we are at a low level of geomagnetic disturbance at this time. As such, the "time span" in question will use from late 1859 to late 2019 as the base time period, i.e., 160 years. **With 160 years and 46 dangerous storms, we can safely infer that the "average time" between is a little bit <u>less than 3 and−a−half years</u>. (160 years / 46 events = <u>3.478 years/event</u>, to 4 significant figures.)**

While my standards for what constitutes a "dangerous" storm are slightly lower than the extreme case, it is clear from looking at the published news reports of each of the 46 events that each one either did, or could very easily, cause significant damage to the electrical and communications grid.

In this manner, the extreme geomagnetic events are not unlike <u>solar eclipses</u>, <u>category−5 hurricanes</u>, <u>volcanoes</u>, and <u>large−magnitude earthquakes</u>: They are happening all the time around the world – example: A solar eclipse over the ocean, where there are no observers, or an earthquake in an uninhabited region, a "submarine volcano" (underwater), which is not always in plain sight, or a "fish storm," a hurricane or tropical storm, with a trajectory towards the open Atlantic, which poses no threat to land.

But, unlike the hurricanes (which pose the same threat in the technology era, as they have in past centuries), the geomagnetic storms in modern times pose a far larger threat than in decades past: We now have very sensitive GPS, satellites, and power & communications grids—and, by extension, a nation's economy and social stability are impacted when (not if, but when) we get hit with "the big one." When past geomagnetic storms hit, we did not have such delicate integrated circuitry, computers, and electrical & communications infrastructure, which is particularly susceptible to damage. But, as many recent geomagnetic events have shown us, the threat is real, interfering with aircraft communications[20], several times tempting us to go to war with the Soviet Union[20][51] (or other nations), when, in fact, they were not the ones disrupting communications, even setting off underwater sea−mines.[18] I estimated above an average of only 3.478 years between severe geomagnetic storms, which implies a very high probability of such a storm in the next decade:

P(x) = [1/(1+ A/t)] = [1 / (1 + 3.478/10)] = 0.7419 = **about a <u>75% chance</u> of such an event within the next decade.** But recalling that only some of the geomagnetic events in my table are documented to have actually done damage, it would only be fair to recalculate this probability:

DATA, from Table 1., above: Number of storms with documented damage to the grid: 14
(List of storms from my table: 1,2,3,4,6,10,24,25,28,29,30,35,40,41) – From 1859 to 2019 is 160 years, and that means that there's an average of about 11.43 years between storms. Re−calculating yields this result:

P(x) = [1/(1+ A/t)] = [1 / (1 + 11.43/10)] = 0.4667 = **about a <u>47% chance</u> of such an event with the next decade.**

That estimate is much higher than either of the previously reported estimates, but each of these events (except the "Near Miss of 2012") were smaller, less−destructive Solar Geomagnetic storms than the "Carrington Event," itself –and are, as such, expected to happen more often.

But I stand by my estimate because each – and every one – of the fourteen (14) named storms on my table, above, are documented to have caused widespread damage to the grid (or, in few cases, threatened the lives of our astronauts—and caused them major discomfort in the interim). Moreover, even those events listed on my table which don't have any record of having caused damage are in most, or all, **are documented to have been very powerful by several metrics:** Dst (Disturbance−storm time) measurements, GLE (ground level enhancement) measurements, size & strength of CME's (coronal mass ejections), and brilliance of polar lights, as well as how far south the “Northern lights” are said to have been seen, as well as size, strength, and/or quantity of solar flares, even for solar storms with “weak” Dst readings.

So, while my calculated probability is for a storm of “less than” the original Carrington Event, nonetheless, each of the 14 examples on my table **are documented to have done actual and tangible damage,** even if not on a “planet−wide” scale in every case. Thus, the threats posed are probably greater than previously reported because previous researchers overlooked events that knocked out only some (but not all) of the planet's power or communications grids. With threatening geomagnetic events occurring, on average, every 11 or 12 years, we now turn to other factors to consider when weighing estimation of probabilities.

The July 2012 “Superstorm,” narrowly missed earth by only about nine (9) days [about **2.46%** of earth's **365¼−day** orbit] from its trajectory[70], with a peak Dst value of **−1,182 nT,** as reported by ***Space Weather***[31], or even a peak Dst value of **−1,200 nT,** as reported by ***REUTERS***[71], thus with such a catastrophic sized storm, a “near miss” of only 2.46% of earth's orbit certainly qualifies as a near miss, and I shall assign this a “½” value of an event: It nearly took out the planet, from top−to−bottom.

In this last probability calculation, I will assume that the “Near Miss of 2012” counts for a “half” of an event, and the actual Carringtom Event counts as “1” event. Thus, I derive an average of 1.5 Carrington−Class Events every 160 years, and come up with this final result: An event occurs—on average—every 106.67 years:

$P(x) = [1/(1+ A/t)] = [\ 1 / (1 + 106.666667/10)\ ] = 0.0857143$ or about **8.57%** rounded to 3 significant figures.

My findings of an **8.57%** chance of another Carrington Event are indeed between the Riley estimates of about **12%** probability[50], and Moriña's estimates[40] about **1.17%** (taking the average of “0.46% and 1.88%,” from his research paper). I stand by my estimate as it's methods are sound and its results are between both extremes in the reported literature.

CAVEATS:

My probability estimation, here, is probably low for several reasons: **First,** due to human limitations, I can not review **all** the solar geomagnetic events in the peer−reviewed scientific literature—meaning there were certainly some data points I overlooked when calculating the probabilities of another catastrophic event. **Secondly,** the upcoming Maunder Minimum is not a certain event. (And, even during solar 'minimums', there have been notably strong solar geomagnetic events), so even given a 'low', there is no guarantee of safety.) **Thirdly,** we have not even accounted for the accelerating collapse (decreases in strength) of earth's protective magnetic field—which protect earth from severe solar geomagnetic events. **Bonus fourth factor:** While the upcoming “magnetic flip,” **in and of itself,** does not place earth in any more jeopardy or danger for severe geomagnetic storms (other than determining ***which*** areas of earth have the strongest magnetic protection, based on the vectorial direction of the magnetic field, which protects most at the equator where magnetic flux is perpendicular to solar rays—and not parallel, as is with the field at the north and south poles), the moving magnetic north and south poles make GPS and other navigation less accurate. And, when the field inevitably collapses (as it has many times in earth's past history), there will be no reliable magnetic north for reference by GPS, compasses, or other geomagnetically−referenced navigation. **Bonus fifth factor:** Even if my estimation is low, the damage done by such a severe event is catastrophic, and it is good to err on the safe side. Given that both the geomagnetic field collapse and the pole “flip” are accelerating at unprecedented rates, caution is in order, and prediction of future field strength is anyone's guess.

Below, I will address additional factors of importance.

7. The upcoming "Maunder Minimum": [PART II: Key findings – continued]

The "Maunder Minimum" is a time period from 1645 to 1715 in which sunspots became exceedingly rare.[52] Without going into details, it is thought that we might be entering another "minimum" solar period.[53] A quick glance at the graph posted on the ***Universe Today*** article[53] is clear: Solar cycles 22, 23, and 24 get progressively smaller. In fact, Miyahara goes on to conclude that "The solar cycle is likely to show characteristic precursory features leading up to intervals of sunspot absence, and which can be differentiated by events of different durations."[54] But the research is still not clear, and thus we can not depend on a new "Maunder Minimum" in the near future to protect us from any severe geomagnetic events.

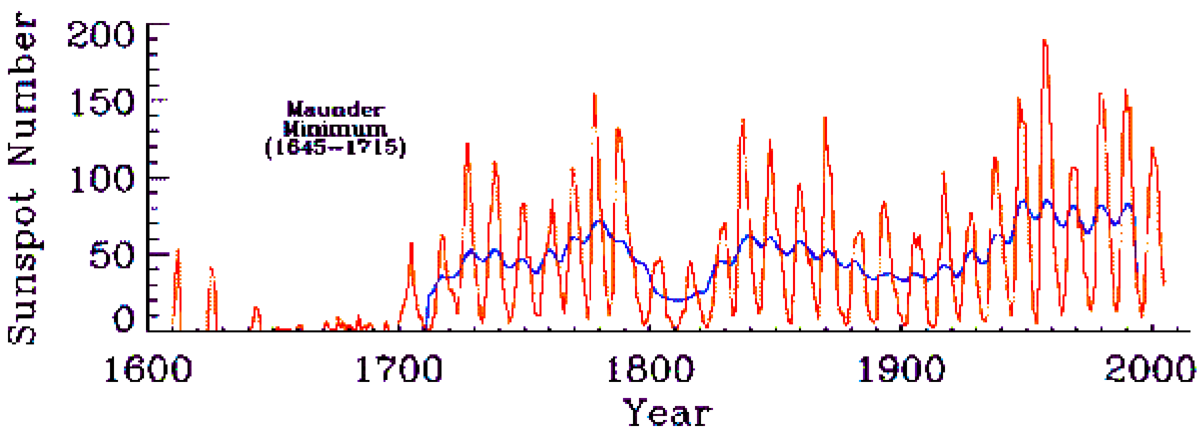


Image 3. The Maunder Minimum, a time in history, from 1645—1715, when sunspots were very rare, and where solar events (CME's, solar flares, solar storms, etc.) were at a low ebb[77]

8. The 11−year solar cycle: [PART II: Key findings – continued]

It is also a known quantity that sunspots (and related solar events: solar flares, CME's – coronal mass ejections, and sever geomagnetic storms, like the 46 storms in my main table, above) increase during a "solar maximum," the peak of the approximately 11−year solar cycle. But, is this any guarantee of protection from a severe geomagnetic storm during a minimum? The Geomagnetic Storm of 8−9 February 1986; had a peak Dst value of **−301 nT,** as reported by the ***Royal Academy of Engineering***[41]; and, it had a peak Dst value of **−307 nT,** as reported by the ***Research in Astronomy and Astrophysics***[42], very powerful by any measure: "By chance this storm was the largest recorded storm, since 1960 and the eighth largest since 1932 (Allen 1986)."[42] However, it occurred at almost the very minimum of the 11−year solar cycle, as reported by the ***Research in Astronomy and Astrophysics:*** "Two other factors made this storm particularly unusual (i) it occurred near the minimum of the Sun's activity cycle; and (ii) it was apparently caused by flares that could be described as moderate to large."[42] This unusual occurrence prompted the ***Royal Academy of Engineering*** to caution us that: "This storm shows that extreme events can occur at any phase of the solar cycle and it is unwise to focus mitigation efforts only around solar maximum." (pp.17—18){small quote used under Fair Use}[41] So, even assuming we enter a new "Maunder Minimum," and then go on to enter the "bottom" of that solar cycle, there is no guarantee of safety of the grid: Dangerous solar flares can happen at any time.

9a. The collapsing geomagnetic field (and upcoming pole reversal)

[PART II: Key findings – continued]

It is a well−known fact that earth's magnetic poles are moving, and, at the same time, the strength of our geomagnetic field has been steadily weakening. These two phenomena are related because when there is a "magnetic field" flip (like has happened many times in earth's past), compasses will point to, basically, the opposite direction. ***SPACE.com*** reports that "Earth's north magnetic pole is so out of whack that scientists need to update the global magnetic−field model they released only four years ago. Could that be a sign that the magnetic pole will flip soon?"[55] ***PHYS.ORG*** warns us that "'This is a region where we see that satellites consistently (experience) electronic failures,' said Prof. Finlay,"[56] a problem we're now facing because earth's magnetic field is what shields us from harmful cosmic rays, solar flares, and the like: "As Earth's magnetic shield fails, so do its satellites. First, our communications satellites in the highest orbits go down. Next, astronauts in low−Earth orbit can no longer phone home. And finally, cosmic rays start to bombard every human on Earth."[56] In fact, ***NASA*** reports that "Earth has a magnetic field. It shields us from the full effects of the solar wind and GCR," referring to galactic cosmic rays.[57] This trend is relevant, not only because earth's magnetic field protects sensitive electronic equipment, but also because is protects us, humans: "Beyond Low Earth Orbit, space radiation may place astronauts at significant risk for radiation sickness, and increased lifetime risk for cancer, central nervous system effects, and degenerative diseases."[57]

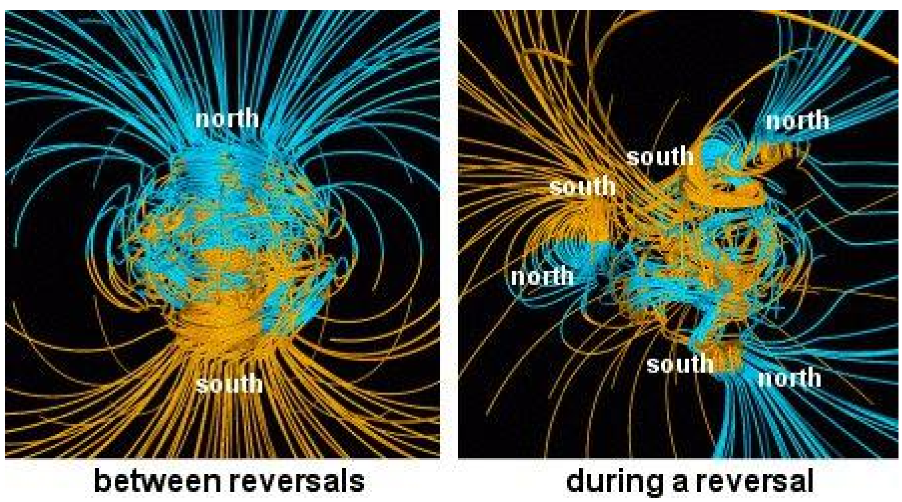


Image 4. Earth's protective geomagnetic field during normal activity, between pole flips / reversals (depicted on the left), and during geomagnetic reversals (depicted on the right)[78]

So, without going into any graphic analysis, it suffices to say that any threats posed by solar flares and catastrophic geomagnetic solar storms will, increasingly, pose more of a threat as Earth's magnetic field continues to weaken. Worse yet, the December 2018 paper by ***PHYS.org*** goes on to report[56] that: "Scientists first noticed the SAA [the "South Atlantic Anomaly"] in the 1950s, and since then it has decreased in strength by a further 6%, as well as moving closer to the west.'"(Comments in bracket to define "SAA"; not in original) The problem here?

While this 6% decrease only refers to the South Atlantic Anomaly region, if the velocity of decrease holds true for the entire geomagnetic field, then 2018 (the date of the article) minus 1955 (the midpoint of the 1950's) implies a 63−year period is needed for every 6% decrease, that is, a reduction to 0.94 for each period. The next 63−year period would, then, be expected to be only 88.36% of the strength in 1955. Moreover, if our previous loss of 30% took 3,000 years[56], then we are accelerating our descent: Notice that it only takes six periods of 63 years to get the same loss at this rate: $(0.94)^6 = 0.689869781056$, or 69% (to 2 significant figures), a loss of 31% in only six 63−year periods, or 378 years, **<u>much faster</u> than our previous 30% loss**

—which took 3,000 years.[56]

Does the SAA trend suggest what happens planet−wide? ***SCIENTIFIC AMERICAN*** gives us a clue: “At most places there has been a general decrease in the strength over the past century, typically ten percent or so.”[58] Is this similar to the velocity of decrease reported by ***PHYS.org*** data, above? ANSWER: Using logarithms (math not shown here, but figures in this paragraph to 7 significant figures), it is seen that we need only 5.764406 “periods” of 63 years (per ***PHYS.org***) or 3.385281 “periods” of a century (per ***SCIENTIFIC AMERICAN***) to get a 30% loss. Let's check our math, first, to be sure:

(0.94)^ 5.764406 = 0.70 or about 70%. [So, 5.764406 periods of 63 years each is 363.157578 years.]**, <u>SAA</u>**

(0.90)^ 3.385281 = 0.70 or about 70%. [So, 3.385281 periods of 100 years is 338.5281 years.]**, <u>planet−wide</u>**

In fact, the SAA estimate I made from ***PHYS.org*** was not even as fast as the “planet−wide” estimate from ***SCIENTIFIC AMERICAN***, achieving the same 30% loss (e.g., down to 70% field strength) in about 338.5 years, even faster than the approximately 363−year estimate merely looking at the South Atlantic Anomaly region. ***NATIONAL GEOGRAPHIC*** also reports that earth's magnetic “pole now is moving faster than it has for decades.”[59] This is significant for 2 reasons: First, the rapid movement of the magnetic field also disrupt communications and navigation: “The changes have been so large that scientists began working on an emergency update for the World Magnetic Model, the mathematical system that lays the foundations for navigation, from cell phones and ships to commercial airlines,”[59] but more−importantly, as we've seen, the rapid movement of the magnetic north and south poles is associated with the collapsing (decreasing) protective geomagnetic field: When there's a “pole flip,” both phenomena occur together. But, just how fast is this pole−flip and field collapse accelerating? In a report this year, ***21stCenturyWire.com*** reports that “The north magnetic pole sped across the International Date Line last year at a rate of 55 km per year, more than three times as fast as it moved before the mid−1990s. Now located in the Eastern Hemisphere, it’s moving away from Canada and approaching Siberia.”[60]

It is known that earth's circumference is about 24,901 miles, or about 40,075 km, meaning the distance between north and south poles is about 20,037.5 km.

Why is that significant? At a rate of 55 km/year, the poles would need only about 364.3 years to “flip,” that is, have the geomagnetic north pole go to the opposite end of earth. Let's do the math, just to be sure:

[20,037.5 km/year] divided by [55 km] = about 364.3 years to 4 significant figures.

The 55 km/year figure quoted by ***21stCentrutyWire.com*** seems accurate: An article, just this year, from ***LiveScience*** gives the same figure: “News of the magnetic north's meanderings isn't exactly new. Researchers figured out in the 1800s that magnetic north tended to drift. Then, in the mid−1990s, it began moving faster, from just over 9 miles (15 kilometers) a year to about 34 miles (55 km) annually, Nature reported. In 2018, magnetic north skipped over the International Date Line and entered the Eastern Hemisphere.”[61] In fact, the ***American Geophysical Union*** reported, in a 2016 paper, a rate as high as 60 km per year[65], an this 60 km/year figure is backed up by an April 2019 paper by ***Magazine of Engineering Dyna***[66] and a paper as recent as mid−May 2019 published by the ***EUROPEAN SPACE AGENCY***[64]. Using this newer updated data finds this result:

[20,037.5 km/year] divided by [60 km] = about **<u>333.9583 years</u>** to 7 significant figures, which is even less than the 338.5281−year calculation, above.

The velocity accelerated to almost four (4) times its prior rate. Moreover, as stated above, the last 30% drop took 3,000 years, and this time, it looks to need only about 338.5 or 363.2 years (or even just 333.9583 years). So, both phenomena are quickly accelerating. If we encounter a pole−flip, the velocity of the magnetic pole movement may accelerate even faster, and earth's protective geomagnetic field may start to collapse at an even faster rate, and it may drop to close to zero, leaving us vulnerable to dangerous cosmic rays and solar flares. In fact, earth's protective magnetic field serves several purposes:

- Navigation by humans (using compasses, and now GPS)
- Navigation by animals who can sense earth's magnetic field
- Protection from both solar flares and cosmic rays

“Our planetary magnetic field has many advantages. For over 2,000 years, travellers have been able to use it to navigate across the globe. Some animals even seem to be able to find their way thanks to the magnetic field. But, more importantly than that, our geomagnetic field helps protect all life on Earth.”(Small 'Fair Use' quote from ***EARTH***)[67]

A ***NASA*** paper suggests it may drop to zero: “If the magnetic field of the Earth suddenly changed...one might expect the field to go to zero strength for a century or so.”[62] ***The Smithsonian Institution*** quotes one scientist with a similar figure: ““When the [magnetic] field is weak, which is during reversals, **the main dipole field collapses to something on the order of <u>ten percent of its normal strength</u>,”** Singer says. This collapse could spell trouble for life on Earth, since the magnetic field stabilizes ozone molecules, shielding the planet from ultraviolet radiation.”(Emphasis added in bold and underline for clarity, not in original.)[63]

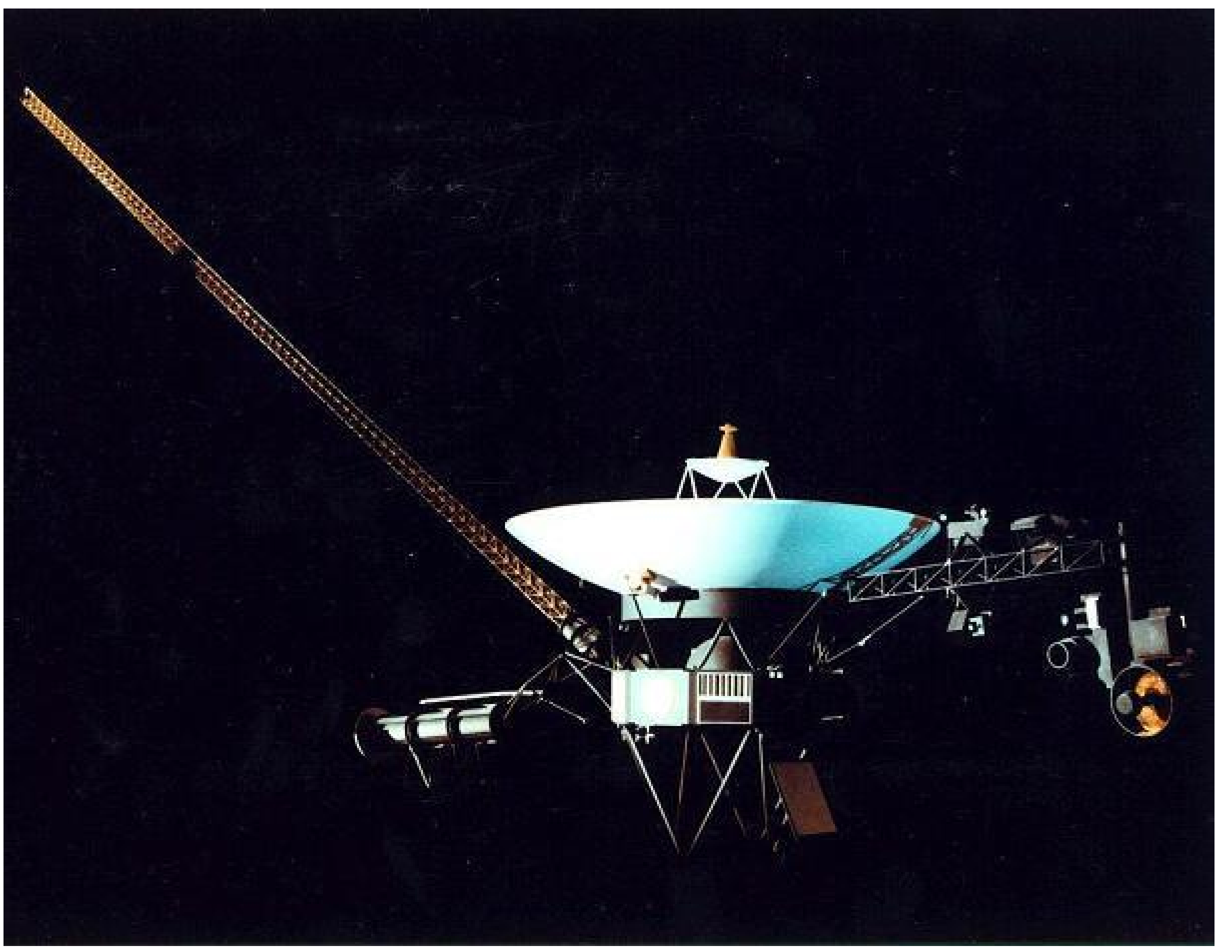


Image 8. Photo of one of the Voyager spacecraft, of NASA's “deep space” Mariner series, and a reminder that similar satellites and NASA equipment, closer to earth, are vulnerable to solar geomagnetic events[82]

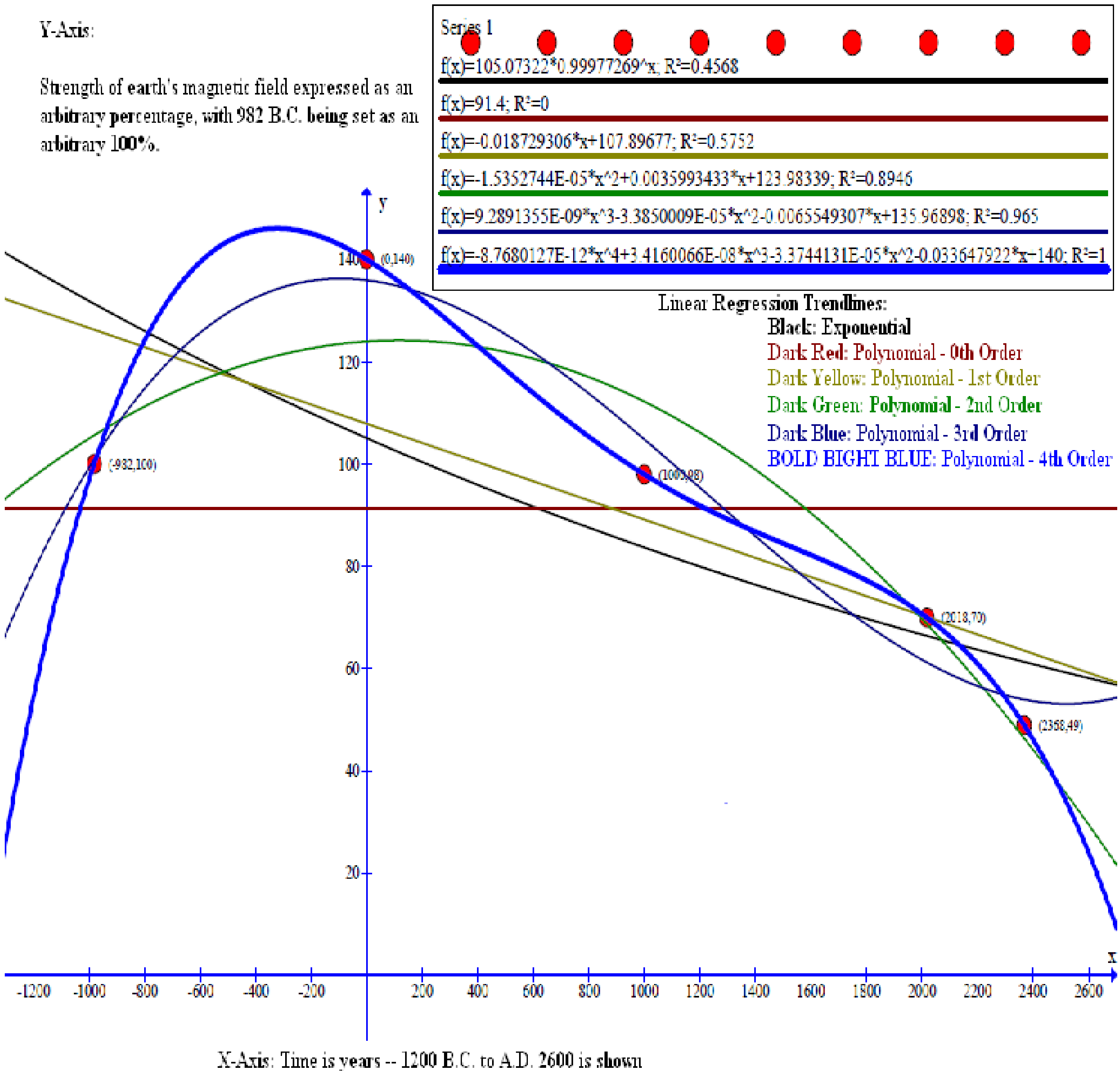
<u>9b.</u> The <u>upcoming pole reversal</u> predicts a collapsing geomagnetic field

[PART II: Key findings – continued]

Oddly−enough, the times I calculated from two (2) independent sources for the earth's magnetic field to drop another 30% (either 363.157578 year or 338.5281 years) are almost the same as the time needed for earth to do a "magnetic flip," at the rate it's been going of late (either 333.9583 years or 364.3 years), calculated from two *other* independent sources—thus, a total of four <u>(4)</u> or more <u>separate</u> (independent) sources were used:

TABLE 3. <u>Selected data comparing rate of geomagnetic field collapse with rate of "magnetic flip"</u>		
<u>What is under review?</u>	**<u>Amount of time needed (with comments)</u>**	**<u>Source(s)</u>**
How long it's estimated the earth's protective geomagnetic field will drop by another thirty (30%) percent—e.g., to **70%** percent of current levels?	(0.94)^ 5.764406 = 0.70 or about 70%. [So, 5.764406 periods of 63 years each is 363.157578 years.], SAA, that is, the [the "South Atlantic Anomaly"] drops by about 6% (to 94%) in the approximately 63−year period reported, and thus would need 5.764406 periods of 63 years, that is, about **<u>363.157578 years.</u>**	This estimate calculated from data obtained from ***PHYS.org***[56]
How long it's estimated the earth's protective geomagnetic field will drop by another thirty (30%) percent—e.g., to **70%** percent of current levels?	(0.90)^ 3.385281 = 0.70 or about 70%. [So, 3.385281 periods of 100 years is 338.5281 years.], planet−wide: Earth's entire geomagnetic field drops by about 10% (to 90%) every century (100−year period), and thus would need 3.38528 periods of 100 years, each, that is, about **<u>338.5281 years.</u>**	This estimate calculated from data obtained from ***SCIENTIFIC AMERICAN***[58]
How long (at a reported rate of 55 km/year) will it take for earth's magnetic poles to "flip," given a known circumference of earth?	[20,037.5 km/year] divided by [55 km] = about **<u>364.3</u>** years to 4 significant figures.	The 55 km/year figure is taken from multiple sources.[60][61]
How long (at a reported rate of 60 km/year) will it take for earth's magnetic poles to "flip," given a known circumference of earth?	[20,037.5 km/year] divided by [60 km] = about **<u>333.9583 years.</u>**	The 60 km/year figure is taken from multiple sources.[64][65][66]
I'm taking the average of the four figures above. **<u>** Editor's Note:</u> The decreases in earth's magnetic field occur together with (are associated with) each magnetic "flip," a well−known phenomenon.**	Mean (average) time−lapse of **<u>349.9859945 years,</u>** or about 350 years. However, the top 2 figures ask only about how soon we will see another 30% drop in geomagnetic field strength. The bottom 2 figures outright contemplate a "pole flip," in which earth's protective geomagnetic field may collapse to 10% or less. So, after the "average" time, we may see LESS THAN the 70% strength (e.g., only a 30% field loss) than expected, as the bottom 2 figures suggest a faster collapse. If this is so, then the top 2 figures may be correct for now—but may become obsolete or outdated of earth's magnetic field collapse continues accelerating even more.	Sources: Those cited above, taking an arithmetic mean (average).A "Geometric mean" (that is, the product of all 4 data, and take the 4^{th} root) would be **<u>349.71 years</u>** to 5 significant figures, but as it's so close to the arithmetic (additive) mean (**<u>349.9859945 years,</u>**) that we can safely ignore it.

Image 9. "Linear Regression" GRAPH of changes in the dipole strength of earth's protective geomagnetic field, as a function of time. DATA used for this graph are the five (5) data points taken from Table 4. of this paper, and using "49%" for the 5th and last data point, where a choice is given.



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Since these two phenomena are related, that is to be expected: If a complete "flip" occurs, the field will probably not drop to zero, but it will decrease significantly. And, as both phenomena (the decreases in earth's protective magnetic field and the velocity of the geomagnetic pole movements) seem to be rapidly accelerating in recent centuries and decades, this leaves us more vulnerable to any geomagnetic solar events, such as documented and discussed above. Even if my research over−estimates the probability of another catastrophic geomagnetic event, nonetheless, this much is clear: Given the dire consequences of documented damage that would be done, it's best to have a cautious and conservative estimate—especially given new unknowns and variables, such as the impending geomagnetic flip & concomitant collapse of earth's protective magnetic field—which, of course, make us even more vulnerable to a "direct hit." Therefore, section 11., below, Recommendation (for lawmakers and citizens) should be given careful review.

Table 4 – Data used to graph changes in earth's magnetic field strength in recent millennia:

<u>Year</u>	**Strength in earth's magnetic field, using 982 BC as the "baseline" for a 100% level of dipole strength. Comments to explain calculations.** **<u>All figures expressed in percentage values (for ease of reading)</u>**	**Percent value (restated for clarity)**	**<u>Source(s) cited</u>**
982 BC	In a 2018 paper, ***PHYS.org*** states[56] that: "The geomagnetic field has been losing 30 percent of its intensity in the last 3,000 years." – We chose this arbitrary value (for year 982 BC) to be **"100%" for convenience of calculations of other figures.**	**100%**	***PHYS.org***[56]
AD 0	In a 2000 paper, the ***Geophysical Journal International*** states[72] that: "the Earth's dipole moment was twice the present−day value 2000 years ago, whilst between 5000 and 6000 years ago it was much weaker." – **Twice our arbitrary 70% modern−day value is 140%.**	**140%**	***GJI***[72]
AD 1000	Both Merrill (as cited by ***CRI***[73]) and Barnes (as cited by ***The University of South Dakota***[74]), both claim that earth's magnetic field was approximately 40 percent stronger in AD 1000 than at the time of their writing. (The CRI article was originally written in 1998, and the U of SD page was updated in 2014, but we approximate 2018, since this is fairly close.) If it were 40% stronger, then you get: **(1.40)*(70%) = 98% of the strength at this time.** *[Editor's note: While I trust the CRI figure, it was from a 'religious' organisation, and may have has bias, so I obtained an assessment from an independant source, namely the University of South Dakota, which made the same assessment of geomagnetic field strength for year AD 1000.]*	**98%**	***CRI***[73] and ***UofSD***[74]
AD 2018	Since ***PHYS.org*** states[56] that we've lost 30% in the past 3,000 years, this figure will be 30% less,than the arbitrary baseline value 3,000 years earlier for year 982 BC, e.g., **70%.**	**70%**	***PHYS.org***[56]
AD 2368	The arithmetic mean of the 4 data points from my Table 3., above, is about 350 years for another 30% drop, so, adding 350 to AD 2018 yields AD 2368. Then, another 30% drop of the 70% current level of earth's dipole yields **(0.70)*(70%) = 49%. ALTERNATE figure for 2368:** ***The Smithsonian Institution***[63] suggests that the field strength may drop off to **10%** during a pole flip, and ***NASA***[62], which is quoted as saying: "**one might expect the field to go to zero strength for a century or so,**" suggests that earth's protective geomagnetic field may drop off to **0.0%** – during a "flip," so, taking the average, we get an estimated **5%** field strength for AD 2368.	**49%** **or:** **5%**	**Table 3., above**

Image 10. "Linear Regression" GRAPH of changes in the dipole strength of earth's protective geomagnetic field, as a function of time. DATA used for this graph are the five (5) data points taken from Table 4. of this paper, and using "5%" for the 5th and last data point, where a choice is given.

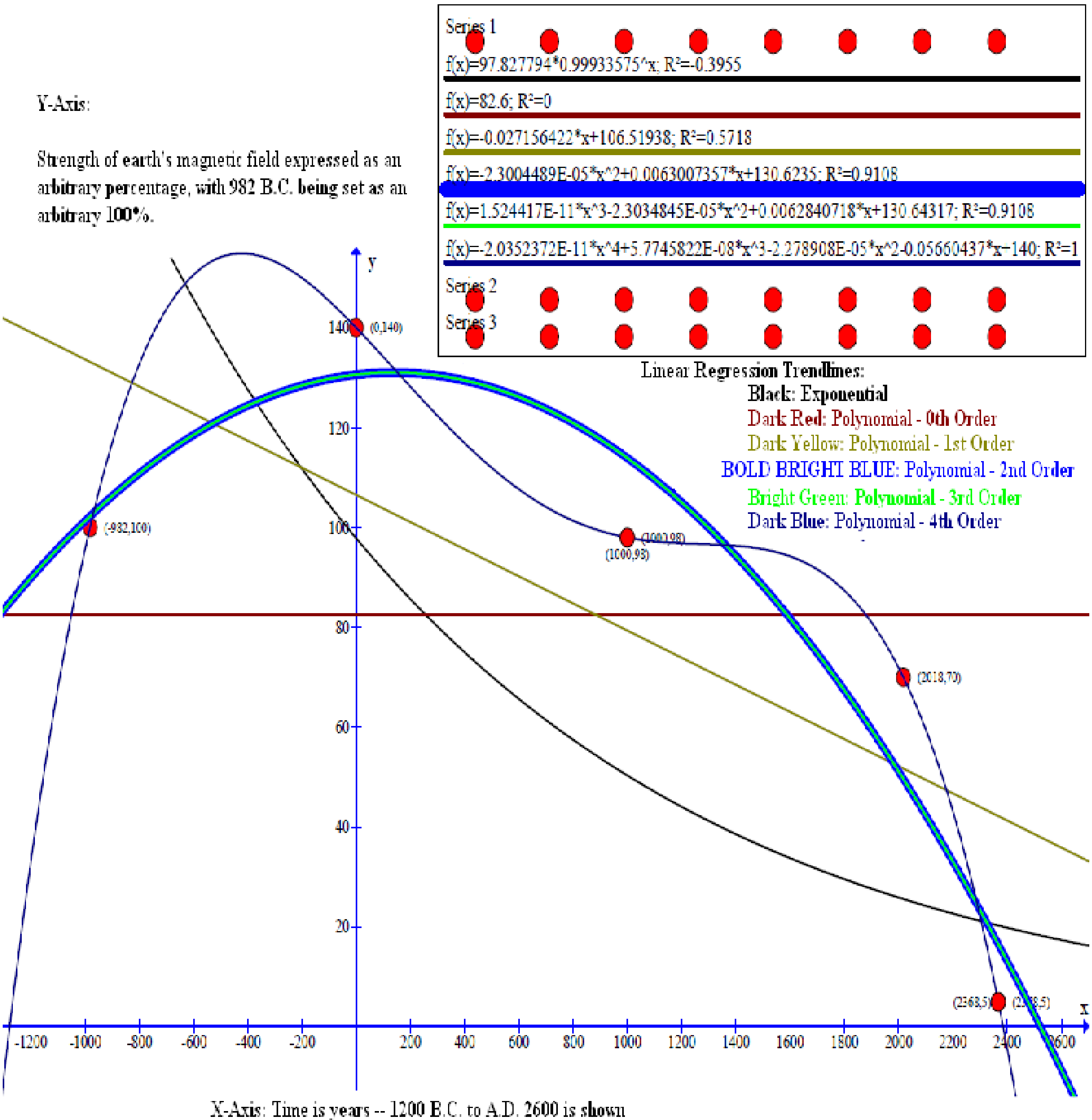

Image 10. "Linear Regression" GRAPH of changes in the dipole strength of earth's protective geomagnetic field, as a function of time. DATA used for this graph are the five (5) data points taken from Table 4. of this paper, and using "5%" for the 5th and last data point, where a choice is given.

<u>10.</u> Conclusions

The top half of this paper documents that, historically, we have encountered more damage to our communications and power grids than is commonly known, the recent outages in Canada and the northeast united states on several occasions to the very least—as well as interference to satellites, GPS, and other infrastructure—even military sea mines being triggered by changes in the earth's magnetic fields from a severe solar event.

However, **[[#1]]** any threats that solar events *already* pose can **[[#2]]** only be expected to <u>worsen</u> as earth's protective magnetic field continues to collapse—and this is **[[#3]] also** compounded as GPS and other navigation continues to lose accuracy as the geomagnetic north and south poles rapidly accelerate their velocity due to unknown geological causes within earth's core. Our environment is giving us **the 1−2−3 knockout punch.** I did not even account for nuclear EMP detonations by rogue nations (which can have similar effects on the electrical portion of the grid).

As can be seen from the second graph (Image 10) using the Table 4. data I obtained from other peer−reviewed research, the 2nd and 3rd order polynomial trendlines are almost identical. This was an unexpected result, since, of course, in the first graph (Image 9), using all the same data points except the last (where I did not factor in the field collapse predictions), all the “trendlines” are quite noticeably different.

Whether this is a random occurrence or not, nonetheless, this researcher infers that changing the last data point from 49% to 5% made an improvement on the prediction, since it factored in the nearly complete expected field collapse (down to 5%, not 49%) when a magnetic “flip” occurs. This prediction is tenable based on what we know about past geomagnetic “pole flips,” and, if this is an improvement on the data, then this may explain why the 2nd and 3rd order trendlines are so identical that I had to make one of them very, very wide, and make the other one a bright green colour, so as to differentiate it.

My two graphs (Images 9 and 10, above) use only five (5) data points, each, and, as such, are probably not quite as accurate as those of other researchers with more resources and collaboration; however, as my data are from reliable sources, and carefully reviewed by this researcher, any errors are expected to be small:

In conclusion, I chose 5 reliable data points for each graph for time periods within the recent several centuries, and showing an approximate “peak” in dipole strength around the time of Christ, so the trendlines generated from these graphs should be reliable for several centuries out into the future.

My inference is that these trendlines are accurate, and thus sometime around A.D. 2500, we can safely expect a magnetic flip, with the dipole strength of earth's magnetic field dropping to about 5% for an appreciable length of time.

This would leave us almost completely vulnerable to both cosmic rays as well as random solar geomagnetic storms, CME's, flares, etc., but (and more importantly), even for those of us who are here and now, the continuing field collapse will likely increase our vulnerability to solar events, even if we don't wait until A.D. 2500: Since we have encountered severe damages from past solar events with the field at present (or stronger) levels, then earth's decreasing magnetic field will only make matters worse, which brings me to my conclusion: We must heed the warnings in the following sections.

11. Recommendations [PART III: Proposed solutions]

11.(A) Recommendations for lawmakers

This paper focuses mainly on solar flare and CME (coronal mass ejection) threats, but EMP nuclear detonations also pose a threat—***Discover Magazine*** recently reported that an EMP 'test' bomb was set off and "even though the test site was about 900 miles from Honolulu, the blast was strong enough to be seen from the island and take out a transmission station."[68] Besides severe solar geomagnetic events, nuclear EMP detonations[68], and cosmic ray threats, the power and communications grids already must prepare for hurricanes, rainfall, droughts, wildfires, and more commonly experienced extreme weather events. (Rainfall, in fact, is known to be a perennial problem for power, phone, and internet cables, many of which are underground.) But, in this paper, I concentrate on the solar CME's, solar flares, and nuclear EMP events—and propose relatively simple mitigation measures—for lawmakers and for citizens. I do acknowledge the current administration's recent efforts: "President Trump has signed an executive order (EO) to boost coordination for and national resilience against electromagnetic pulse (EMP) threats—both from nuclear warfare and natural events like solar superstorms," as reported by ***POWER*** magazine{"Trump Acts on Critical Infrastructure Resiliency Against EMP Threats," by Sonal Patel, ***POWER,*** 26 March 2019}[69], but much more needs to be done by lawmakers and leaders of both political parties. For lawmakers (particularly Federal lawmakers), I offer these proposals:

- Local voltage surge protection devices and/or filters, and even "double−surge" protection in critical electric power, communications, and military infrastructure; Require critical infrastructure to also include EMP power line transient suppressors;
- Upgrading cables, wireless communications systems, electric substation control boxes/houses, and operating centres to be properly hardened, shielded, and grounded with such as a "Faraday Cage";
- Use of fiber optic−based communications, where possible (which, of course, aren't susceptible to electromagnetic pulses);
- Sufficient "backup" systems to store critical data and provide alternate power in the event of a power outage, including alternative power sources (solar, wind, etc.);
- Having "backup systems" unplugged & disconnected from the grid would help protect them greatly: Disconnecting any sensitive "backup" excitement (computers, solar panels, etc.) from wires (which could pick up an EMF pulse and induce a high−voltage current) would also greatly help, especially if they contain very little 'sensitive' electronics that could be affected by an EMP;
- "Capacitor banks," which work like batteries to absorb & dissipate excess energy;
- Possibly even an artificial geomagnetic field (using a combination of electromagnets and permanent magnets) across the globe: Would require much international cooperation
- PREVENTION: Forecasting or predicting a solar event, and shutting down (disconnecting) sensitive equipment from the grid is a good precaution. (Proper monitoring of solar events by satellites and deep−space probes would be useful here.);
- Creating guidelines and emergency plans for "black start" and "grid hardening" measures that will improve resiliency and recovery;
- Research, preparation, & review of emergency plans for EMP & solar geomagnetic event scenarios (like is done with hurricanes and earthquakes).
- Protect critical computers / Internet from hacking & cyber-attacks and computer viruses (and not just EMP nuclear detonations or solar flares / geomagnetic storms).
- **Prevention and protection in advance would cost Billions of dollars, but cleanup of the mess from a severe EMP or solar event would cost Trillions of dollars—several orders of magnitude greater in cost (not counting the emotional and social costs).** *Quotable quotes:*
  - "An ounce of prevention is worth a pound of cure."
  - "A Billion in prevention is worth a Trillion in cure."
  - "Prevention is the best medicine."

<u>11.</u> Recommendations [PART III: Proposed solutions, continued]

<u>11.(B)</u> Recommendations for citizens

- Have plenty of canned and non−perishable food & drink stored, manual can openers, water for bathing & flushing the toilet, as well as potable drinking water. Peanut butter is an especially good source of fats, proteins, and carbohydrates, and has a long shelf life. (Include Emergency First Aid Kits, prescription and over−the−counter meds, as needed, and also personal items like soap, shampoo, and plenty of toilet paper and/or wash cloths, if you run out of toilet paper—and spare clothing & underwear.)
- Have handy printouts (paper) of important names, addresses, phone numbers, and websites of key emergency contacts (friends, family, police, fire, hospital, electric power & phone companies, local news media phone numbers, to get the latest news, local emergency shelter, animal shelters, etc.), as well as hard copies of good personal, scientific, and religious reading materials (which can come in handy if computers and television grids go down). Also a map (paper printout) of your city—and surrounding cities—might be useful.
- Besides these key paperwork items, ID's, e.g. driver's license, photo ID's, Cash, Credit Cards, and several extra set of house, car, & storage building keys.
- Have printed and/or flash drive (thumbnail USB storage devises) of key paperwork (financial, insurance, & medical records, with deeds and titles to house, vehicles, etc.).
- Invest in several small magnifying glasses (which can be used to start a fire with the sunlight, as well as help you to read fine print if you're far−sighted)
- Have standby generators, backup batteries (preferably NiMH or Li−Ion rechargeable), and/or solar−powered chargers and power supplies. (This is especially needful for portable smart−phones, which need to be charged up periodically.) Portable fire extinguishers would also be useful here.
- Invest in EMP power line transient suppressors and voltage surge protection devices and/or filters;
- When storing your backup generators, leave extension cords UNPLUGGED, lest a solar or EMP event occur, and induce a large current in the lines, and "fry" your equipment. Same is true with radio and television and computer equipment: Don't put them in storage connected to power sources, antennas, etc. (Perhaps wrap "spare equipment" in several layers of aluminum foil, a "makeshift Faraday Cage," and place this in a metal garbage can, for extra−added 'Faraday' protection.)
- Make sure that stored equipment (batteries, gasoline, tools) has not rusted or gone bad.
- Invest in 1 or 2 cheap bicycles (which will come in handy should petroleum−based fuel becomes scarce), as well as a bicycle air pump, chain oil, etc.
- Invest in some FRS (Family Radio Service), GMRS (General Mobile Radio Service), CB (Citizen's Band), and/or Ham (Amateur) radios as an 'alternate' form of local communication, should the cellular phone grid go down. [NOTE: GMRS and Amateur radios require a license from the FCC to operate, whereas FRS and Citizen's Band don't, but during a state of emergency, that may not matter.]
- Invest in several solar−powered weather radios, which include AM, FM, NOAA Weather, and local television broadcast frequencies. (Portable televisions are optimal, but, lacking that, radios that receive audio of TV broadcasts are a good substitute.)
- Invest in several small LED flashlights. (LED's, light−emitting diodes, use far less current than 'regular' incandescent light bulbs, and produce much less heat.) Some flashlights have solar and/or "hand crank" chargers.
- Have handy emergency medical kits (in the event hospitals lose power and/or become over−crowded.)
- Maintain close ties with friends, neighbours, relatives, local government (police, fire, etc.), and church & community groups, as teamwork would become necessary in the face of adversity.

12. Ethics declarations:

I self−identify and lean noticeably to the "Conservative right" end of the political spectrum, and, like many of my peers and colleagues on my end, am leery of claims of climate change or other "environmental" issues, and, as such, may have a slight bias "against" making a full declaration of any potential environmental hazard; therefore, my research might accidentally (due to human error) underestimate any potential solar flare environmental threats. [Any bias, if it exists, is not intentional, as good science must be without bias, preconceived ideas, or other prejudices.] Furthermore, when I was young, I was a CB (citizens band) and ham (amateur) radio enthusiast, and currently hold an Amateur Extra license (the highest license that the FCC confers), with call letters "N2GY"**:**
https://wireless2.FCC.gov/UlsApp/UlsSearch/license.jsp?licKey=2702986
http://HamCall.net/call/N2GY
https://www.FccBulletin.com/callsign/?q=N2GY
http://www.InterceptRadio.com/ham.php?call=N2GY
https://www.RadioReference.com/apps/ham/callsign/N2GY
http://www.MyHamShack.com/CallsignDatabase/N2GY/Default.aspx

Therefore, I also have a "bias" for science and radio electronics, and particularly recall, in my youth, that high "solar activity" would interfere with local HF (high frequency) communications, but also "charge" the ionosphere, and help increase "skip wave" radio communications, in which 'regular' CB and Ham radios could communicate at far−greater distances during times of high solar "skip" activity. I am not sure what net effect (if any) such a bias to be fascinated with radio−electronic communications science might have on this present research (whether to exaggerate or diminish results), but I do declare this bias in my ethics statement to be whole, complete, and transparent.

I have not received any compensation (financial or otherwise) for my research, and declare no conflicts of interest in this regard. [But I am actively seeking and soliciting financing, should any donors be willing: Please contact me through my websites or social media: https://GordonWatts.com / https://gordonWAYNEwatts.com / https://YouTube.com/GordonWayneWatts / https://Facebook.com/GordonWayneWatts / or via email: Gww1210@gmail.com / Gww1210@AOL.com]

13. References (Literature cited), Acknowledgements, & Appendix

I cite all my **references** above, in Section 4, but don't list them alphanumerically, as that would require additional manpower. The references, though not alphabetised, are sufficient. **Acknowledgements:** I would like to acknowledge George Noory, the regular host of "Coast to Coast: AM" (Link: www.CoastToCoastAM.com) for having brought this matter to my attention: His overnight radio call−in program, which used to have the late Art Bell as a regular host, has regular guests of various (and opposing) topics, some related to science and health, and, in particular, Mr. Noory has taken it upon himself to lead in advocating Federal legislation to mandate a "Hardening of the Grid" of our communications, power, and military infrastructure, in order to protect against the inevitable solar flare event, or a possible EMP attack. I also acknowledge and thank my dear mother for putting up with me taking time off from my regular work to do this research. **APPENDIX of tables only, not of images or sections:** **Table 1:** List of solar storms**;** **Table 2:** Selected data from other published research**;** **Table 3:** Selected data comparing rate of geomagnetic field collapse with rate of "magnetic flip"**;** **Table 4:** Data used to graph (with trendlines aka "linear regression") changes in earth's magnetic field strength in recent millennia—as a function of time.

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About this article: **VERSION 2.0** – Not "Received" or "Accepted" as yet by any major peer-reviewed scientific organisation. This article has been reviewed and edited by the author, but by no one else. As such, it originally bore the designation as "Version 1.0." I've minor typo corrections and added one suggestion from a Conservative Republican friend, who suggested that I add "protect from cyber-attacks" to my proposed solutions. This revision is "Version 2.0." [I am not identifying my friend, as a professional courtesy, but I felt it's important to mention that he's a fellow-Conservative like myself, so that it's clear that there's plenty of support for this issue from both sides of the political isle, where we can agree on many things regarding protecting the environment.]

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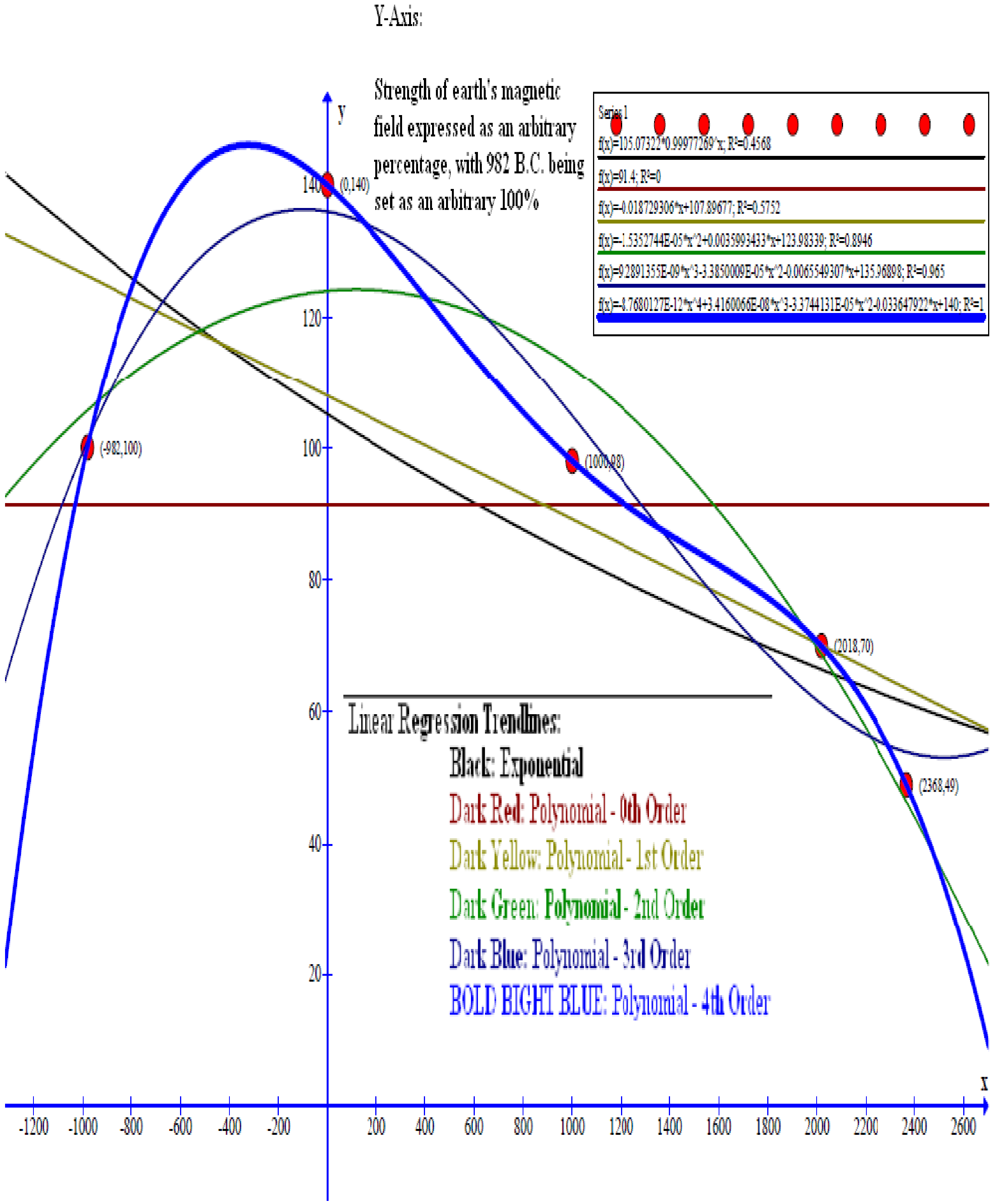
Subjects: Solar physics • Statistics • Environment • Radio Electronics • Public Safety • Politics • Law

Further reading: See my References section for further reading.

EDIT YOUR PAPER!!! **– Notes: Editing has been done, and has passed stage 1 of the edit process; Now, I shall aspire to submit this to peer-reviewed scientific organisations, lawmakers, and news outlets for proper review, press coverage, and legislative action. – Gordon Wayne Watts, author///**

Image 9. "Linear Regression" GRAPH of changes in the dipole strength of earth's protective geomagnetic field, as a function of time. DATA used for this graph are the five (5) data points taken from Table 4. of this paper, and using "49%" for the 5th and last data point, where a choice is given.



X-Axis: Time is expressed in years -- 1200 B.C. to A.D. 2600 is shown on graph

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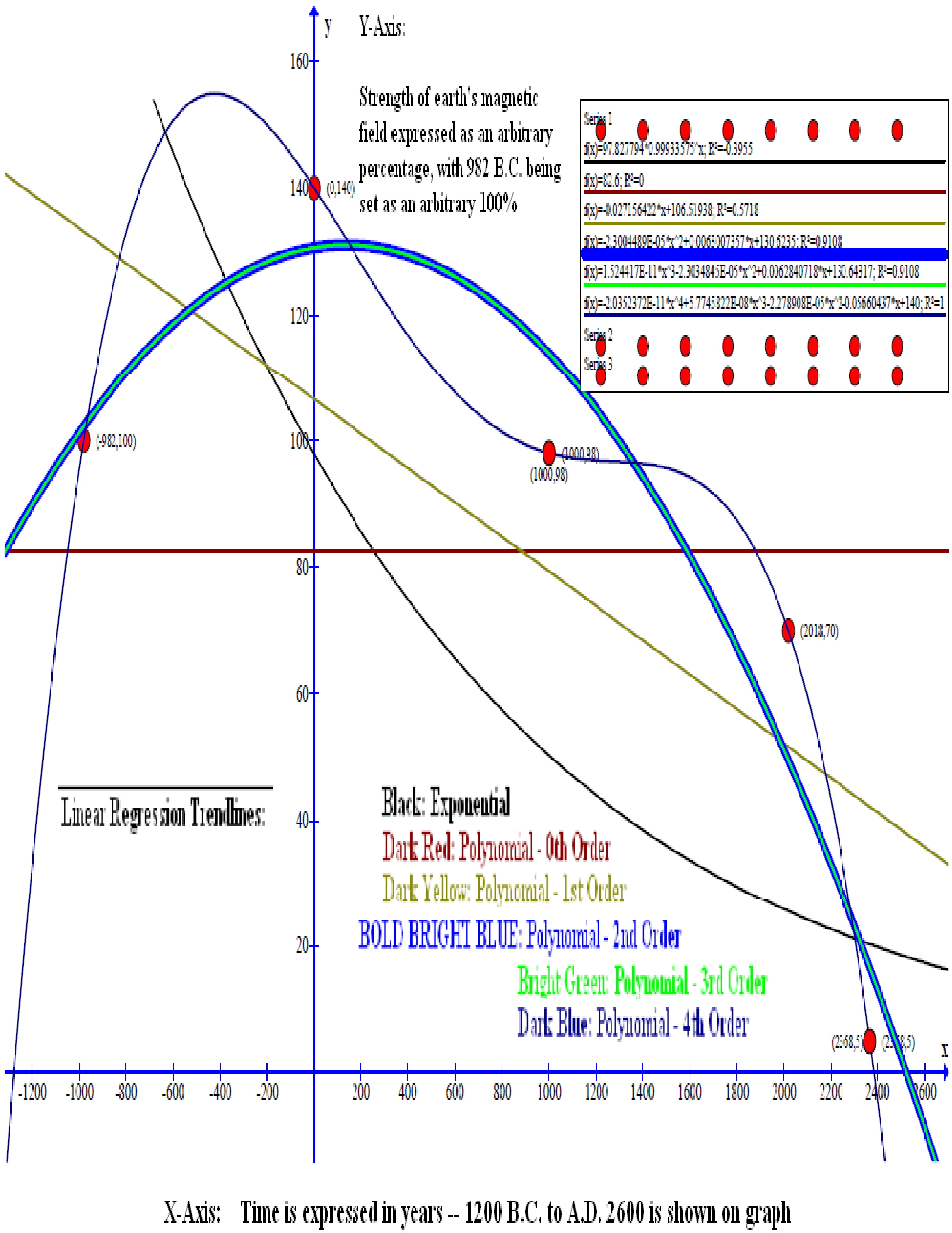


Image 10. "Linear Regression" GRAPH of changes in the dipole strength of earth's protective geomagnetic field, as a function of time. DATA used for this graph are the five (5) data points taken from Table 4. of this paper, and using "5%" for the 5th and last data point, where a choice is given.

Image 9. "Linear Regression" GRAPH of changes in the dipole strength of earth's protective geomagnetic field, as a function of time. DATA used for this graph are the five (5) data points taken from Table 4. of this paper, and using "49%" for the 5th and last data point, where a choice is given.

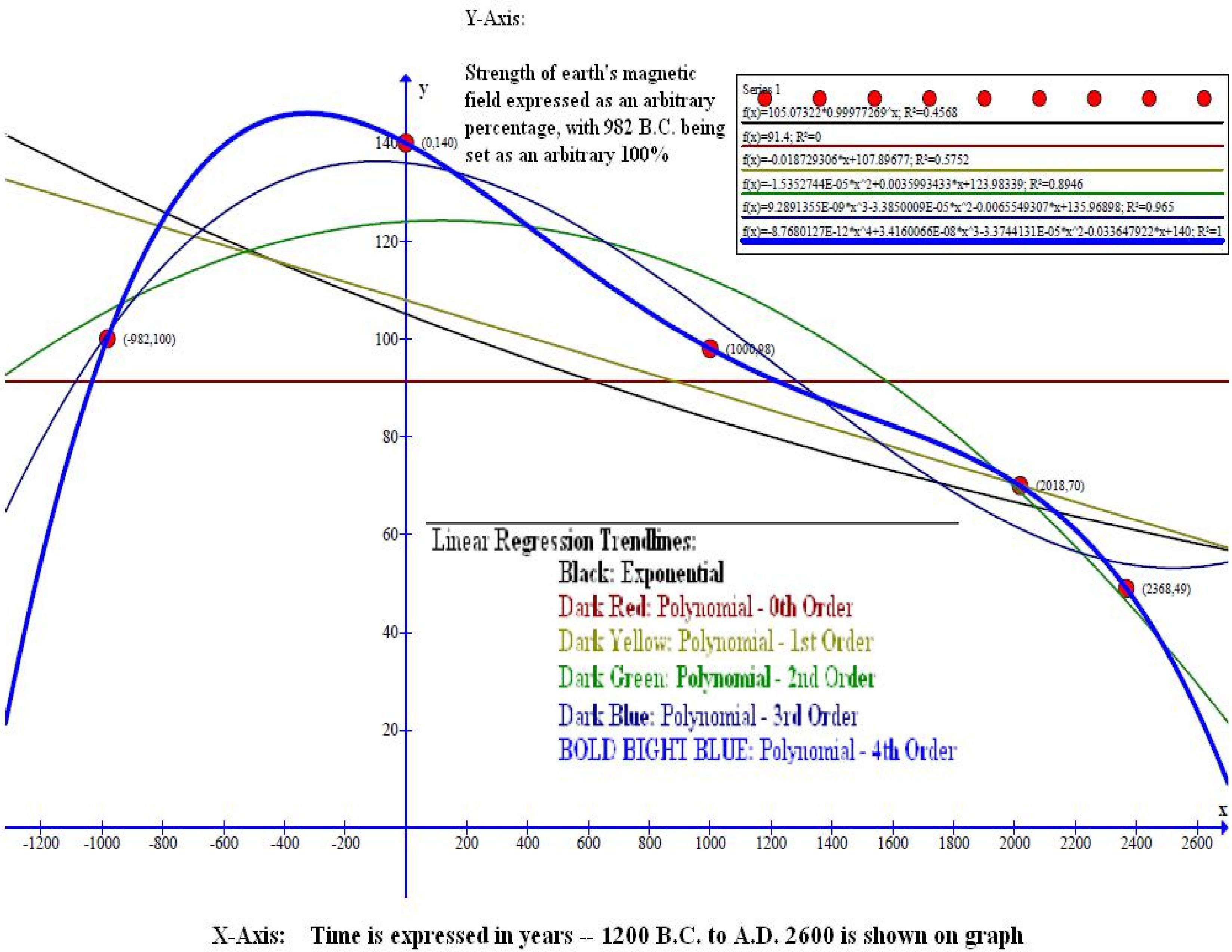


Image 9. "Linear Regression" GRAPH of changes in the dipole strength of earth's protective geomagnetic field, as a function of time. DATA used for this graph are the five (5) data points taken from Table 4. of this paper, and using "49%" for the 5th and last data point, where a choice is given.

Image 10. "Linear Regression" GRAPH of changes in the dipole strength of earth's protective geomagnetic field, as a function of time. DATA used for this graph are the five (5) data points taken from Table 4. of this paper, and using "5%" for the 5th and last data point, where a choice is given.

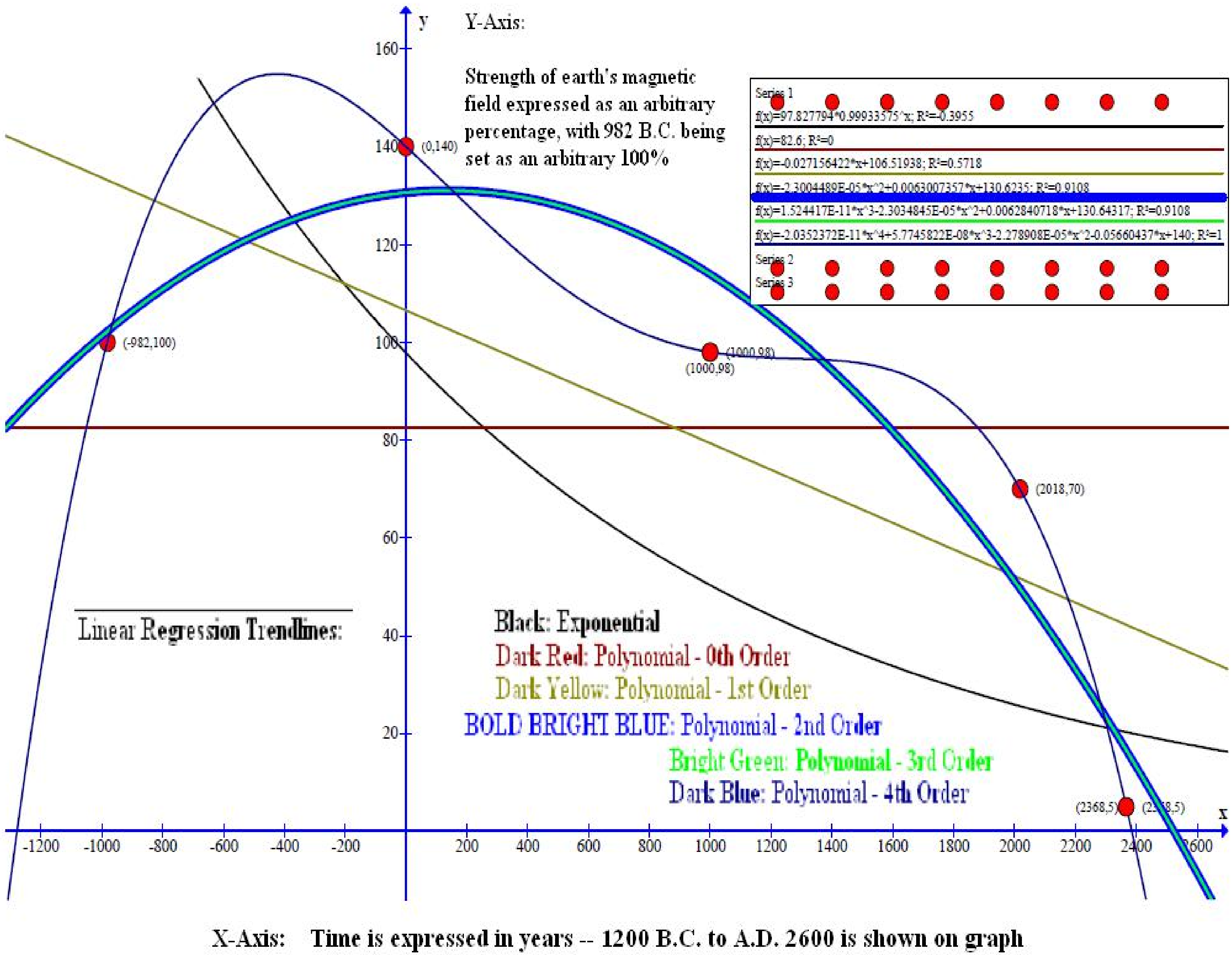
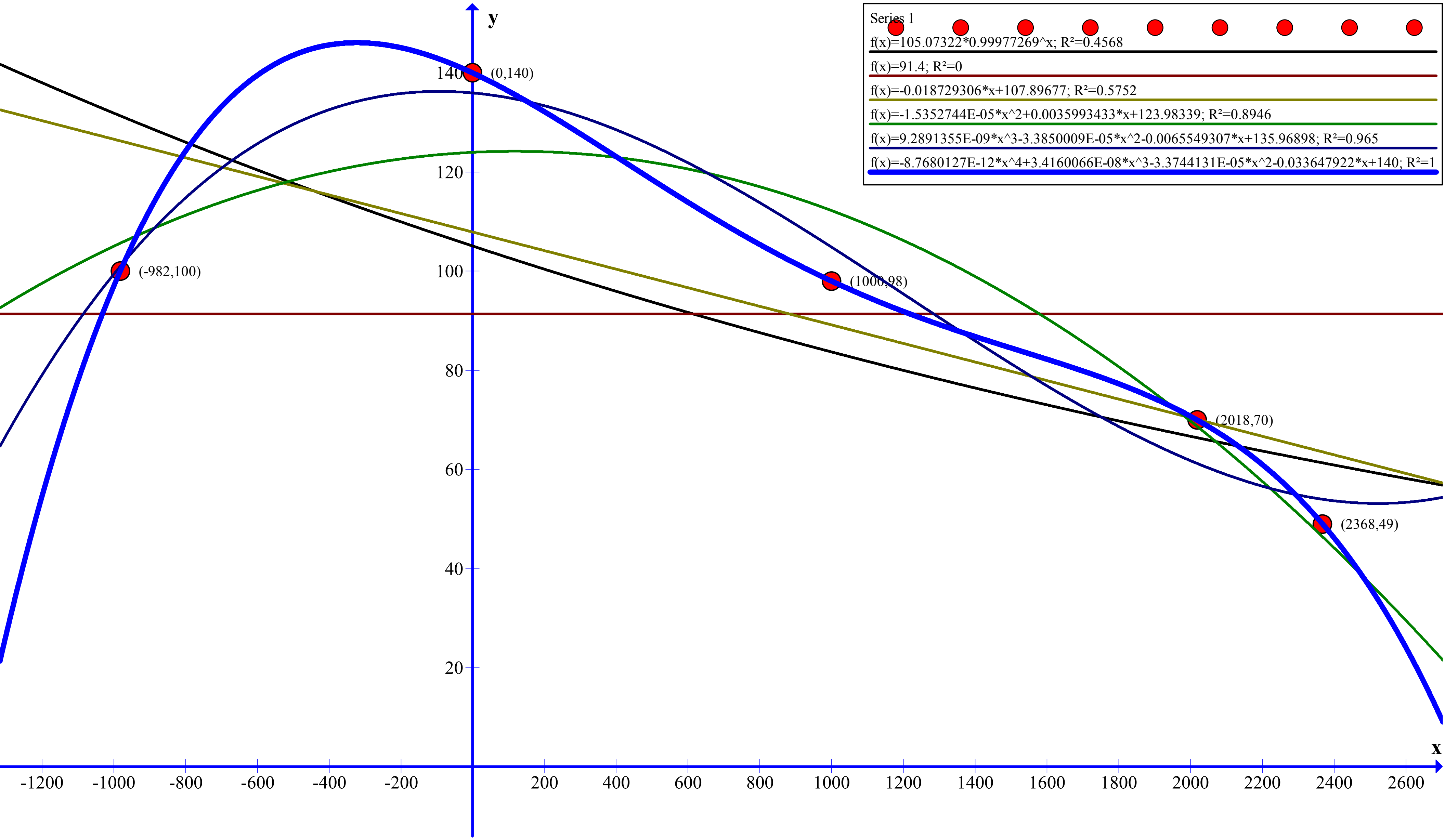
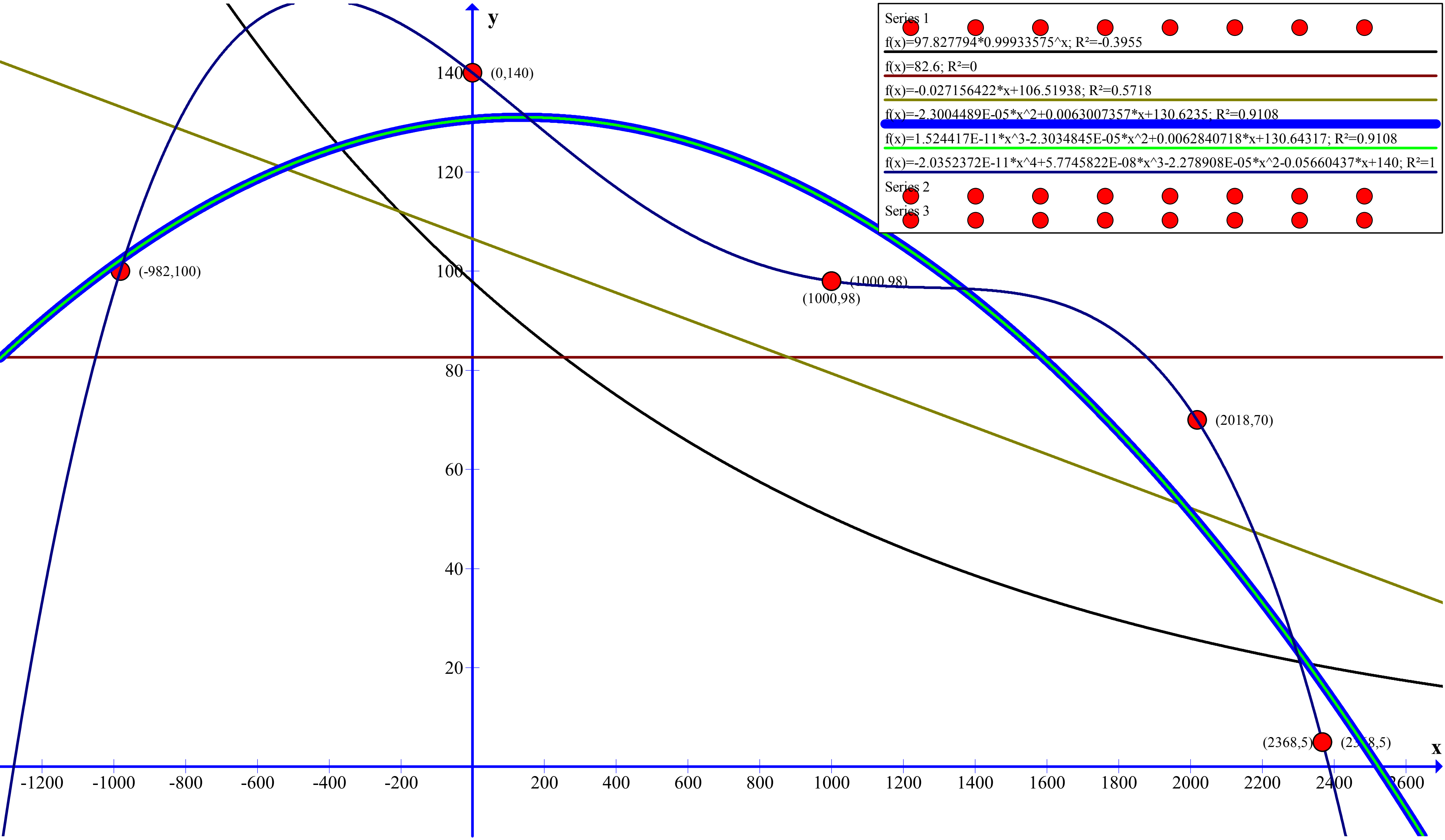


Image 10. "Linear Regression" GRAPH of changes in the dipole strength of earth's protective geomagnetic field, as a function of time. DATA used for this graph are the five (5) data points taken from Table 4. of this paper, and using "5%" for the 5th and last data point, where a choice is given.



y
x
Series 1
f(x)=105.07322*0.99977269^x; R²=0.4568
f(x)=91.4; R²=0
f(x)=-0.018729306*x+107.89677; R²=0.5752
f(x)=-1.5352744E-05*x^2+0.0035993433*x+123.98339; R²=0.8946
f(x)=9.2891355E-09*x^3-3.3850009E-05*x^2-0.0065549307*x+135.96898; R²=0.965
f(x)=-8.7680127E-12*x^4+3.4160066E-08*x^3-3.3744131E-05*x^2-0.033647922*x+140; R²=1
(0,140)
(-982,100)
(1000,98)
(2018,70)
(2368,49)
140
120
100
80
60
40
20
-1200
-1000
-800
-600
-400
-200
200
400
600
800
1000
1200
1400
1600
1800
2000
2200
2400
2600



y
x
Series 1
f(x)=97.827794*0.99933575^x; R^2=-0.3955
f(x)=82.6; R^2=0
f(x)=-0.027156422*x+106.51938; R^2=0.5718
f(x)=-2.3004489E-05*x^2+0.0063007357*x+130.6235; R^2=0.9108
f(x)=1.524417E-11*x^3-2.3034845E-05*x^2+0.0062840718*x+130.64317; R^2=0.9108
f(x)=-2.0352372E-11*x^4+5.7745822E-08*x^3-2.278908E-05*x^2-0.05660437*x+140; R^2=1
Series 2
Series 3
(0,140)
(-982,100)
(1000,98)
(2018,70)
(2368,5)
140
120
100
80
60
40
20
-1200
-1000
-800
-600
-400
-200
200
400
600
800
1000
1200
1400
1600
1800
2000
2200
2400