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The Impact of Space Weather on Social Dynamics: Homicide Trends in Canada and the USA

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Abstract

We contribute to academic discourse by examining the influence of solar-driven geomagnetic disturbances (GMD) on homicide rates in the USA and Canada. Despite the substantial discrepancy in homicide rates between the two countries, our analysis uncovers a remarkable synchronicity in homicide trends from 1990 to 2020, demonstrating an 89% correlation. This suggests a shared underlying factor influencing homicidal behavior on both sides of the border. Furthermore, our initial findings reveal a significant correlation between GMD and annual homicide rates in both nations, ranging from 57% to 65%. We present the results of rigorous econometric tests incorporating the Kp index for GMD, highlighting the potential link between GMD and homicides. We also propose a medical pathway to explore the role of the circadian regulatory system, which responds to environmental cues. Additionally, we suggest how our findings, which partially attribute responsibility for homicides to environmental factors, may impact a legal system founded on the premise of free will.

Keywords: Geomagnetic Disturbances; Homicide Trends

Abbreviations: GMD: Geomagnetic Disturbances; SCN: Suprachiasmatic Nucleus; ANS: Autonomic Nervous System; HPA: Hypothalamic-Pituitary-Adrena; SPDF: Space Physics Data Facility; OLS: Ordinary Least Squares.

Introduction

Homicide, a deeply ingrained and morally reprehensible act throughout history, continues to loom large over contemporary society. In the USA, the surge in gun-related homicides has reached alarming proportions, prompting calls for urgent action to address it as "a national emergency that requires urgent public health interventions at the local and national levels" [1]. Even in Canada, where homicide rates are substantially lower, there remains a need for "ongoing surveillance and policy evaluation related to public health interventions" [2]. It's concerning to note that only about half of yearly homicides in the USA are resolved, leaving approximately 13 thousand victims without justice. While in Canada, although the share of resolved homicides is higher at 80%, it shows a declining trend [3].

However, the pervasive fascination with the mysterious aspects of homicide often obscures its epidemic proportions, diverting attention from the urgent need to address its underlying causes, which can no longer be solely attributed to societal factors. While factors such as easy access to firearms, substance abuse, socioeconomic disparities, and demographic composition contribute to explaining homicide rates, the synchronous occurrence of these acts across the USA-Canada border, despite differing societal contexts, suggests the presence of additional underlying forces beyond conventional societal influences. We proceed to analyze the characteristics of homicide rates in Canada and the USA, uncovering their synchronicity and proposing geomagnetic disturbances (GMD) as an external driver of the near-simultaneous fluctuations in these rates. We then delve into the cyclical nature of GMDs and offer an interpretation of how a cyclical approach aids in understanding the medical pathway through which GMDs translate into aggressive behavior. Subsequently, we detail the data utilized, the econometric model employed, and its results. This is followed by a discussion, including considerations on the adequacy of a judicial system grounded in notions of free will when sentencing individuals for crimes for which they may not bear full responsibility.

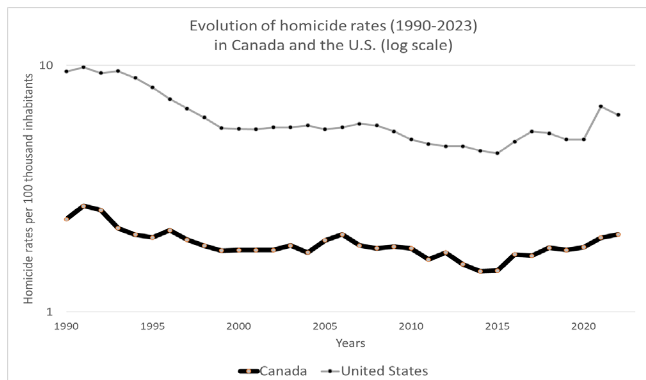
Homicide Rates in Canada and the USA

The glaring disparity in homicide rates between Canada and the USA is evident. The USA consistently reports markedly higher homicide rates, often exceeding those in Canada by at least threefold, despite exhibiting similar temporal trends in homicide rates over time. This discrepancy hints at a deeper-rooted culture of violence within the USA, fostering a heightened propensity for violent resolutions to interpersonal conflicts [4]. The prevalence of violence in the USA is further accentuated by the increased likelihood of law enforcement officers resorting to lethal force in addressing criminal activity (Parent, 1992) [5]. While this inclination may partly stem from higher instances of racial discrimination, as suggested by Hagan J [6], it's crucial to consider regional, situational, and circumstantial differences alongside structural factors to comprehend the complexities of violence [7].

A nuanced examination of US homicides spanning seven decades challenges the conventional belief that age structure is the primary explanatory factor. Nunley JN, et al. [8] argue that variations in the misery index, reflecting factors such as inflation and unemployment, also significantly influence fluctuations in murder rates, underscoring the multifaceted nature of homicidal behaviors. Despite differences in homicide rates, both the USA and Canada, along with numerous other Western democracies, witnessed substantial declines in homicide rates during the 1990-2000 decade [9]. This convergence suggests that factors beyond the declining share of young cohorts contribute to this trend. Mishra S, et al. [10] observe that both Canada and the U.S. experienced decreases in various risky behaviors with health implications. Efforts to explain the higher murder rates in the USA often revolve around the easier access to guns compared to Canada. However, Centerwall BS [11] contends that when examining gun ownership across adjacent US states and Canadian provinces, no consistent pattern emerges regarding homicides. Despite significantly greater private gun ownership in American states, homicide rates do not consistently correlate with gun ownership levels in neighboring Canadian provinces.

Preliminary Investigation

Graph 1 depicts the homicide rates in the USA and Canada across three solar cycles. Despite the structural factors contributing to significant differences in yearly homicide rates between the two countries, the graph suggests the presence of another influential factor driving fluctuations in homicide rates. Remarkably, these rates exhibit near-simultaneous ups and downs in both countries, as evidenced by a Pearson correlation coefficient of 0.89 (with a p-value <0.001). Please refer to Table 1 for detailed data.



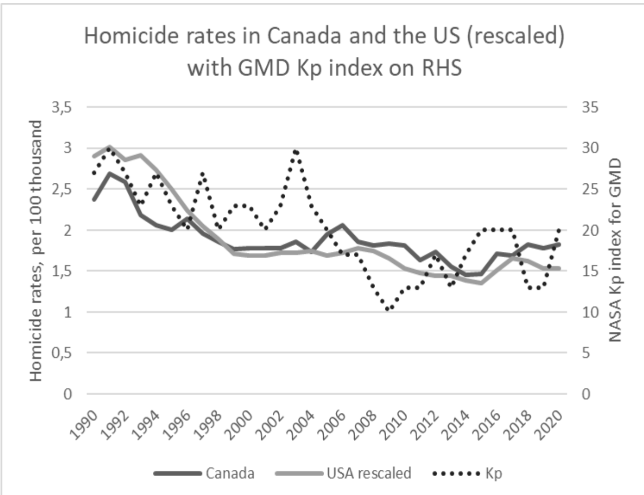
Graph 1: Evolution of Homicides rates (1990-2023) in Canada and the US (log scale).

Variable		Canada
USA	n	32
	Pearson's r	0.893
	p-value	< .001
	Spearman's rho	0.854
	p-value	< .001
	Kendali's Tau B	0.705
	p-value	< .001

Table 1: Homicide rates in Canada and the USA.

What could be the Underlying Synchronizing Factor?

Evidence points to solar-driven GMD as a potential common driver behind these trends, as illustrated in Graph 2. This graph demonstrates the correlation between fluctuations in homicide rates in both countries and the solar-driven GMD Kp index.



Graph 2: Homicide rates in Canada and the US (rescaled) with GMD Kp index on RHS.

Could Geomagnetic Disturbances Induce Homicides?

The coexistence of humanity with the Sun over millions of years hints at a complex interplay between variations in solar activity and biological responses to geomagnetic fluctuations. Nevertheless, it's plausible that certain individuals might be more vulnerable to these disturbances due to factors like age, location, or gender. While the impact of geomagnetic disturbances on cardiovascular health is well-documented, their potential association with homicide remains largely unexplored within the medical community. Unfortunately, there is a dearth of research on the influence of solar-driven geomagnetic disturbances on human behavior. To address this critical gap in scholarly discourse, we recently embarked on a ground breaking investigation, suggesting that solar storms may indeed exert a noticeable influence on homicide rates across the Atlantic [12]. Our empirical findings paint a compelling picture of a shared force shaping homicidal patterns across vast geographical, economic, and cultural divides, potentially linked to solar-driven GMD. This hypothesis resonates with the seminal work of Ertel S [13], who proposed that creativity cycles in China and Europe over four centuries may have been influenced by solar cycles. Similarly, Mikulecky M [14] provided support for Chijevsky's (1971) hypothesis, suggesting a correlation between solar maxima and epidemics, as well as what he termed as societal excitations, encompassing phenomena ranging from riots to wars.

What are Solar-driven Geomagnetic Disturbances?

Solar-driven GMDs on Earth are manifestations of the Sun's dynamic behavior that occur cyclically, notably during the Schwabe cycle, which spans approximately 11 years [15]. These disturbances, instigated by solar flares and coronal mass ejections, manifest as disruptions in Earth's magnetic field and are commonly known as solar-driven GMDs. The Schwabe cycle, characterized by fluctuations in the number of sunspots over the aforementioned period, plays a pivotal role in shaping solar activity as experienced from Earth. These sunspots, discernible as darker areas on the Sun's surface, signify regions of intense gravitational disturbances within the solar structure, often leading to eruptions of ionized plasma. Depending on the Sun's rotation, these eruptions may be directed towards Earth, impacting Earth's magnetic field, and resulting in what we perceive as solar-driven geomagnetic disturbances, which are stronger at higher latitudes. These disturbances, varying in magnitude, consistently induce disruptions in Earth's magnetic field. GMDs are more frequent and intense at the peak and descending numbers of sunspots in a solar cycle. However, the presence of sunspots in the solar cycle serves as an indicator of future geomagnetic disturbances on Earth, which can induce aggressive behavior, potentially leading to homicide, as our work intends to reveal.

From GMD to Aggressive Behavior

To explain homicidal cycles, we will first turn to why the cycles approach is a revealing one, then we will turn on to the cyclical looped physiological pathway that might translate GMD into aggression.

Interpreting Cycles through Cycles

Rates of homicides have increased and decreased in cycles that the analysis of the immediate environment has not been able to predict [16-19]. Yet it is interesting that the difficulty has rekindled a methodological approach: interpreting cyclical phenomenon through other cycles. The effort to approximate cycles using other cycles can be traced back to ancient times, with early civilizations observing recurring patterns in nature and attempting to understand and predict them. For instance, the Babylonians and ancient Egyptians developed calendars based on celestial cycles, such as the lunar and solar cycles, to track time and seasons for agricultural and religious purposes. Similarly, ancient Chinese astronomers studied the movements of celestial bodies to develop calendars and predict celestial events.

In more recent history, the study of cycles and attempts to approximate them using mathematical models and statistical methods gained momentum during the scientific revolution in the 17th century. Scholars like Isaac Newton and Johannes Kepler made significant contributions to understanding celestial mechanics and the periodic motions of planets, which laid the groundwork for modern theories of cyclic phenomena. In the field of economics, the study of business cycles became prominent in the late 19th and early 20th centuries. Clément Juglar was the first to analyse business cycles systematically. His work preceded that of both Stanley Jevons and Joseph Schumpeter. Juglar, a French economist, identified what became known as "Juglar cycles" in the mid-19th century. These cycles, characterized by periodic fluctuations in economic activity, typically lasting around 7 to 11 years, gained recognition as an important aspect of economic dynamics. Juglar saw the cycles as being fuelled by credit, while Jospeh Schumpeter approached them as the result of technological progress.

William Stanley Jevons was an English economist, whose work did not specifically focus on business cycles to the extent that Juglar's did. Yet Jevons was the first to associate trade cycles to extraterrestrial phenomena: sunspots, which, incidentally, have a cycle of Juglar-like duration, as if the Jevons and Juglar cycles were powered by the same forces. Jevons' contribution was received with contempt, unfairly so, because what Jevons brought to light was the role of "moods", picked-up by Keynes, and considered an early interpretation of the role expectations, which is now currently accepted in Economics, particularly since Milton Freedman and Franco Modigliani [20,21]. Nonetheless, the idea that sunspots may have an impact in economics has made in inroad in the last few decades [22-24]. To some extent this is a vindication of Jevons' insight, originally spelled out as a reflection of sunspots on weather and impacting on harvests and income. That it had fallen out of grace was mostly because agriculture's high share of GDP during Jevons' time has declined substantially over the last century. Yet the relative decline of agriculture does not mean that the impact of the Sun's radiation has ceased to have an impact on life, or on business moods, and Jevons' stance is making a come-back at the time of concern with climate warming.

Yet, if economic behavior can be the sunspots' reflection of moods and behavior influenced, by the cycle of the Sun and the seasons, it was only natural to focus on homicidal cycles as reflecting cycles of geomagnetic disturbances. We propose that the stressor effects of solar activity may activate and adjust human behavior in situations when the structural and circumstantial conditions predispose to aggressive responses, such as homicides. The issue at stake is how to translate GMDs into aggressive behavior, which we now turn to.

From GMD Cycles to Homicide Cycles

We first propose that humanity, akin to many other species in the animal kingdom, may have retained some sensitivity to the Earth's magnetic field [25]. This sensitivity could potentially catalyse hormonal reactions leading to aggression and, in extreme cases, homicide. Given humanity's historical nomadic lifestyle, it's plausible that we have maintained some ability to navigate using magnetic receptors, albeit with a sensitivity to fluctuations in the Earth's magnetic field [25]. Research suggests that, akin to birds, the human eye's responsiveness to light may also be influenced by variations in the Earth's magnetic field [26]. However, we now understand that the Earth's geomagnetic field can experience temporary disruptions due to space storms originating from the Sun. The foundation of heliobiology as a scientific discipline, including its objectives, challenges, and methodologies, was laid a century ago by the pioneering works of [27,28]. Tchizhevsky AL [29] expanded his scope to elucidate rhythms of social unrest. More recently, there has been a resurgence in interest, akin to these Russian perspectives, in the impact of geomagnetic disturbances (GMDs) on social phenomena such as the onset of wars, revolutions, or economic recessions [30].

As scientists delve into the effects of cyclical GMDs on humans, research emphasis naturally gravitates towards quantifiable and cyclical issues, particularly those characterized by rhythmic patterns, including disruptions in circadian rhythms known to influence suicidal ideation [31] and circulatory functions [32,33]. Consequently, numerous studies have explored the effects of geomagnetic storms on circulatory functions, such as irregularities in heart rate [34] and concerns related to cardiovascular health [35], extending even to mortality [36,33]. Research has indicated that GMDs, leading to magnetic field pulsations close to the heartbeat frequency, may have significantly contributed to abnormally high myocardial infarction rates in Russia and Bulgaria [37]. Additionally, geomagnetic storms may have induced an unusually high admission rate to British hospitals due to depression [38] and schizophrenia cases resulting from births during periods of high geomagnetic disturbances [39]. While most studies are conducted in high latitudes, where the impact of geomagnetic storms is highest, evidence in Central America also suggests associations between geomagnetic storms and myocardial infarctions [40].

At this stage of understanding GMDs, one should not be searching for a trigger but rather for a catalyzing role [27]. However, in the realm of homicides, conventional explanations have fallen short, and geomagnetic disturbances have thus far been overlooked. Merely assessing the number of sunspots is insufficient to establish the relationship. There is a need for evidence regarding the timing, intensity, and fluctuation of geomagnetic disturbances in proximity to the research subject and to suggest why human physiology may be responsive to these GMD fluctuations. Tchizhevsky AL [29] subsequently expanded his outlook to explain rhythms of social unrest. Of recent, closer to these Russian viewpoints, GMDs impact was focused on social events, like the onset or wars or revolutions or economic recessions, which is now gaining renewed traction [30]. Geomagnetic storms may have also induced an abnormally high admission rate to British hospitals due to depression [38] and schizophrenia cases resulting from births at times of high geomagnetic disturbances [39]. While most studies are carried out in high latitudes, where the impact of geomagnetic storms are highest, there is also evidence in Central America of myocardial infarctions associated with geomagnetic storms [40].

Nevertheless, with regards to homicides, conventional explanations have fallen short, and geomagnetic disturbances have been present, but so far ignored. The number of sunspots is no longer enough to prove the relationship. One needs evidence of the time, intensity, and fluctuation of geomagnetic disturbances close to the research subject and one also needs to suggest evidence on why human physiology may be responsive to those GMD fluctuations.

Why the Circadian Cycle?

A substantial body of literature highlights the connections between space weather and societal upheavals. The circadian rhythm hypothesis emerges as a convenient avenue of exploration due to its cyclical nature, responsiveness to GMDs, and its role as a zeitgeber (temporal synchronizer) for other physiological processes. Research in this domain often centers on tangible outcomes, such as instances of violence [41], and in extreme cases, homicide [12], or suicide. Of particular interest is the impact of magnetic fields on the circadian regulatory system, as proposed by psychiatrist Kelly Posner [42]. This suggests a potential mechanism through which GMDs may influence behavioral patterns.

The Melatonin Pathway

Our research has evolved from investigating the impact of GMDs on moods and behavior to exploring the connection between geomagnetic storms and aggressive behavior mediated by the melatonin pathway, which is intricately linked to circadian rhythms [31,36,43,44]. The pivotal role of the melatonin pathway in circadian dynamics is emphasized by its involvement in the metabolism of melatonin, with the pineal gland emerging as a crucial player in seasonal variations of aggression [45,46]. Seasonal fluctuations in extreme solar storm activity align with the physiological rhythms of the pineal gland, suggesting a potential interplay between geomagnetic disturbances and endocrine function [36,47-49].

Individuals with mood and anxiety disorders often exhibit significant disturbances in sleep and circadian rhythms, highlighting the involvement of the hypothalamus, thalamus, amygdala, and autonomic nervous system-the limbic center-in regulating emotions and behavior in the brain [50]. The "fight-or-flight" response, triggered by the sympathetic and parasympathetic nervous systems, initiates a set of physical and physiological stress reactions. Arousal serves as the catalyst for activating this defensive response, with modulation of the limbic system-a neural network comprising the sympathetic nervous system, amygdala, hypothalamus, and vagal nuclei-across all defense reactions [50]. Due to its role as the "central pacemaker," an imbalance in the suprachiasmatic nucleus (SCN) of the hypothalamus can profoundly affect the autonomic nervous system (ANS), leading to heightened anxiety-like behaviors that manifest as irritability and anger rhythms [51].

The hypothalamic-pituitary-adrenal (HPA) axis plays a pivotal role in modulating the fight-or-flight stress response through its neuroendocrine output [52]. This mechanism is supported by extensive research conducted across various animal species. Hormone cycles are intricately regulated by both the circadian and autonomic systems, with each system interconnected and capable of influencing the emotional state and potential behavioral outcomes of an agonistic interaction.

How GMD Translates into Aggressive Behavior?

Todd et al. (2018) [53] elucidated the intricate mechanism through which the central circadian system regulates aggressive behavior rhythms. Neurons within the suprachiasmatic nucleus (SCN) modulate the "attack circuit" located in the ventromedial hypothalamus and dorsomedial hypothalamus, thereby influencing the propensity for aggressive behavior. Furthermore, a known pathway from the SCN to the dorsomedial nucleus of the hypothalamus (DMH) via the SPZ governs various circadian rhythms, including sleep-wake cycles, locomotor activity, and eating behavior [54]. The dorsomedial hypothalamus also regulates the fight-or-flight response within the autonomic nervous system [50].

Individual differences in ANS functioning, particularly nonreciprocal activation of the sympathetic (SNS) and parasympathetic (PNS) nervous systems, heighten the susceptibility to aggressive behavior, especially in response to adversity, potentially even during prenatal development [55]. Symptoms associated with sympathetic nervous system activation, such as increased heart rate and skin conductance levels, have been linked to partner violence [56]. Moreover, studies have demonstrated how electromagnetic radiation and potential geomagnetic disturbances stimulate SCN activation, leading to elevated levels of intercellular calcium (Ca2+) [57]. This cascade of events influences various physiological functions, including hormone secretion, enzyme activity, neurotransmitter release, calciumdependent gene transcription, and spontaneous pacemaker activity in neurons and muscle cells. Dysfunction in these Ca^{2+} pathways has been implicated in psychiatric disorders such as schizophrenia and bipolar disorder [50].

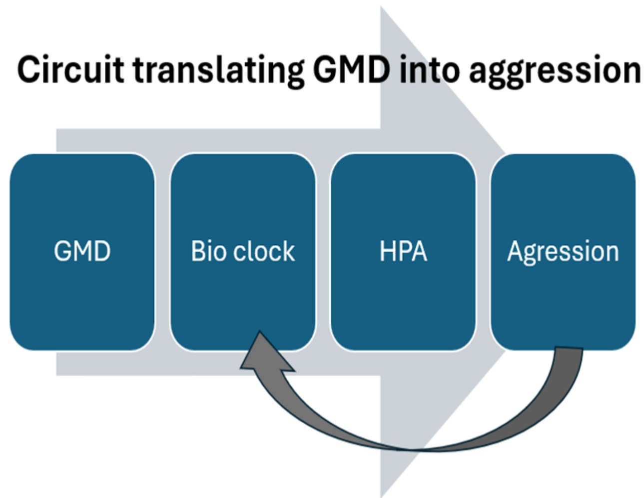


Figure 1: Feedback loop of circuit translating GMD into Agression.

Moreover, the disruption of the 24-hour circadian rhythm within the SCN, altered by solar radiation and other forms of electromagnetic radiation exposure, significantly impacts the release of diurnal and nocturnal hormones such as cortisol and melatonin. Melatonin, a potent nocturnal antioxidant hormone primarily synthesized by the pineal gland, is intricately tied to the circadian rhythm. The oscillator responsible for generating the melatonin rhythm resides within the SCN, which regulates the nocturnal secretion of melatonin by the pineal gland. Additionally, the pineal gland modulates the release of serotonin during the day and melatonin during the night. Serotonin, a precursor of melatonin, and its metabolism are highly sensitive to light exposures [58]. Melatonin levels have been utilized as a marker for mood disorders, given their significant oscillations in individuals with depression, bipolar disorder, and seasonal affective disorder [59]. Furthermore, serotonin plays a crucial role in inhibiting and regulating emotions and social functioning, with low serotonin levels associated with impulsivity, violent behavior, and aggression [60]. When retinal cells in the eyes absorb external electromagnetic radiation, serotonin-mediated photoactivation occurs in other mood centers of the brain, such as the amygdala and habenula. The amygdala, being the brain's fear circuit, is particularly influenced by serotonin, and its dysregulation is implicated in various mental illnesses in humans [61,62]. Studies indicate that electromagnetic radiation exposures, including sunlight and periods of severe GMDs influence melatonin and serotonin secretion by suppressing pineal gland and SCN stimulation, thus affecting melatonin secretion [63].

During daylight hours, the SCN regulates the adrenal gland's secretion of the steroid hormone cortisol, a crucial element associated with severe trait-like fear-related behaviors such as aggression and depression in both animals and humans. Aberrant function of the limbic system and cortisol levels are linked to pathological forms of aggressive behavior [64]. Beyond disruptions to the circadian rhythm, stressful events, such as frustration, enhance brain circuit activity governing aggression, suggesting a bidirectional association between circadian rhythm disruption and mood disorders and mental health [50,64]. Solar activity stimulates physiological reactions associated with the fight or flight response, heightening responses to perceived threats and inducing emotions such as anxiety, fear, rage, and violence. These responses may exacerbate pre-existing behavioral and emotional ecologies. In the social sciences, emotions are understood as fundamental phenomena influenced by and shaping power processes in social, political, and economic life [65-67]. Emotions are relational and embodied [68,69] influenced by and shaping power processes in social, political, and economic life [50,66,67].

These emotions, connected with fight or flight responses, in structural situations involving social discrimination, injustice, substance abuse, or gun ownership, the additional physiological and behavioral pressures of solar activity may intensify transient triggers, contributing to the initiation of homicidal intent. Solar activity could metaphorically be seen as 'energizing' the act of homicide rather than directly causing it. The amplification of physiological responses around the peaks of solar maximum may lead to a more widespread experience of discomfort, anger, and other states associated with chronic nervous system activation, exacerbating pre-existing conditions. This notion is supported by Babayev ES, et al. [70], who demonstrated that severe geomagnetic disturbances raised an unpleasant emotional background. May establish a feedback loop with existing emotional ecologies created by social and political instability, or these sensations may be attributed to such instabilities, resulting in feedback loops. In essence, while previous research in this domain has predominantly focused on tangible health outcomes, recent awareness suggests a complex connection between geomagnetic events, endocrine regulation, and behavioral patterns, prompting additional multidisciplinary exploration to elucidate cycles in homicide rates. We propose that solar activity-related radiation can act as a behavioral stressor mediated by the physiological pathway through the dysregulation of the 24-hour circadian rhythm.

Data

Solar-driven GMDs typically last from hours to several days, posing a challenge to assessing their impact on human behavior. Due to the transient nature of GMDs, a comprehensive understanding of their influence necessitates daily data on homicides. However, the availability of such granular data is limited, with public datasets typically offering only yearly statistics for relatively brief periods. Despite these constraints, it's plausible that frequent or significant geomagnetic disturbances could indeed leave observable imprints on human behavior, including homicide rates, which are often analyzed through yearly statistical approaches. Our previous investigations into the correlation between solar-driven geomagnetic disturbances and homicides lend credence to this premise. Building upon this foundation, this study aims to deepen our comprehension of the link between yearly geomagnetic disturbances and homicide rates by comparing data from countries situated along similar longitudes, thus subjected to comparable solar storm exposure. A comparative examination of homicide rates between the USA and Canada offers a promising avenue for elucidating the immediate impacts of geomagnetic disturbances on violent behaviors, serving as a proxy for broader human behavioral patterns. Despite the constraints posed by data availability, the hypothesis that frequent or intense disturbances leave discernible traces in yearly statistical analyses remains compelling. Our prior research findings bolster this assertion, emphasizing the need for further exploration into this intriguing relationship. Our overarching purpose is to elicit the influence of solar activity on human behavior. Behavior is what someone does, especially towards others. Agressive behavior involves a broad range of behaviour and may involve subjetive appreciations on the nature or intention of the behaviour.

For our research, it was imperative to focus on behaviors that are readily observable and quantifiable, much like the incidence of homicides. Unlike assaults, which can vary in severity and may not always result in fatality, homicides offer a clear and objective measure. Essentially, a homicide involves a deceased individual, a fact promptly documented by law enforcement upon discovery. Our interest lies in the manifestation of aggressive behavior, rather than the legal nuances of murder, making homicide rates an ideal proxy for aggression due to the availability of reliable, internationally comparable data over the long term. While homicide cases are recorded daily, publicly accessible data typically present rates per 100,000 inhabitants on a yearly basis, with records spanning relatively shorter durations compared to those for Solar Activity. Given the cyclic nature of Solar Activity, which occurs in approximately eleven-year periods, our analysis necessitated long-term homicide records adjusted for population size, predominantly available on a yearly basis. Thus, our dataset encompasses nearly three complete solar cycles. Although Rogers ML, et al. [71] advocate for using the World Health Organization database for international homicide data comparisons, our focus remained on the USA and Canada, where reliable and sufficiently comparable homicide data are available. Homicide rates for both countries from 1990 to 2022 per 100,000 inhabitants were sourced from Macrotrends, supplemented by FBI data for the missing 2022 figure for the US obtained from Statista.

Solar activity, measured consistently at three-hour intervals since Matzka J, et al. [72] served as another crucial component of our analysis. Data on Solar Activity, specifically the Kp index for the magnitude of solar-driven geomagnetic disturbances from 1985 to 2022, were accessed from the Space Physics Data Facility (SPDF) of the US government at https://omniweb.gsfc.nasa.gov/html/ow_data.html. This allowed us to explore the potential impact of antecedent solar-driven geomagnetic disturbances on available homicide rates.

Econometric Model

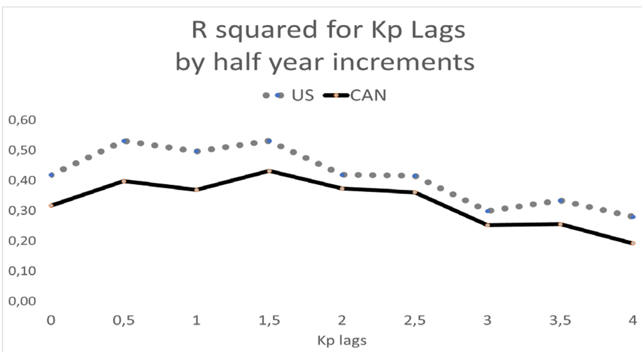
$$H_{it}=a_i+b_i*Kp_{t-n}+e_{it},$$

Where,

- H_{it} is the homicide rate for country i at time t;
- Kp_{t-n} is the Kp index at time t-n, where n is the time lag; half lags were estimated as the average of two adjacent years;
- a_i is the intercept for country i; and
- b_i is the Kp coefficient.

Results

During the period from 1990 to 2022, we observed a correlation between same-year homicide rates and the Kp index of 57% in Canada and 65% in the USA. This finding strongly suggests that despite the transient nature of GMDs, homicide rates in both countries may exhibit responsiveness to fluctuations in geomagnetic activity within the same year. To delve deeper into this relationship, we conducted Ordinary Least Squares (OLS) regressions using half-year lagged Kp data. This approach aimed to mitigate potential data imprecision. Our analysis revealed that the best fits in both countries were achieved with 1.5 lags in Kp. Moreover, we observed a decline in the fit for subsequent lags. For a visual representation of these findings, refer to Graph 3.



Graph 3: R squared for Kp Lags by half year increments.

For the chosen 1.5 year lags the summary of the regression results and in Table 2.

	Canada	U.S.
Kp lags for best fit	1.5	1.5
Kp coefficient	0.43165	0.53113
Intercept	1.17134	1.45092
R squared	0.41332	0.53113
F - statistic	23.54427	35.11591
Sample size	33	33
Note: All statistics with p-value < 0.001		

Table 2: Regression of homicide ratios over GMD as measured by Kp index.

Discussion

Given the high correlation observed in the evolution of homicide rates in Canada and the USA over three solar cycles, we embarked on an investigation into the potential impact of solar-driven geomagnetic disturbances (GMDs) on homicide rates in both countries. Approximately two-thirds of the populations of Canada and the USA reside within 100 miles of their shared border. This geographical proximity implies that while GMDs tend to be stronger at higher latitudes, the majority of the population of both countries is exposed to similar intensities of these disturbances. Additionally, despite Alaska being considerably farther north, its lower homicide rates do not significantly distort our analysis [73].

Although solar-driven geomagnetic disturbances typically dissipate within days, our methodology, based on yearly data, entailed comparing homicide rates between neighboring countries situated on comparable longitudes, thereby simultaneously exposed to similar solar storms. Our regression analysis revealed significantly positive coefficients for lagged Kp values, indicating responsiveness to lags. Notably, we obtained high R-squared regression results with robust significances for the highest 1.5 Kp lags in both countries. We hypothesize that conducting similar regressions on monthly data could yield even more robust results. However, access to such data hinges upon a growing interest in studies like ours, potentially prompting police authorities to provide daily or monthly data for extended periods.

Conclusion

Yearly homicide rates in both Canada and the USA during 1990-2022 are markedly influenced by GMDs with a correlation short of 90%. While existing research underscores the role of structural social factors in homicides, explaining why the homicide rates in the USA are approximately three times higher than those in Canada, our work reveals that GMDs also contribute to the incidence of homicides on both sides of the border, alongside these social considerations. Indeed, social issues create environments conducive to violent behaviors. Although GMDs are not directly responsible for homicides, they play a significant role in catalyzing aggressive behaviors, particularly in regions already burdened by active stressors. Despite the inevitability of GMDs occurrences and the lack of early warning systems, our research also highlights a physiological pathway through which GMDs may induce aggressive behaviors. Consequently, our findings pave the way for therapeutic interventions aimed at mitigating the influence of GMDs on individuals vulnerable to their energizing effects, potentially preventing the enactment of homicidal intentions.

Efforts to prevent homicides must involve raising public awareness of relevant issues, especially those that have been overlooked thus far. Given the frequent turnover in political leadership, achieving sustained public awareness necessitates a collaborative and persistent initiative involving a diverse range of stakeholders [73]. Moreover, acknowledging the significant role of GMDs in inducing homicidal behavior prompts a revaluation of the foundational principles of punishment, which traditionally rest on the assumption of free will and individual responsibility. In conclusion, our research underscores the multifaceted nature of homicidal behavior, shedding light on previously overlooked influences and challenging conventional approaches to prevention and punishment. Last, but not least, recognizing that GMD have an important role in inducing homicidal behavior, questions the very foundation of punishment, which rests on the belief that people have free will and are responsible for their acts. And yet, the same structural factors that are commonly considered conducive to a homicidal environment, i.e. availability of guns, substance abuse, inequality, and more, may have been present for long, only that homicide tends to happen near simultaneously in Canada and the USA, coinciding with GMD, over which the homicide perpetrator has no control.

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