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BRIAN W. KABAT, Major, USAF

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THE SUN AS A NON-STATE ACTOR: THE IMPLICATIONS ON MILITARY OPERATIONS AND THEATER SECURITY OF A CATASTROPHIC SPACE WEATHER EVENT

by

Brian W. Kabat

Major, USAF

A paper submitted to the Faculty of the Naval War College in partial satisfaction of the requirements of the Department of Joint Military Operations.

The contents of this paper reflect my own personal views and are not necessarily endorsed by the Naval War College or the Department of the Navy.

Signature: ____________________

03 May 2010

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Abstract

Modern society relies heavily on robust technology to provide basic communications, positioning, timing, and general population security. The operational commander similarly relies on technology to prosecute missions both in peace and during times of conflict. This paper examines the possibility of a severe space weather event changing the operational environment. The author suggests a repeat of the historic “Carrington event” of 1859 would devastate entire fleets of spacecraft and wipe out entire electrical grids. The result would severely blunt most technological advantages modern commanders currently enjoy and threaten theater security if infrastructure is unable to be reconstituted in a timely manner. This paper begins with a brief description of the Carrington event and how it relates to the modern operational environment. It concludes that there exists a general lack of space environmental awareness in the joint force and recommends commanders at all levels prepare to mitigate these effects through training and proper allocation of resources.

INTRODUCTION

The twenty-first century military relies on high technology. Trillions of dollars in space assets enable global communication, intelligence collection, missile detection, munitions guidance, and precision navigation. Interdependent systems rely on robust computer networks to move data and control assets throughout the theater of operations. Ground-based sensors and transmitters provide unprecedented situational awareness and tactical connectivity. The evolution of contemporary operations has left a military completely dependent on technology. The sudden and unexpected loss of the technological edge would have catastrophic effects on how joint forces operate across the range of military operations.

Similarly, the fabric of modern society as a whole is woven from the conductive fibers of electric grids. Critical components of infrastructure depend on the availability of electricity. Widespread and sustained power outages would have devastating second-order economic and social implications ranging from failure of essential public sanitation systems to loss of refrigeration for food and medical stockpiles. The inability to rapidly recover from a large-scale blackout could promote regional instability, depending on the robustness of energy delivery infrastructures.

An electro-magnetic attack is one mechanism in which a state or non-state actor might exercise “directed-energy warfare.” Delivered through a host of possible weapons systems, the range of impacts to friendly systems is vast; from a high-precision laser device capable of rendering individual weapons systems useless, to a nuclear detonation wiping out electronic systems over an entire region.

But, perhaps surprisingly, the greatest threat to this critical vulnerability may not be posed by a belligerent adversary at all. Rather, it could arrive in a stream of high-energy particles bombarding the Earth's magnetic field, the result of a massive explosion on the surface of the Sun. Space weather is the collective term used to describe the various manifestations of this phenomenon. While minor events have caused numerous operational impacts over the past 20 years, an event of theoretical maximum proportions has not occurred since the evolution of the "wired planet."[1]

A century and a half ago, however, such a storm *did* hit the planet. Known more commonly as "the Carrington event," this episode serves as an ominous warning of disruptive capacity of the space environment. A recurrence of a similar event would trigger geomagnetically induced currents capable of destroying electrical components both on orbit and on the ground. Without an adequate mitigation strategy, nearly every aspect of modern operational warfare will be impacted. Commanders at every echelon must develop and exercise a plan to manage the first- and second-order effects of a worst-case space weather event on the modern operational environment or risk losing command and control capability and jeopardizing theater security.

BACKGROUND

The 1859 Carrington Event

On 2 September 1859, sailors aboard the Southern Cross, a 70-ton schooner in service for the Anglican Church from 1857-1860, observed an astounding display of the southern aurora while sailing northward along the coast of South America. Notable due to the exceptionally low latitude, the glowing sky was accompanied by intense and unusually red St. Elmo's Fire dancing about the deck of the ship. "…vivid bolts flew across the sky in

1. The author uses this term to illustrate how the technological evolution over the past century has led to pervasive dependency on electrical power grids and telecommunications networks. Even less-developed regions of the world rely on the transmission of electrons over hard-wired delivery systems to some extent. In essence, the fundamental nature of how humans interact and survive has changed globally over the past 150 years.

spiral streaks, heading for the zenith before exploding in silent brilliance."[2] Numerous people reported light so bright, they could read newspapers at night as though it were daylight. There are accounts of the aurora rousing people from their sleep in Bermuda and Hawaii, again, unusually Equator-ward and bright for the aurora.

It was during this time that the telegraph was becoming standard equipment. As Dr. Milan Vego points out,

> "Along with the railroad, and the steam engine, the electric telegraph made the largest impact on the planning and conduct of war. The invention of the electric telegraph and Morse code in the 1840s allowed near-instantaneous transmission of messages over hundreds of miles between headquarters. The telegraph fundamentally changed strategic command and control. It also provided statesmen with better knowledge of the strategic situation…The telegraph allowed the advancing army to keep contact with distant headquarters. Instructions could be sent instantaneously to any headquarters within reach of a telegraph wire."[3]

Unfortunately, this magnificent leap in technology was to be the most visible casualty of the severe space weather that was to follow.

Geomagnetically-induced currents disabled telegraph systems on 2 September 1859, wiping out communication worldwide for days. In Philadelphia, a telegrapher was severely shocked while testing his equipment. Power surges at communications nodes ignited several telegraph stations. In those stations where the battery power was disconnected from the transmission lines, operators were able to transmit messages for days without power, presumably taking advantage of residual current induced by the solar storm. Compasses

2. Stuart Clark, *The Sun Kings – The Unexpected Tragedy of Richard Carrington and the Tale of How Modern Astronomy Began* (Princeton, NJ: Princeton University Press, 2007), 10.
3. Milan Vego, *Joint Operational Warfare* (Newport, RI: Naval War College, 2007), I-17.

around the world swung wildly for days, completely losing orientation along the otherwise stable geomagnetic field lines.[4]

Eighteen hours earlier, Dr. Richard Carrington had witnessed what he knew was a phenomenal solar flare from his London observatory. His subsequently-corroborated documentation of the event revealed a stunning connection between what was happening in the interplanetary space between the Earth and the Sun and what was being observed on the ground. In essence, the "Carrington event" was a tipping point in astronomy – it showed for the first time that the Sun could impact life on Earth in ways previously unimagined. Over the course of the next few days, Dr. Carrington was able to link the unusual accounts of 2 September directly to the flare he had witnessed the day prior.

Subsequent reanalysis confirmed the Carrington solar flare of 1859 (represented by red star in Figure 1) to be a landmark in space weather, likely the most severe event in recorded history.[5] While spectacular to observers on the ground, the negative impacts were rather subtle. For a brief period, sailors likely reverted to celestial navigation in lieu of the compass. Telegraph traffic was hampered for a few days while damaged components of the system were repaired. Otherwise, modern society, as it was in the day, was completely intact. After all, power grids, satellites, radios, and microprocessors had yet to appear on the world stage in 1859.

DISCUSSION / ANALYSIS

Appreciation of the space weather threat must start during the operational planning process. Joint Intelligence Preparation of the Operational Environment (JIPOE) is a four-

4. Stuart Clark, *The Sun Kings – The Unexpected Tragedy of Richard Carrington and the Tale of How Modern Astronomy Began* (Princeton, NJ: Princeton University Press, 2007), 15.
5. Xinlin Li , B.T. Tsurutani, et al, "Modeling of 1–2 September 1859 Super Magnetic Storm," *Advances in Space Research* (Boulder, CO: 11 June 2005), 7.

step continuous process prescribed in Joint Publication 2-01.3. It is intended to provide Joint Forces Commanders (JFCs) with an understanding of the impacts of the environment on the ability to accomplish operational objectives. The first step in the JIPOE process begins with the characterization of the physical environment, which includes "terrain, topography, hydrology, meteorology, oceanography, and ***space***, surface, and subsurface ***environmental conditions*** (natural or man-made)…"[6] Despite the explicit reference to the importance of understanding the space environment, JFCs and operators seemingly abrogate this responsibility to the intelligence community. However, true understanding of the space environment and its impact on operations requires only a worthwhile minimal investment in deliberate study.

Unlike other physical realms of warfare, few have experienced space first-hand. Contrarily, operational planners are quite comfortable utilizing topographic charts to exploit physical characteristics of the battlefield terrain. Courses of action for movement and maneuver are often determined through the examination of the range of possibilities afforded by changes in elevation, coastlines, soil type, etc. Operators, whether through extensive training or intuition, appreciate the limitations imposed by the terrain, because they've experienced its effects. Likewise, aviators understand the limitations imposed by inclement weather, and sailors feel the direct manifestation of sea state on naval operations.

Unfortunately, most operators do not have a commensurate understanding of the space environment and its effects on operations. We do not directly operate there, and as a result, few have any idea of the limitations it can impose on our ability to conduct operations everywhere else. Therefore, it is a domain taken somewhat for granted; perhaps too abstract

6. Chairman, U.S. Joint Chiefs of Staff, *Joint Intelligence Preparation of the Operational Environment*, Joint Publication (JP) 2-01.3 (Washington, D.C.: CJCS, 16 June 2009), I-2.

to be intuitive. However, as our dependence on interconnected high-tech systems grows, it is imperative that joint forces understand what is at stake in other physical domains when chaos reigns above the atmosphere.

Operators understand weather; space weather is another story

The general lack of understanding of space weather is pervasive throughout the Department of Defense (DoD), even among military leaders charged with running the military's space segment. This was illustrated well when General Eberhart, commanding U.S. Space Command in 2002, addressed the Air Force Association's national symposium. "I am a little frustrated because I get these forecasts of space weather, but I have a hard time tracing those down…so what? So what happened?"[7] Despite an inability to instinctively link the natural space environment to impacts on his operations, General Eberhart recognized the shortfall and consistently advocated more fiscal investment and increased emphasis on understanding the space environment throughout the DoD. Just three years later, Major General Burg, while serving as the Air Force's Director of Strategic Security, trumpeted in the same forum, "… we're educating the rest of the force on the benefits of space weather information. We know that the sun continuously bombards the ionosphere. It changes the nature of the ionosphere. Understanding that is particularly important to ground operations…"[8]

The collective appreciation for the space environment is growing among senior leaders. However, it's not enough for operational commanders to rest on a mere qualitative

7. Gen Ralph E. Eberhart, commander in chief, NORAD and U.S. Space Command and commander, Air Force Space Command (address, Air Force Association National Symposium, Orlando, FL, 14 February 2002). http://www.afa.org/aef/pub/eber202.asp (accessed 24 Mar 2010).
8. Maj Gen Roger W. Burg, Director of Strategic Security, Office of the Chief of Staff for Air & Space Operations (address, Air Force Association National Symposium, Los Angeles, CA, 18 November 2005). https://www.afa.org/media/scripts/Burg_natlsymp05.asp (accessed 24 March 2010).

understanding of space weather impacts. A complete JIPOE *requires* quantitative operational risk assessment based on the state of the space environment. Fortunately, the knowledge gap is not all that difficult to bridge if one considers some analogous mission-limiting natural phenomena.

Environmental Apples and Oranges

Simple orbital geometry drives annual periodic temperature fluctuations on Earth, which in turn drive fairly predictable seasons. We know, for instance, that the best chance for sweltering heat is in the summer, and we exploited this knowledge to prosecute the combat phases of both Operations DESERT STORM and IRAQI FREEDOM. By attacking during the relatively cooler spring, the Coalition maximized combat efficiency by reducing the impacts of high temperature on systems and forces. Thus, in these cases, weather played a large role in balancing the operational factors of force and time. Space weather should be a coequal player during the operational planning process.

Like the Earth, the Sun is a dynamic entity. The solar cycle, however, is not measured in terms of temperature. Rather, the magnetic structure of the star drives solar seasons. Whereas the peak in annual temperature generally occurs every twelve months on Earth, the peak in solar magnetic activity occurs only once every eleven years. The following graph shows the solar activity since the mid-eighteenth century. The data shown here are indicative of a relatively predictable periodic peak in the number of sun spots,[9] a condition commonly referred to as "solar max."

9. Sun spots are described by the National Aeronautics and Space Administration (NASA) as being "dark, often roughly circular features on the solar surface" forming "where denser bundles of magnetic field lines from the solar interior break through the surface." Because intense magnetic anomalies on the Sun's surface contort solar matter, the relatively cooler regions often appear darker than the surrounding matter. (Source: http://www.nasa.gov/worldbook/sun_worldbook.html) Sun spots have been observed for centuries and have been inextricably linked to active magnetic regions on the Sun's surface. Thus, they are considered a proxy for the measuring the relative magnetic activity on the solar surface.

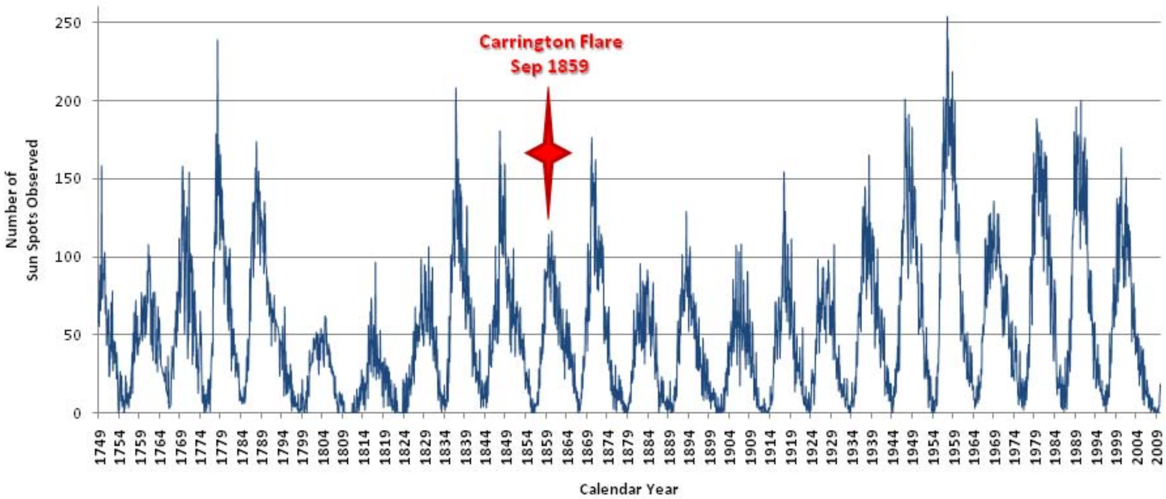

Figure 1: This chart represents the average number of sun spots observed per month since the mid-18th century. The cyclic nature of solar activity is evident in the peak (solar max) in sun spots occurring every 11 years. Severe space weather is most likely to occur near solar max. The Carrington event of 1859 (represented by red star) is considered a landmark in space weather, likely the most severe event in recorded history. Plotted by author with data derived from NASA data available at: http://solarscience.msfc.nasa.gov/greenwch/spot_num.txt

These heightened periods of activity often result in large anomalies in the Sun's magnetic field. Occasionally, when these highly-concentrated anomalies break down, massive solar flares eject trillions of tons of highly-charged particles away from the Sun's surface. In general, as these particles stream through space, they shower on-orbit spacecraft with often devastating effect and crash into the upper atmosphere, distorting the otherwise stable planetary magnetic field on the way. An eighteenth century observer, while awed by the vibrant light show of the aurora, would have been otherwise oblivious to what was happening. The twenty-first century operator, however, cannot afford to be as passive a player. [For a more complete characterization of the operational impacts and a categorical description of space weather, see the Appendix.]

Why Space Weather Matters to the Operational Commander

Operation DESERT STORM is considered the first "space war" due to its widespread use of satellite-dependent systems. In fact, U.S. space intelligence platforms are largely credited with enabling the massive flanking maneuver which abruptly ended the conflict.[10] Yet, the campaign was conducted during a solar max. At the time, it was the third most active period on record. During the 41-day war, 81 minor solar flares were observed and widespread disruption of Ultra High Frequency (UHF) and satellite communications were reported.[11] Additionally, in the first large-scale employment of satellite navigation in combat operations, Global Positioning System (GPS) service was temporarily disrupted by the active solar weather.[12] Perhaps the most poignant impact during the conflict occurred when repeated requests for fire support, made by High Frequency (HF) radio communications, were interrupted for several hours by anomalies in the ionosphere.[13] The life and death implications of losing this capability are obvious.

Planners must consider the heightened probability of severe space weather when executing an operation during solar max. Figure 2 represents the same data as Figure 1, with two modifications: The scope of the analysis is narrowed to the last three decades and few of the strongest solar flares (orange triangles) as measured by the magnitudes of their X-ray

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10. William J. Burke, "Treacherous High Ground: the Near-Earth Space Environment," *Air Force Research Laboratory (AFRL) Technology Horizons* (March 2000), 44.
11. Michael A. Neyland, "Weather Support for America's Warfighters," Powerpoint, 01 December 1999, Washington, D.C.: Office of the Federal Coordinator for Meteorology. http:www.ofcm.gov/wist_proceedings/pdf/panel1/mneyland.pdf (accessed 13 March 2010).
12. Peter N. Spotts, "Science gets a new weather forecaster for space," *Christian Science Monitor*, 18 September, 2002, http://www.csmonitor.com/2002/0918/p02s02-usgn.html (accessed 12 March 2010).
13. Michael A. Neyland, "Weather Support for America's Warfighters," Powerpoint, 01 December 1999, Washington, D.C.: Office of the Federal Coordinator for Meteorology.

emissions (numbers inside the triangles) are superimposed.[14] The high correlation between severe space weather and the solar max is immediately evident.

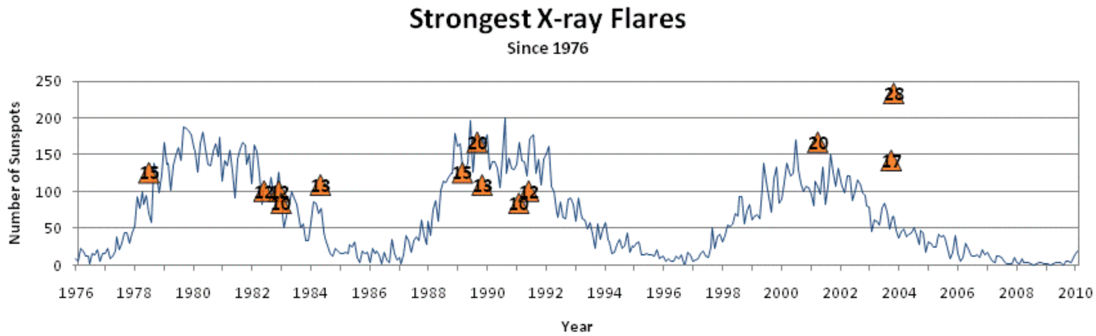

Figure 2: Same as Figure 1 with 13 of the Top-20 X-ray solar flares superimposed. This plot highlights the strong correlation between solar max and severe space weather. The magnitude of the flares is represented by the number at the center of each triangle. Operation Desert Storm was conducted during solar max, a four-year period when over half of the Top-20 flares were observed.

Fortunately, the geomagnetic conditions observed during Operation DESERT STORM's ground campaign were relatively benign. Had a more severe event occurred, however, the impacts might have been much more profound. Because space weather was not yet a routine inject into the military planning process in 1991, operators rarely considered the state of the space environment. Despite the lack of *severe* space weather, minor activity still imposed limitations on operations. In retrospect, things could have been much worse.

Narrowing the analysis to the first half of 1991and including the remaining Top-20 X-ray flares in Figure 3, it's easy to see that the ground campaign was conducted during a lull in severe space weather. Closer examination of the data highlights a two week period in early June where six strong flares were measured. This accounts for a full 30 percent of the strongest X-ray flares observed over the past 30 years. Based on the established correlation between space weather impacts and solar flares, had the ground campaign been executed in

14. U.S. Department of Commerce, *Halloween Space Weather Storms of 2003,* NOAA Technical Memorandum OAR SEC-88 (Boulder, Colorado: Space Environment Center, June 2004), 12, http://www.swpc.noaa.gov/Services/HalloweenStorms_assessment.pdf (accessed 13 March 2010).

June, it is reasonable to conclude that there would undoubtedly have been more widespread and possibly catastrophic communications losses throughout the theater of operations.

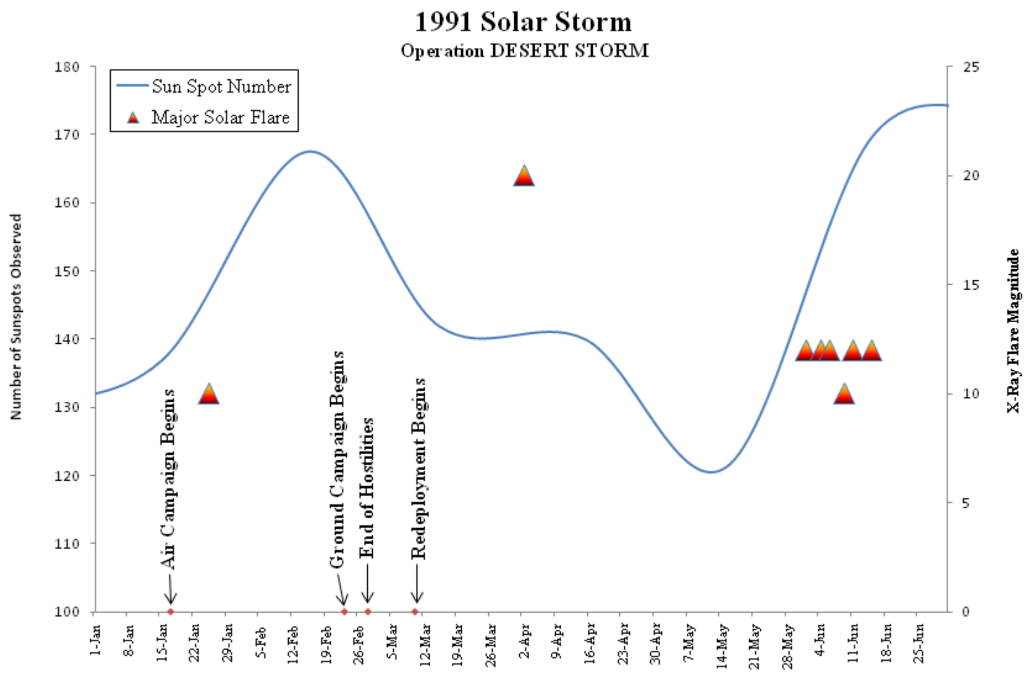

Figure 3: Despite the declining solar activity and lack of strong flares during the ground campaign, numerous space weather impacts were observed. The first half of June would have been extremely unfavorable for maintaining command and control.

Clearly, the JIPOE process must consider that space-dependent technology is most susceptible to space weather during solar max. This is also when the greatest threat to ground components and electrical infrastructure are most likely to occur. While solar max is no guarantee of operation-limiting impacts, it *is* a strong indicator of increased risk.

What Another Carrington Event Would Mean Today

In May 2008, the National Academy of Science (NAS) convened a committee of space weather and infrastructure experts to examine the potential societal impacts of a space weather event on the order of the Carrington flare. The motivation for the workshop was partly rooted in another substantial space weather event which occurred during the last solar max, in October and November 2003. Dubbed the "Halloween Space Weather Storms," they produced 17 significant solar flares, including the strongest X-ray flare recorded in the last 30 years (see the orange triangle of X-ray magnitude 28 in Figure 2).[15] The following are just a few examples of the dramatic unclassified impacts of the Halloween storms:

- DoD Satellite operations over high-interest regions were lost for 29 hours when three spacecraft either experienced anomalies or were shut down to avoid damage[16]
- The U.S. Navy's Relocatable Over-the-Horizon Radar at San Francisco and the Kodiak, AK ground stations had severe HF degradation[17]
- Japan's newest $640 million environmental satellite was rendered useless[18]
- Geomagnetically-induced currents overwhelmed power grids in Northern Europe, causing power blackouts for over 50,000 people in Sweden[19]
- Worldwide marine emergency call system became inoperable for 40 minutes[20]
- Climbers lost contact with base camps on Mount Everest[21]
- Communications between crews fighting forest fires in California was degraded[22]
- Both magnetic compasses and GPS measurements were highly erratic[23]
- At the cost of tens of millions of dollars in fuel and days of delays, commercial flights to Alaska, Scandinavia, and Russia were rerouted south and limited to maximum flight levels of 25,000 feet[24]
- Power at two New Jersey nuclear power plants was reduced to prevent catastrophic surges[25]

In another classic tactical example, the radio blackout associated with the Halloween storms nearly ended in disaster for one U.S. Marine Corps CH-53 mission. On a 24 October 2003 cross-country flight from Cherry Point, NC to Miramar, CA the crew lost radio contact somewhere between San Antonio and Albuquerque. Realizing their instruments were reading erroneously, they attempted to determine their exact position using GPS and radio

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15. U.S. Department of Commerce, *Halloween Space Weather Storms of 2003,* NOAA Technical Memorandum OAR SEC-88 (Boulder, Colorado: Space Environment Center, June 2004), 12. http://www.swpc.noaa.gov/Services/HalloweenStorms_assessment.pdf (accessed 13 March 2010).
16. Ibid, 34.
17. Jose Harris, Air Force Space Weather Operations Center, e-mail message to author, 18 March 2010.
18. Stuart Clark, *The Sun Kings – The Unexpected Tragedy of Richard Carrington and the Tale of How Modern Astronomy Began* (Princeton, NJ: Princeton University Press, 2007), 6.
19. L. Rosenqvist et al, "Extreme solar-terrestrial events of October 2003: High-latitude and Cluster observations of the large geomagnetic disturbances on 30 October," *Journal of Geophysical Research*, (September 2005).
20. Stuart Clark, *The Sun Kings – The Unexpected Tragedy of Richard Carrington and the Tale of How Modern Astronomy Began* (Princeton, NJ: Princeton University Press, 2007), 6.
21. Ibid.
22. Ibid.
23. Ibid, 7.
24. Ibid.
25. Ibid.

navigation systems. Neither was functioning, and magnetic fluctuations had all but disabled onboard compasses. The crew immediately flew to the nearest visible population center and slowed to a hover near the town's water tower. Eventually, they were able to fix their position by correlating the name painted on the tower with a paper map. To their surprise, they had deviated nearly 80 miles off course. Since technicians were onboard, all systems were troubleshot both while in-flight and upon arrival in Albuquerque. All systems were functioning normally in repeated diagnostic tests. The aircraft commander determined that he had indeed encountered the "possible magnetic anomalies" he had been briefed to anticipate prior to departing Randolph Air Force Base, TX.[26]

If the 2003 storms were symptomatic of our increasing vulnerability to the space environment, they do not adequately portend the true scope of the threat. In fact, experts in the scientific community warn of much more dire consequences. Late into the same active period, a massive flare, estimated to be at least twice as strong as the one which resulted in the largest impacts in October, exploded from the edge of the Sun's visible disk. Fortunately, since the blast was not directed toward Earth, no significant impacts were experienced.[27]

Indications are that the Carrington event was at least five times stronger than the Halloween event.[28] According to Dr. Ed Cliver at the Air Force Research Laboratory, a reoccurrence of the Carrington event would be a "worst- case scenario" for modern society.[29] All of the standard effects would be significantly magnified. Radio and telephone coverage would be disrupted, power stations would be at high risk due to induced currents, a large portion of our satellite fleets would be devastated, commercial and military flights would

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26. Maj Ken Merhige (U.S. Marine Corps command aviator), interview by author, 29 March 2010.
27. Stuart Clark, *The Sun Kings – The Unexpected Tragedy of Richard Carrington and the Tale of How Modern Astronomy Began* (Princeton, NJ: Princeton University Press, 2007), 7.
28. Ibid, 173.
29. Ibid, 177.

necessarily be rerouted to avoid communications blackouts and to prevent excessive radiation exposure.

The direct tie of these effects to military operations is clear. In a worst-case space weather scenario, communications throughout the area of operations would be tenuous at best. Whatever reliance we have on commercial power sources will have to be backed-up by locally generated power. Our space-based intelligence collection and battlefield characterization capabilities would be severely degraded. In short, some of the most basic technological advances of the past century, those which have given us the edge in combat operations in recent years, could unravel within as little as 18 hours notice, the time it takes the high energy particles to cover the distance between the Sun and the Earth.

What are not immediately obvious, though, are the long-term second-order effects of a Carrington-class flare. The U.S. Government describes the situation in the following way: "The space environment around Earth is becoming of ever-increasing importance for the successful operation of commercial, government, and national security infrastructure essential to the Nation."[30] The 2008 NAS workshop concluded that the economic blow to the U.S. economy would be $1 trillion to $2 trillion during the first year alone. It is also estimated that complete recovery of infrastructure would take anywhere from four to ten years.[31]

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30. U.S. Department of Commerce, *Report of the Assessment Committee for the National Space Weather Program*, FCM-R24-2006, (Silver Spring, MD: Office of the Federal Coordinator for Meteorology (OFCM), 2006), *i*. http://www.ofcm.gov/r24/fcm-r24.htm (accessed 25 March 2010).
31. National Academy of Sciences, *Severe Space Weather Events—Understanding Societal and Economic Impacts Workshop Report*, (Washington, D.C.: National Research Council, Committee on the Societal and Economic Impacts of Severe Space Weather Events, 2009), 4.

The recently published Joint Operating Environment (JOE) 2010 highlights the potential of cascading socio-political effects owing to the collapse of infrastructure.[32] Particularly in weak states, the loss of power production capability is a direct threat to theater stability. In fact, one of the major measures of success for the coalition in Iraq today is the effectiveness of community power grids. A recent Multi-National Corps press release stated, "Next to clean drinking water, the people of Samarra mark access to electricity as their most important concern."[33] It is important for operational commanders to realize that whatever progress has been made on the ground in terms of infrastructure improvement is vulnerable to severe space weather events. However, planners must strike a delicate balance between building capacity and survivability on an acceptable timeline.

It is true that communities such as Samarra, where hundreds of meters of power lines have been strung and efforts to connect local grids to substations are of the highest priority, lack the infrastructure robustness to withstand a severe geomagnetic storm. However it can be argued that space weather is merely a peripheral issue. While a Carrington-class flare would pose some threat to theater security, the necessity of providing a basic capability to the population far outweighs any requirement to safeguard it from such a low-probability event.

In reality, the 1859 solar flares satisfied every criterion for a major solar storm. It was the "perfect solar storm," and one of similar magnitude has not happened since, nor is it *likely* to happen in the near future. With the multitude of threats to theater security and with resources already stretched to the breaking point, it would be too costly to mitigate most impacts. Ideally, operations would always be conducted during a solar minimum, but it is

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32. Commander, U.S. Joint Forces Command, *Joint Operational Environment 2010*, (Norfolk VA: 18 February 2010), 47. http://www.jfcom.mil/newslink/storyarchive/2008/JOE2008.pdf (accessed 24 March 2010).
33. Multi-National Corps – Iraq, "Samarra's improving electrical grid brightening lives," *Press Release No. 20090305-01*, 5 March 2009. http://usfi-dev-new-en.nsadev.net/news/press-releases/samarras-improving-electrical-grid-brightening-lives (accessed 15 March 2010).

unrealistic to steer foreign policy around the status of the space environment. Quite simply, it is what it is.

For example, we could not have planned Operation DESERT STORM around the solar cycle. The strategic situation at the time did not allow for it. In fact, close examination of Figure 3 shows a Top-20 flare *did* occur in the middle of the air campaign. Yet the operational objectives were achieved in spite of the space environmental situation. There is an argument to be made that, as long as space weather is considered in the JIPOE process, operational commanders must simply accept the increased risk to vulnerable systems and plan to operate in a degraded state.

However, that the cost of not preparing for this high-impact, low-frequency event is much higher. The fact of the matter is, the Carrington event happened. Despite the low probability in the short term, an eventual reoccurrence is only a matter of time. As the events of the last two solar cycles have shown, even relatively mild geomagnetic storms jeopardize military operations and cost societies billions of dollars. If operational planners and commanders prepare for the worst-case scenario, they will naturally mitigate the impacts from less extreme events.

> "...[There is] a tendency in our planning to confuse the unfamiliar with the improbable. The contingency we have not considered looks strange; what looks strange is therefore improbable; what seems improbable need not be considered seriously."[34]

This quote, attributed to Thomas C. Schelling, is from the forward of a scathing after-actions report on the government's response to the attack on Pearl Harbor. Interestingly, these words appeared again in 2004, in the *Report of the Commission to Assess the Threat to the United States from Electromagnetic Pulse (EMP) Attack*. In the report, that commission

34. House, *Report of the Commission to Assess the Threat to the United States from Electromagnetic Pulse (EMP) Attack*, (Washington, D.C.: U.S. Congress, 2004), A-1. http://www.empcommission.org/docs/A2473-EMP_Commission-7MB.pdf (accessed 25 March 2010).

identified an attack on the U.S. electrical grid by a hostile actor as a major threat to regional security:

> "It is impractical to protect the entire electrical power system from damage by an EMP attack. There are too many components of too many different types, manufacturers, designs, and vulnerabilities within too many jurisdictional entities, and the cost to retrofit is too great. Widespread functional collapse of the electrical power system in the area affected by EMP is possible in the face of a geographically broad EMP attack… The United States must not permit an EMP attack to defeat its capability to prevail. The Commission believes it is not practical to protect all of the tactical forces of the US and its coalition partners from EMP in a regional conflict. A strategy of replacement and reinforcement will be necessary. However, there is a set of critical capabilities that is essential to tactical regional conflicts that must be available to these reinforcements. This set includes satellite navigation systems, satellite and airborne intelligence and targeting systems, an adequate communications infrastructure, and missile defense. The current capability to field a tactical force for regional conflict is inadequate in light of this requirement."[35]

At first glance, it would appear the EMP and space weather threats are unrelated. On the contrary, the alarming description of our inability to counter a threat to technology is even more poignant when one examines how the Commission quantified the potential effects of a "geographically broad EMP attack." They describe the currents induced by the most effective EMPs as being "comparable to those expected to arise in the largest geomagnetic storm ever observed." This analysis supports the hypothesis that a repeat of the historical Carrington event would have devastating effects on the joint operational environment, both in terms of military capabilities and theater security. It also highlights the fact that global impacts from cataclysmic space weather could potentially be on par with many of the electromagnetic effects of a global thermonuclear attack.

The lack of preparedness has not gone unnoticed. In an 18 Nov 2009 House Armed Services Committee hearing, Representative Roscoe G. Bartlett (R-MD) relayed his concern

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35. Ibid, 48.

about the reoccurrence of a Carrington event. In discussions with "a high official" in the Federal Energy Regulatory Commission (FERC), Rep. Bartlett was told that "our grid would come down" and that it would be years before it could be restored. The official relayed to the Congressman that "probably 80 percent of the population would die."[36] Rep. Bartlett went on to express his dismay at the lack of action on the part of the Departments of Defense and Homeland Security. When pressed for an explanation, David Berteau (Director, Defense Industrial Initiatives Group, Center For Strategic and International Studies) acknowledged his concern but steered clear of the FERC prediction. He did, however, point out another critical vulnerability: "Fifteen years ago, much of the defense infrastructure in the U.S. had its own independent power sources. Today that's no longer true. We've now privatized, and DoD is largely dependent on the commercial grid."

What's the likelihood of Carrington II?

As remote as a Carrington-class event might seem, Dr. William Burke of the Air Force Research Lab concedes, "Natural processes pose a more serious threat…than enemy action."[37] Similarly, world-renowned physicist Dr. Michio Kaku, in an interview on the Lou Dobbs show described the worst-case scenario. "We're talking about wiping out all satellite communications, all weather satellites, spy satellites, internet, GPS and blackening out most cities. Every 11 years we are playing Russian roulette with the Sun. So sooner or later we are going to lose that bet."[38]

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36. House. *Implications of Long Term Defense Budget Trends: Hearing before the House Armed Services Committee*. 111th Cong., 2nd sess., 2009. http://republicans.armedservices.house.gov/hearings/hearingdetail.aspx?NewsID=841 (accessed 29 March 2010).
37. William J. Burke, "Treacherous High Ground: the Near-Earth Space Environment," *Air Force Research Laboratory (AFRL) Technology Horizons* (March 2000), 44.
38. Michio Kaku, interviewed by Lou Dobbs, *Lou Dobbs Tonight*, Cable News Network. 11 May 2009. http://search.ebscohost.com (accessed 20 February 2010).

Unfortunately, there's little consensus in the scientific community when it comes to forecasting the relative strength of the next solar cycle. While some predict the next max will be the most active in 50 years, and perhaps the last 400 years,[39] the official U.S. Government forecast issued in May 2009 by the National Oceanic and Atmospheric Administration's (NOAA) Space Weather Prediction Center predicts the lowest number of sunspots since 1928. However, the discrepancy is largely irrelevant. As the forecast's panel chairman, Doug Biesecker intimated in an associated press release, "The great geomagnetic storm of 1859, for instance, occurred during a solar cycle of about the same size we're predicting for 2013."[40] One last glance at Figure 1 shows that we're once again moving toward solar max and a potentially dangerous operational environment.

CONCLUSIONS

Three things are abundantly clear. First, combatant commanders and operators neither fully understand nor appreciate the threat posed to military operations by the space environment. As illustrated in the statements by the senior brass running the DoD's space segment, there is a tremendous shortfall of space weather knowledge in our operational and training processes. Furthermore, as highlighted in the Congressional testimony, the DoD is ill-prepared to mitigate its effects on the battlefield and on its military installations worldwide.

Secondly, when one considers the interdependency of systems serving basic infrastructure requirements throughout civilization, it's easy to conclude that the second-

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39. Stuart Clark, *The Sun Kings – The Unexpected Tragedy of Richard Carrington and the Tale of How Modern Astronomy Began* (Princeton, NJ: Princeton University Press, 2007), 178.
40. National Aeronautics and Space Administration, "New Solar Cycle Prediction," (Washington, D.C.: Press Release, 29 May 2009).   http://science.nasa.gov/headlines/y2009/29may_noaaprediction.htm (accessed 29 March 2010).

order effects of a severe geomagnetic storm might lead to regional and, perhaps, theater-wide instability. On a smaller scale, this point is driven home almost daily throughout Southwest Asia, as evidenced in the aforementioned Samarra case.

Thirdly, as another period of increasing solar activity approaches at the same time dependence on technology is growing, operational-level decision-makers are becoming increasingly vulnerable to space environmental effects. In some sense, we are even more at-risk of mission failure today than we were in 1859 during the infancy of global telecommunications.

RECOMMENDATIONS

Regardless of the state of readiness of the U.S. Government, and with the active solar phase predicted to begin in the next two to three years,[41] it's critical for commanders to prepare now to be able to operate in a technologically-degraded operational environment. Despite the somewhat dire portrait of military readiness presented above, there are many ways in which commanders can minimize susceptibility to severe space weather. Operators would do well to note the ultimate mission success of the USMC crew discussed previously. Because they had been trained in map navigation and had current maps on-hand, and because they had trained to operate during communications blackouts, the space weather impacts to their mission were mitigated. Commanders at all levels must similarly insist on bolstering high-tech training with "old-school" backup tactics, techniques, and procedures (TTPs).

Additionally, total communications outages must be exercised routinely, both at the operational and the tactical levels. Scenarios should play themselves out, so that the cascading effects of widespread power failures are realistically captured and courses of action can be developed to deal with the security implications of infrastructure collapse.

41. Ibid.

Finally, joint doctrine, theater security plans and formal training must fully incorporate lessons learned from previous real-world space weather events as well as those gleaned from exercises. Only through institutionalizing the threats posed by a hostile space environment can progress be made toward insulation from its effects. At the very least, when executed, the JIPOE process must include the prescribed thorough analysis of the space environment in order to mitigate impacts to friendly operations and to identify vulnerabilities to space weather in enemy courses of action.

These measures will significantly increase the viability of combat power in a degraded operational environment. As technology continues to drive the evolution of modern operational warfare, recognition of its inherent vulnerabilities to space weather is essential. Only through due diligence and deliberate planning can we mitigate the potentially catastrophic impacts to communications and theater security. The bottom line is this: the Sun is a completely indiscriminant actor. All other things being equal on the battlefield, the ability of one belligerent to overcome the other may just lie in his ability to better minimize and exploit the adverse effects of severe space weather.

APPENDIX

A General Description of Space Weather Impacts

Solar particles interacting with Earth's magnetic field may result in a ***geomagnetic storm.*** The effects can rapidly overwhelm electrical circuitry and induce currents in existing power grids and pipelines. Excessive geomagnetically-induced currents can produce dangerously high currents in long transmission lines and damage vulnerable power transformers and electrical transfer nodes. Under the right circumstances, isolated faults can cascade to cause systematic failure of regional energy infrastructures.

Spacecraft are particularly vulnerable to geomagnetic storms. One way in which satellites might succumb to space weather occurs when sensitive components exposed to the ambient environment accumulate electrical charge from the transiting particles. If sufficient electric potential develops between spacecraft components, devastating arcing can literally fry the multi-million dollar assets.

Geomagnetic storms are also capable of changing the flight path of a satellite. Increasing the number of energetic particles causes the upper atmosphere to expand, leading to increased density at altitude and drag on a spacecraft in low-earth orbit. Unless corrected, the resultant loss in altitude ultimately shortens the lifespan of the asset and makes it more difficult for operators on the ground to locate and use the spacecraft for its intended purpose.

The fluctuations in ionospheric (the ionosphere can be considered the top of the atmosphere for the purposes of this paper) density caused by geomagnetic storms can also result in severe propagation errors. Take for example, looking toward the horizon down the length of a hot blacktop road. The mirage you see (product) is the result of the distortion of light (signal) passing through differing densities of air in the lowest layer of the atmosphere prior to arriving at your eye (sensor). Geomagnetic storms likewise distort signals traveling through the ionosphere. Positions derived from Global Positioning System signals are occasionally so erroneous that they become unusable. Precision-guided munitions, satellite navigation, satellite telephones, and precision timing can be significantly degraded during geomagnetic storms. Additionally, high frequency communications equipment which relies on the ionosphere for long-distance transmission may be unusable.

Secondly, increased levels of radioactivity both in space and in the upper atmosphere result in ***solar radiation storms***. During severe events astronauts may be exposed to lethal doses of radiation. Aircrews and passengers flying at high latitudes may also experience life-threatening exposure, depending on the flight level. During a space weather event in 2003, NASA directed astronauts to take shelter. Commercial airlines rerouted all flight plans north of 57 degrees latitude in order to avoid hazardous radiation levels, estimated to be the equivalent of 100 chest X-rays.[42] Excessive solar radiation also causes permanent damage to spacecraft solar panels, the only means of powering some satellites.

Lastly, high-levels of X-ray radiation associated with space weather may lead to ***radio blackouts***. During these periods, High Frequency (HF) communications and low-frequency navigation aids may be degraded or unavailable for hours at a time on the entire sunlit side of the planet.

[42] U.S. Department of Commerce, *Intense Space Weather Storms October 19 – November 07, 2003.* (Boulder, CO: April 2004). http://www.swpc.noaa.gov/Services/SWstorms_assessment.pdf (accessed: 24 Mar 2010).

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