REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. AGENCY USE ONLY *(Leave blank)*

2. REPORT DATE
5 Jun 98

3. REPORT TYPE AND DATES COVERED
Master's Thesis

4. TITLE AND SUBTITLE

Determining If "Space Weather" Conditions Should Be Considered In The Intelligence Preparation Of The Battlefield Process

5. FUNDING NUMBERS

6. AUTHOR(S)

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8. PERFORMING ORGANIZATION REPORT NUMBER

9. SPONSORING / MONITORING AGENCY NAME(S) AND ADDRESS(ES)

10. SPONSORING / MONITORING AGENCY REPORT NUMBER

11. SUPPLEMENTARY NOTES

19980731 092

12a. DISTRIBUTION / AVAILABILITY STATEMENT

Approved for public release; distribution is unlimited.

..IBUTION CODE

A

13. ABSTRACT *(Maximum 200 words)*

This study investigates whether or not space environmental conditions, commonly referred to as space weather, should be considered in Army Intelligence Preparation of the Battlefield (IPB). Space weather refers to a variety of naturally occurring phenomena involving electromagnetic radiation, electrically charged particles, and the earth's upper atmosphere and magnetic field. IPB includes a process in which military decision makers evaluate the environmental conditions and consider the expected impacts on friendly and enemy operations.

The study identifies a number of Army systems that are adversely affected by space weather. These systems are used at all echelons by combat arms and combat support units for communications, intelligence collection and dissemination, electronic attack, and a number of navigation applications. The study discusses how the Army uses the systems and then identifies potential mission impacts and failures due to the effects of space weather.

In determining the utility of space weather information as part of IPB, the study presents examples of how commanders and system operators could use space weather information to mitigate the adverse effects. The study concludes that space weather conditions should be formally considered during IPB.

14. SUBJECT TERMS
Space environment; space weather; Intelligence Preparation of the Battlefield (IPB); weather

15. NUMBER OF PAGES
91

16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
Unclassified	Unclassified	Unclassified	Unlimited

DETERMINING IF "SPACE WEATHER" CONDITIONS SHOULD BE CONSIDERED IN THE INTELLIGENCE PREPARATION OF THE BATTLEFIELD PROCESS

A thesis presented to the Faculty of the U.S. Army
Command and General Staff College in partial
fulfillment of the requirements for the
degree

MASTER OF MILITARY ART AND SCIENCE

by

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1998

MASTER OF MILITARY ART AND SCIENCE

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The opinions and conclusions expressed herein are those of the student author and do not necessarily represent the views of the U.S. Army Command and General Staff College or any other governmental agency. (References to this study should include the foregoing statement.)

ABSTRACT

DETERMINING IF "SPACE WEATHER" CONDITIONS SHOULD BE CONSIDERED IN THE INTELLIGENCE PREPARATION OF THE BATTLEFIELD PROCESS by Major Thomas B. Frooninckx, USAF, 91 pages

This study investigates whether or not space environmental conditions, commonly referred to as space weather, should be considered in Army Intelligence Preparation of the Battlefield (IPB). Space weather refers to a variety of naturally occurring phenomena involving electromagnetic radiation, electrically charged particles, and the earth's upper atmosphere and magnetic field. IPB includes a process in which military decision makers evaluate the environmental conditions and consider the expected impacts on friendly and enemy operations.

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In determining the utility of space weather information as part of IPB, the study presents examples of how commanders and system operators could use space weather information to mitigate the adverse effects. The study concludes that space weather conditions should be formally considered during IPB.

PREFACE

Soon after entering the Air Force, I had the best job a meteorologist could hope for: I served on an airborne command post, escorting fighter squadrons over the Atlantic and Pacific Oceans, monitoring the weather along the way, and informing aircrews when adverse weather conditions would affect their ability to refuel in midair, land at a remote island, or reach their intended destination. I witnessed the interface between weather and air operations. There were air aborts, canceled missions, missed approaches, and irate pilots. The command and control aircraft used high frequency radio to communicate with bases located a thousand miles away, and I recall struggling to clearly understand the communications because the radio signals were filled with interference. The radio technicians were in constant motion, changing from one frequency to another in search of a useable signal. I was told the problem was "caused by sunspots;" no one was really sure, but I would eventually learn all about it.

It has been almost nine years since the Air Force sent me to formally study "space" and the various processes that occur there. Soon after, my duty included monitoring the environmental conditions in space, talking with satellite controllers, and determining if "space weather" was causing the satellite problems that would occur from time to time. I quickly realized that the interface between space weather and military systems could not be "seen" in the same way that I had witnessed the terrestrial weather (meteorological) effects on air operations. The latter is easy to see and feel; the former is virtually impossible. Consequently, weather is recognized as a friction of warfare, as Clausewitz would say, while space weather and its effects remain largely unknown or, perhaps even more detrimentally, they are misunderstood.

As a student at the United States Army Command and General Staff College, I realized that I had an opportunity to perhaps erase some of the ambiguity relating to the effects of space weather on Army operations and to establish a baseline from which related efforts could proceed. I have attempted to write the thesis in a way that is understandable to those who have no formal training in this field, with an eye toward commanders, staff officers, and soldiers who may make decisions and perform operations which are affected by space weather. I also wanted the thesis to be specific enough so that agencies responsible for considering the conclusions and potentially implementing the recommendations would have a solid foundation from which to start.

Of course, I am grateful for having had the opportunity to attend the Army Command and General Staff College. I have a deeper understanding of how the Army operates and a new respect for those who serve in it. I also enjoyed reminding my classmates and instructors about the capabilities of the Air Force and about the power of weather to allow success or cause failure. Most importantly, I have gained a profound admiration for what our nation's veterans have accomplished and sacrificed.

LIST OF ILLUSTRATIONS

CHAPTER ONE

INTRODUCTION

Background

"Know the ground, know the weather, your victory will then be total."[1] Sun Tzu recognized nearly 2,500 years ago that a warfighter could gain an advantage by being aware of the weather conditions and by understanding how those conditions affect the terrain and the enemy. Conversely, he also realized the risks and disadvantages of not being aware of the weather conditions and of failing to consider the effects on both friendly and enemy forces. His wisdom has proved to be timeless despite the centuries of technological improvements that have mitigated some adverse weather effects on weapons and soldiers. Examples of how weather conditions have led to military successes and failures are scattered generously throughout the historical accounts of battles, campaigns, and wars, and so too are examples of how military commanders have exploited or neglected information concerning the weather.

Perhaps two of the better known illustrations of how weather and weather information have played decisive roles in United States military operations are taken from the successful D day invasion of Normandy during 1944 and from the failed American embassy hostage rescue operation in Iran during 1980. Exploiting the combined capabilities of the Army Air Forces Weather Service and the British meteorological service, General Eisenhower relied on weather forecasts in selecting the optimum time to launch the Normandy invasion. Nearly two months before the operation, he told his senior staff and the air, ground, and naval commanders-in-chief, "As you all know, when the time comes to start Overlord we are going to have to rely very much on the weather forecast."[2] True to his word, he obtained frequent weather updates and successfully chose a time that provided the most favorable sea wave, wind, and cloud cover conditions during a period of otherwise very poor weather.

Thirty-six years later, during the EAGLE CLAW operation, a lack of knowledge and perhaps concern for desert sand storms and suspended dust in Iran caused the hostage rescue mission to fail.[3] Seven RH-53D helicopters were unable to reach their objective on time due to reduced visibility caused by blowing sand and suspended dust. Air Force and Navy meteorological personnel who had been specifically designated by their respective service's weather organizations to support the rescue operation were not allowed to interface directly with the aircrew members prior to the mission. Such an indifferent policy as to how weather information was integrated into the planning and execution cycle of the operation suggests that senior commanders had not considered weather to be an important factor and/or had dismissed any potential weather impacts.

More recent examples of how weather and weather information have played prominent roles in United States military operations include URGENT FURY in Grenada,[4] JUST CAUSE in Panama,[5] DESERT STORM in Iraq,[6] and JOINT ENDEAVOR in Bosnia.[7] Summarily, with respect to considering meteorological conditions and their effects, United States combat operations have sometimes been conducted in accordance with the principles of Sun Tzu and the practices of General Eisenhower, while at other times they have been conducted with an apathy consistent with the sentiment described by General Philip H. Sheridan, Commanding General of the Army, who testified to Congress in 1886, "But what does a soldier care about weather? Whether good or bad, he must take it as it comes."[8] The answer to General

Sheridan's rhetorical question is that it depends on the specific military operation and on the particular systems being used by the soldiers.

While the types of weapons and other systems used in military operations have evolved over time, so too have the types of weather that have adversely impacted the operations. Moreover, the number of meteorological elements affecting military operations during the last two centuries has increased as technology has improved. Prior to the nineteenth century, armies were concerned primarily with temperature, rain, and snow because of their adverse effect on soldier exposure, trafficability, maneuverability, and visibility. As the range of artillery and other weapon projectiles increased during the nineteenth century, the importance of wind conditions increased. With the advent of air operations in the early twentieth century, cloud conditions gained relevance. And as sophisticated battlefield sensors and target acquisition systems were born in the mid-to-late twentieth century, subtler weather elements, such as humidity and slant-range visibility, took on new importance. Now, as the United States Army, together with the entire Department of Defense, accelerates the use of space systems to conduct command and control, communications, navigation, weapons delivery, surveillance, reconnaissance, theater defense, and other operations, a less familiar type of geophysical phenomena known as "space weather" is increasing in importance.

Space weather refers to electromagnetic radiation, electrically charged particles, and the environmental phenomena that the radiation and charged particles create as a result of their interactions with the earth's upper atmosphere and magnetic field. The sun is the primary source of the radiation and charged particles, and the interactions with the earth's upper atmosphere and magnetic field cause additional complex and rapidly changing space weather phenomena that can affect ground, sea, air, and space operations. Figure 1 depicts the radiation and charged particles streaming outward from the sun and engulfing the earth.

The sun emits different types of electromagnetic radiation that make up what is known as the electromagnetic spectrum (see figure 2). While "weather" refers to meteorological phenomena caused primarily by the sun's infrared radiation and its interaction with the earth's land masses and oceans, "space weather " refers to processes caused by the sun's gamma, X-ray, ultraviolet, and radio wave radiation. The sun continuously emits all of these radiation types at various intensities, and sometimes the sun emits a burst of one or more of these radiation types. In addition to the continuous radiation and the bursts of radiation, space weather includes electrically charged particles and their related phenomena.

Electrons and protons are the electrically charged particles that are most relevant to space weather, and they come from two sources. First, the sun continuously emits electrons and protons, an emission referred to as the solar wind. Similar to radiation bursts, the sun may also emit a burst of these charged particles. Additionally, the sun's ultraviolet and X-ray radiation interacts with the atoms and molecules of the earth's upper atmosphere to create a layer of electrons around the earth known as the ionosphere.

Different types of space weather occur virtually everywhere: at the sun, in interplanetary space, and in the near-earth environment to include on the earth's surface. The region of primary interest is the near-earth environment where Department of Defense operations are currently confined, and figure 3 depicts the key space weather

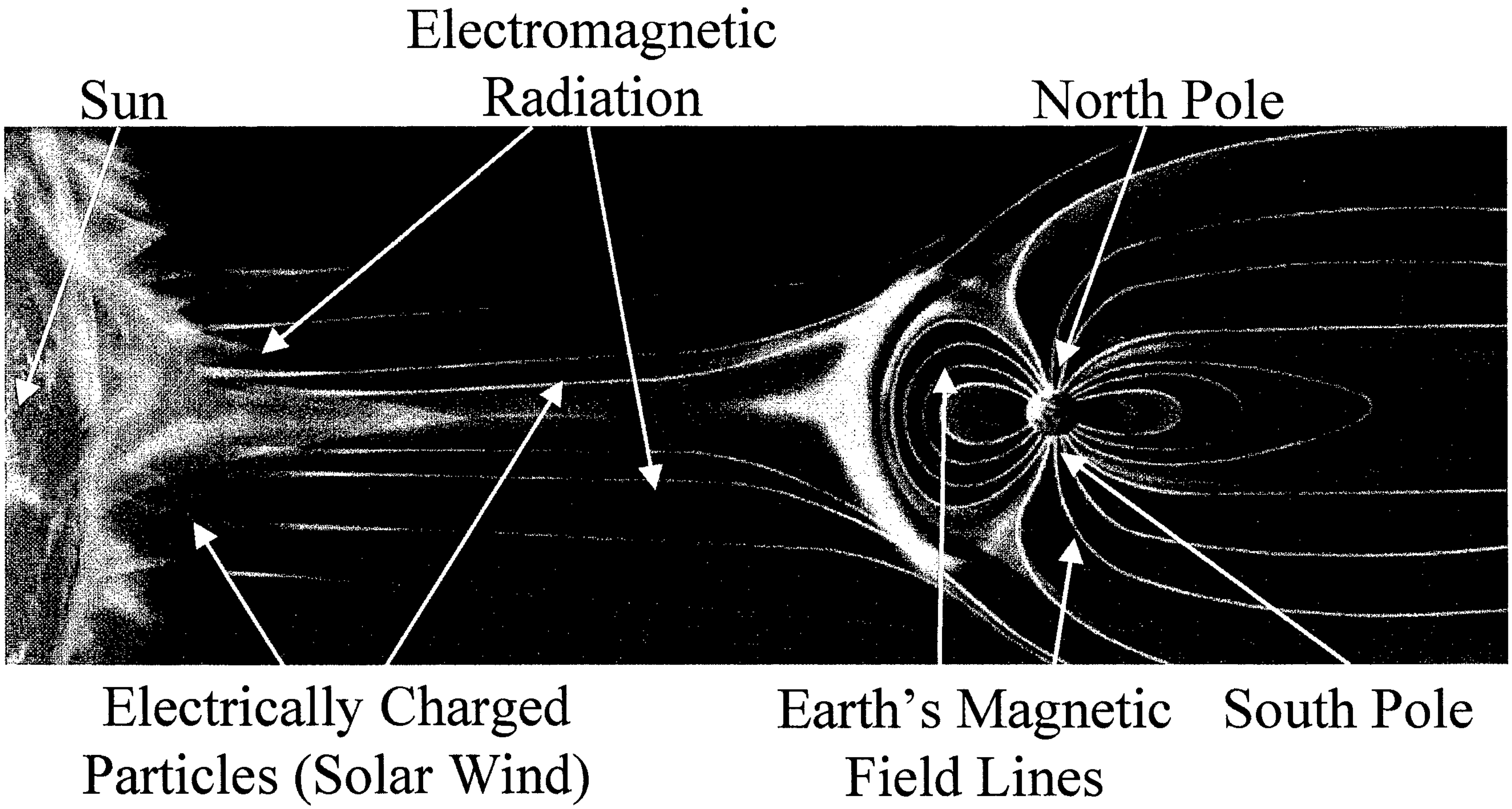

Fig. 1. Depiction of Sun-Earth environment with electromagnetic radiation and electrically-charged particles streaming outward from the Sun and engulfing the Earth. The radiation and charged particles interact with the Earth's atmosphere and magnetic field. (Not drawn to scale.)

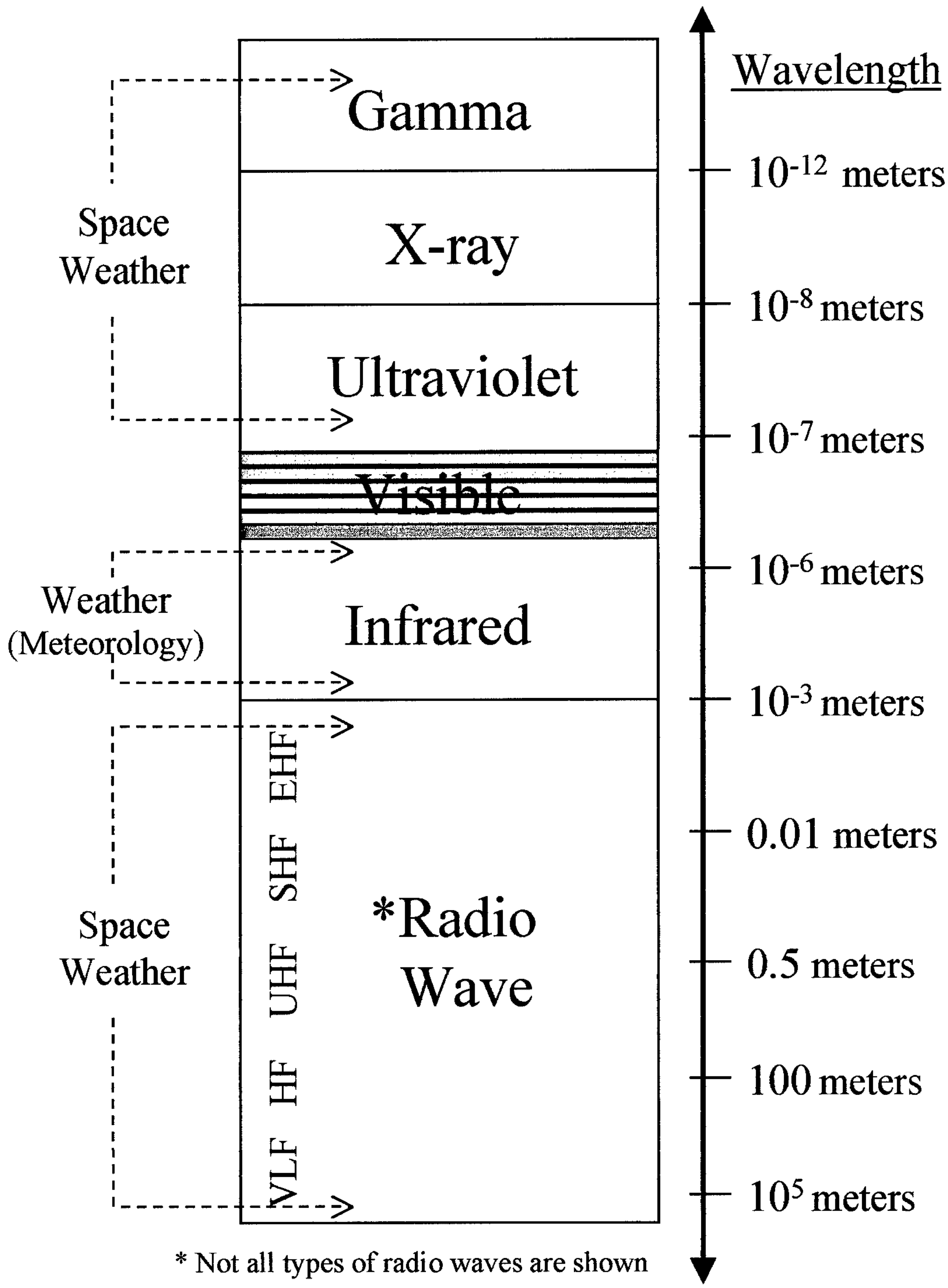

Fig. 2. Depiction of electromagnetic spectrum. Ultraviolet, X-ray, gamma, and radio wave radiation are sources of space weather, while infrared radiation is the primary energy source causing traditional weather (meteorology). The Sun emits all types of radiation at all times and may also emit bursts of one or more types.

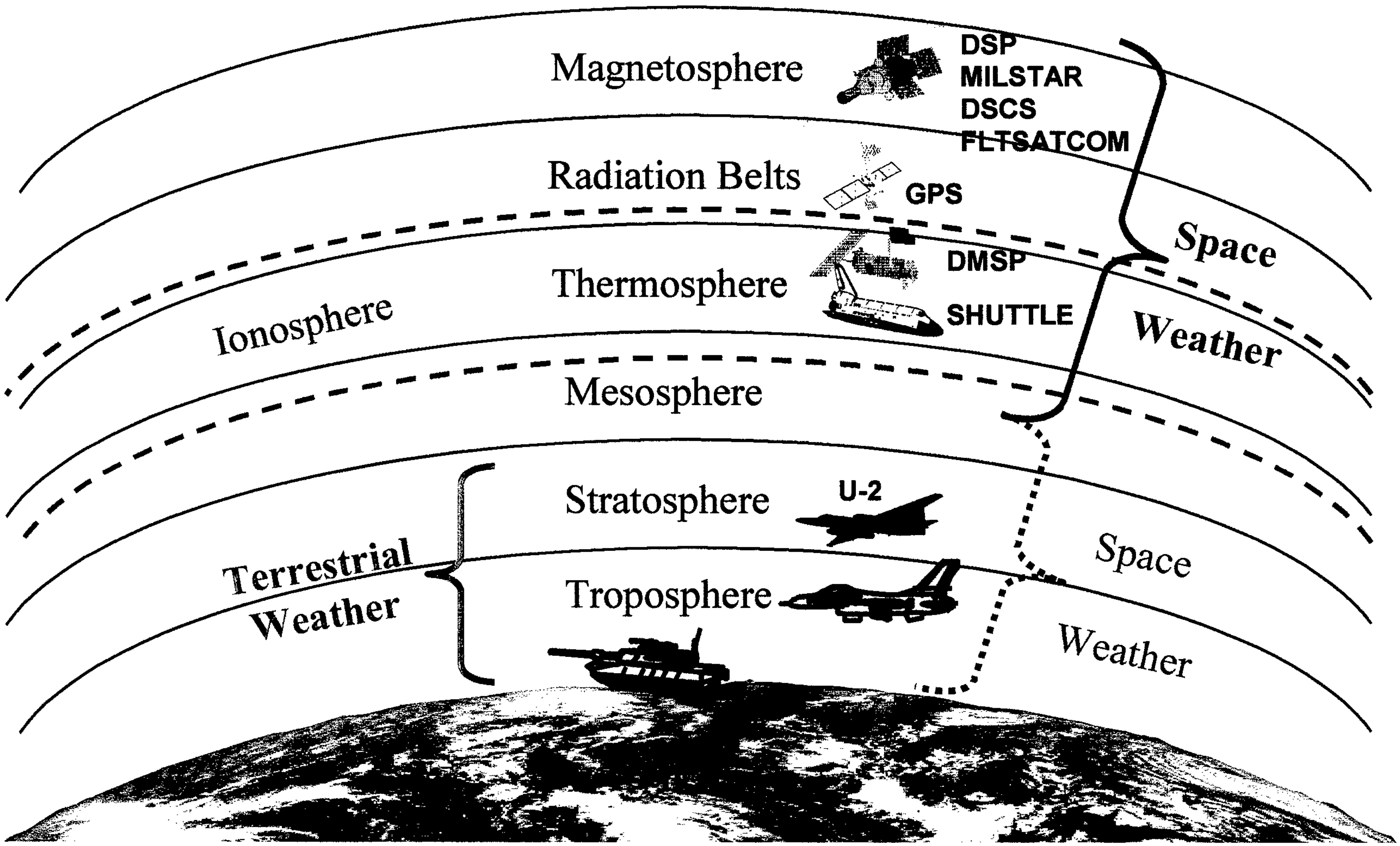

Fig. 3. Depiction of key environmental regions and examples of satellites currently in orbit. Most space weather occurs in and above the mesosphere, though some space weather also occurs in the lower layers. (Not drawn to scale.)

regions surrounding the earth. Most space weather occurs in and above the mesosphere; however, space weather, such as the sun's radio waves, can penetrate the earth's atmosphere and descend to the earth's surface. Likewise, the magnetic fields that are generated by the electrically charged particles moving within the ionosphere and magnetosphere can reach the earth's surface.

The ionosphere is an especially key layer of the earth's upper atmosphere where electron disturbances may disrupt the radio wave signals used in satellite communications, high frequency radio communications, and other space-based applications, such as navigation and surveillance. Most satellites are located above the ionosphere, and, therefore, the radio wave signals transmitted to and received from these satellites must traverse the ionosphere. Meanwhile, satellites typically orbit within either the upper ionosphere, the radiation belts, or the magnetosphere, all of which are regions where the satellites may be bombarded by energetic electrically charged particles that can cause abnormal behavior in a satellite's subsystems or sensors.

Based on this brief description of space weather, one may reasonably argue that the United States Army has not historically needed to be particularly concerned about space weather, especially in comparison to the Army's greater concern about meteorological conditions and their effects on ground operations. One seemingly obvious exception is high frequency radio wave propagation conditions in the ionosphere because high frequency radio was once a primary over-the-horizon communication mode for the Army. Regardless, military scientists are now concerned about the increased risk to Army operations due to space weather. With the Army's increasing reliance on space-based systems, the effects of space weather may adversely influence mission success.

A space weather effect refers to the radiative, electromagnetic, chemical, or dynamic interaction between space weather and system hardware, or between space weather and an electromagnetic radio wave. For example, the sun's radio wave radiation may interact with a ground-based satellite communication receiver; the magnetic field generated by electrically charged particles may interact with magnetic field sensors; electrically charged particles may collide with an orbiting satellite; or finally, the electrons in the ionosphere may interact with a communication, navigation, or surveillance radio wave signal as the signal traverses through the ionosphere. Moreover, there are two general categories of space weather effects: the effect on an actual system as space weather interacts directly with the system hardware in space and/or on the ground; and the effect on a radio wave signal as space weather interacts with the electromagnetic properties of the radio wave. Sample space weather effects include: bending, fading (weakening), or distortion of satellite communication signals, high frequency communication signals, and various surveillance signals; slowing, fading, or distortion of Global Positioning System navigation signals; generation of electric potential differences (voltages) within satellite subsystems and circuitry; and production of interference, false targets, and tracking errors in space tracking and inter-continental ballistic missile defense radars.[9] These space weather effects, discussed further in chapter two, can directly impact military operations depending on the severity of the effect and on the particular military system being used.

A space weather impact refers to the operational result or consequence caused by one or more of the physical space weather effects just described. The military space weather community delineates between "space weather effect" and "space weather impact" to separate the scientific aspect of the phenomena (effect) from that of the operational relevance of the phenomena (mission impact). For example, space weather may distort a satellite radio wave signal (effect) and disrupt tactical communications between two ground locations (impact). Space weather may weaken a space-based navigation signal (effect) and result in an artillery round missing its target because of imprecise positional data (impact). Finally, space weather might induce abnormal electrical currents within a satellite (effect) and cause the temporary loss of satellite service (impact). Some of these potential impacts are described in chapter four.

The impacts of space weather are likely to be subtler than the mission impacts caused by traditional weather. A tank becoming stuck in mud due to heavy rainfall is more recognizable than a few rounds of artillery fire barely missing a target due to slightly inaccurate space-based positional/targeting data. In the fog and friction of warfare, such a space weather impact may go unnoticed or at least may not be attributed to an atmospheric phenomenon, or it may be attributed to the wrong atmospheric phenomenon such as wind in this example.

Therefore, the nature of this problem is twofold. First, space weather awareness is not widespread, and soldiers would not, therefore, be inclined to consider or investigate it as a problem. Second, the presence of space weather is not obvious, even when it is affecting a system, because space weather cannot typically be seen or felt. Unlike clouds, wind, and precipitation, space weather is virtually invisible to the eye and is not felt by humans even when penetrating through the earth's lower atmosphere. There is one exception: the northern and southern lights, formally referred to as the "aurora borealis" and "aurora australis," respectively, are visible at high geographic latitudes and represent the presence of disturbed space weather. This lack of awareness, further magnified by the Army's expanding use of space systems, has led to the current void in understanding the relevance of space weather to Army operations.

Problem and Fundamental Question

The effects of space weather on United States Army systems have not been specifically identified, and an analysis has not been performed on the potential cumulative impacts that space weather may have on Army tactical- and operational-level operations. Therefore, a comprehensive understanding of the relationship between space weather and Army operations does not exist. The question of whether the Army needs to consider space weather during the planning and execution phases of operations is unanswered. This thesis seeks to determine whether the Army should formally include space weather information in the Intelligence Preparation of the Battlefield process.

Intelligence Preparation of the Battlefield (IPB) is the United States Army's formal process used to understand the battlefield and to identify the options that the battlefield presents to friendly and threat forces.[10] IPB is a continuous process of analyzing the threat and environment and is designed to support military decision making by determining the adversary's likely course of action, describing the environment that friendly and enemy units are operating within, and identifying the effects of the environment on those units. In essence, IPB is that part of the military decision-making process in which commanders consider weather conditions (e.g., precipitation, cloud cover, winds, air temperature, visibility, and humidity) and identify the anticipated impacts on friendly and enemy operations due to these weather conditions. The importance of weather to Army operations is reflected not only in its formal inclusion within IPB,[11] but also in how fundamental Army doctrine treats the subject of weather.

United States Army doctrine, enriched with the historical lessons of how weather can influence operations, clearly states the need for commanders to consider weather and its potential impacts. Although the Army Signal Service had first issued a weather forecast in 1871,[12] and several Army documents in the late 1800s and early 1900s had included discussions of the impacts of weather on military operations, the first United States Army doctrinal publication to describe the need for commanders to use weather forecasts appears to have been published in 1941. United States Army Field Manual 100-5 (1941) stated, "In estimating the capabilities of air, armored, and motorized forces, both friendly and hostile, the commander must be provided with full and up-to-date information on the existing and probable future weather conditions and their effect."[13] Today, United States Army Field Manual 100-5, Operations, states the importance of weather and weather information for both offensive and defensive operations, "Weather and visibility conditions significantly affect offensive operations,"[14] and "A defensive plan that succeeds in clear [weather] conditions may be less effective in periods of bad weather. Commanders and staffs need local tactical weather information as well as theater-level forecasts."[15] In stark contrast, the Army doctrinal and IPB publications are essentially silent with respect to space weather.

Current Army publications scarcely note the existence of space weather. It is not mentioned in Field Manual 100-5, Operations; Field Manual 34-130, Intelligence Preparation of the Battlefield; Field Manual 100-18, Space Support to Army Operations; or Army Regulation 115-10, Weather Support for the United States Army. However, it is briefly noted, though not described, in Field Manual 34-81, Weather Support for Army Operations,[16] and Field Manual 34-81-1, Battlefield Weather Effects.[17] The virtual exclusion of space weather from these documents is likely due to the lack of space weather awareness and understanding as previously discussed. More importantly, there is no evidence that suggests space weather had previously been considered or is intentionally being omitted from seminal Army doctrine or IPB. Somewhat paradoxically, both Joint doctrine and United States Air Force doctrine state that the Air Force is responsible for observing and forecasting space weather in support of all United States military services, although specific space weather support requirements for the Army remain undetermined.

The United States Air Force has been observing and forecasting space weather since the 1960s. Historically, the focus has been to observe and forecast the effects and impacts on strategic space assets rather than on ground and air warfighting systems.[15] The responsibility of the Air Force to provide space weather support to the Army is described in Air Force Doctrine Document 45, Aerospace Weather Operations;[19] Air Force Policy Document 15-1, Atmospheric and Space Environmental Support;[20] and Joint Publication 3-59, Joint Doctrine for Meteorological and Oceanographic Support.[21] As previously noted, space weather is not included in Army Regulation 115-10, Weather Support for the United States Army, nor is it described in Field Manual 34-81, Weather

Support for Army Operations. One consequence of these omissions is that Air Force resources currently used to observe, forecast, and disseminate space weather are not necessarily allocated or designed based on what space weather information, if any, the Army actually needs.

To determine whether or not space weather conditions should be considered in the Army's IPB, several subordinate issues must be analyzed. First, Army systems (or those systems used by the Army) susceptible to the effects of space weather must be specifically identified. Then the concepts of operations related to each of these systems must be evaluated (i.e., how does the Army use these systems). The specific effect and system must then be evaluated to determine whether the effect and potential impact is significant based on the concept of operation identified. Finally, an analysis must be performed to determine whether there would be any benefit if Army planners, operators, and decision makers had space weather information available through the IPB process.

In order to answer these questions within the time constraints of completing this thesis, four delimitations exist. First, the thesis will remain unclassified, thus excluding research efforts on operations that may be affected by space weather, such as classified space-based intelligence collection. Second, the thesis will only address systems used by the Army that are either currently operational or are scheduled to become operational before the year 2000. Third, the thesis will not consider specific enemy systems that may be affected by space weather, allowing only inferences concerning the effects on enemy systems based on the effects identified on friendly systems. Finally, because the Air Force already has an existing capability to observe and forecast space weather and to disseminate this information, the thesis will not specifically address the costs of the resources necessary to provide space weather information as part of IPB should a need be identified. Moreover, the thesis does not consider the cost benefit of including space weather in IPB; rather, it only addresses whether a reasonable need exists to do so.

In addition to the delimitations, the thesis includes one limitation. The research will rely largely on military personnel assigned to the Army Command and General Staff College to provide system technical information and to describe concepts of operation, both of which may not be available through traditional research means, such as libraries and formal publications. Therefore, the thesis research may in part be steered by and limited to the expertise, biases, and opinions of United States military personnel who may be unable to provide completely accurate and thorough information or who may provide information that is not unilaterally accepted throughout the Army.

In spite of these delimitations and limitation, this study remains potentially very significant to current and future Air Force and Army operations and may prompt a similar investigation of Navy and other United States government operations. The results of this thesis may affect acquisition and/or operational decisions within the Army and Air Force. For example, if systems are identified which are clearly affected by space weather and for which a ground commander could reasonably take action based on appropriate space weather information, then the weather information that the Air Force provides the Army during IPB may be modified to include space weather. In this case, the ultimate objective of the thesis would be to cause the Army to modify operational procedures before a real-world operational lesson is learned that identifies the need to consider space weather as part of IPB. Conversely, if the thesis identifies no operationally relevant need for the Army to consider space weather information as part of IPB, then resources now used by the Air Force to observe and forecast space weather may be adjusted or reassigned accordingly.

These issues have received visibility at the highest levels of United States military leadership as well as within the United States civilian government. The Army Deputy Chief of Staff for Intelligence noted that this issue should be investigated specifically for Army applications, and the Commander-in-Chief, United States Space Command and the Administrator of National Aeronautics and Space Administration signed an agreement to work together on space weather issues.[22] During the last two years, several United States government agencies (Department of Defense, Department of Commerce, Department of Interior, Department of Energy, National Science Foundation, and National Aeronautics and Space Administration) have formed a National Space Weather Program[23] to improve the nation's ability to observe and forecast space weather. One result of this new program is the recognition that the space weather effects and impacts on the civilian and military communities are not well quantified and must first be identified before assigning resources to improve space weather observation and forecasting capabilities.

An additional issue that further strengthens the immediate relevance of this study is related to a phenomenon known as solar maximum, a period of more frequent and severe space weather. Space weather varies in intensity and frequency over an eleven year period known as the solar cycle. The number of sunspots rises and falls during the cycle, and the number of sunspots generally reflects the severity and frequency of space weather. Solar minimum is a period of few sunspots and relatively less severe and frequent space weather, while solar maximum is about a three year period when hundreds of sunspots exist and when space weather is more severe and frequent. Based on the current phase of the solar cycle, solar scientists expect the next solar maximum to occur from 1999-2002,[24] about eleven years after the last solar maximum peak in 1989.

Advanced technology during the last two centuries has yielded more sophisticated and capable weaponry, but technology has not eliminated the need for combat forces to cope with or avoid adverse weather impacts on soldier and weapon performance while trying to exploit those weather conditions more disadvantageous to the opponent. In some cases, new systems have yielded a greater sensitivity to environmental conditions. The full significance of space weather is not yet known, particularly with respect to United States Army operations. New technologies may eliminate some adverse space weather effects experienced by currently fielded systems, while increasingly sophisticated and electronically sensitive systems planned for the near future may be affected in ways never anticipated. This thesis attempts to determine whether or not space weather conditions should be considered in Intelligence Preparation of the Battlefield in order to serve the Army's decision-making process.

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CHAPTER TWO

LITERATURE REVIEW

There are four categories of publications relevant to the question of whether space weather conditions need to be considered in Army Intelligence Preparation of the Battlefield (IPB): those that describe the United States military's expanding use of space; those that identify space weather phenomena and their geophysical causes and properties; those that specify the effects of space weather on systems and on electromagnetic radio waves; and those that address the potential space weather impacts to United States military operations.

The amount of published literature varies significantly among the four categories. There are several Joint and Army publications that describe the importance of space systems to current and future military operations. Scientific journals contain hundreds of technical articles that describe various space weather phenomena and their causes, while publications that address the specific effects of space weather are less abundant. Conversely, as alluded to in chapter one, virtually nothing has been published regarding the potential space weather impacts on current or future Army operations, nor has there been anything published regarding the need, or lack thereof, to include space weather information in IPB.

The published literature leaves little question as to the future relevance of space systems with respect to United States military operations. While the Air Force is currently transitioning from an air force to "an *air and space* force on an evolutionary path to becoming a *space and air* force,"[1] the Army is simultaneously leveraging the existing national space capabilities and is advancing toward information-intense operations using space technologies. Field Manual 100-18, Space Support to Army Operations, establishes doctrine for the Army's use of space and states, "The Army is involved in space because it can no longer effectively and efficiently execute its missions and maintain a technological advantage without exploiting space-based capabilities."[2] The Army space policy, issued by the Secretary of the Army and the Army Chief of Staff, states, "Future success of Army forces will be critically dependent upon exploitation of space assets, capabilities, and products across the entire spectrum of military operations."[3] FORCE XXI Operations, describing in general terms how the Army will operate in the early twenty-first century, states, "In addition to strategic and doctrinal changes, significant technological advances are associated with entry into the Information Age. Air Force satellite technology could greatly benefit land operations."[4] The success of FORCE XXI operations depends on spectrum supremacy; "as a result, future organizational design must consider increased use of electronic and direct-energy warfare."[5]

In concert with these Army publications, Joint Vision 2010 also states the importance of exploiting space applications. Providing a conceptual description for how combat forces will leverage technological opportunities to improve joint warfighting, Joint Vision 2010 states, "Technological advances will continue the trend toward improved precision. Global positioning systems, high-energy research, electromagnetic technology … will provide increased accuracy and a wider range of delivery options."[6] Collectively, these Army and Joint policy and doctrinal statements provide a hint of the potential increased relevance of space weather in the future.

The Department of Defense Technology Area Plan predicts what types of technology and scientific advances will be necessary to achieve the military services' visions. Regarding space and space weather, the plan states, "Information superiority relative to the space/upper atmosphere environment is required in order to maintain control of the 'high ground' during all levels of engagement. Recognized communications deficiencies in recent warfighter engagements (Panama, Bosnia, and the Persian Gulf) have identified the need for improved C3I battlespace [environment] specifications."[7]

One category of literature that has flourished in recent years includes highly technical articles that describe various space weather phenomena and their solar, electromagnetic, chemical, and other geophysical causes. These publications serve this thesis in that they confirm the existence of space weather and provide a confidence that the phenomena are observable, measurable, and predictable because they follow physical principles and laws. The Department of Defense Handbook of Geophysics and the Space Environment[8] provides a comprehensive review of various space weather phenomena. During the last decade since the publication of the handbook, space physicists have published hundreds of additional scientific papers in journals such as the Journal of Geophysical Research and Radio Science. These efforts have focused primarily on expanding the knowledge of the geophysical processes that cause space weather phenomena. Less technical descriptions of space weather have been recently published in Discover,[9] Time,[10] Aviation Week and Space Technology,[11] and Army Times,[12] all of which make the discussion of space weather more palatable to a nonexpert. The challenge remains to bridge the gap from the study of space weather and its causes to the study of space weather effects and subsequent impacts.

The United States government agencies that form the National Space Weather Program (see chapter one) have published an implementation plan[13] in part to improve the understanding of the effects and impacts of space weather on the military and civilian communities as well as to increase the understanding of specific space weather geophysical processes. Because the plan was just published in 1997, it will take a period of time for the scientific community to respond. In the mean time, a pamphlet published by Air Force Space Command currently stands as the most militarily applicable formal publication regarding space weather types, effects, and potential impacts.

Air Force Space Command Pamphlet 15-2, Space Environmental Impacts On DoD Operations, identifies various types of space weather, discusses their general effects, and relates the effects to the potential impacts on United States military systems.[14] This publication is not quantitative (i.e., it does not include magnitudes of effects or specifically identify which and how many military systems are potentially affected), and it focuses primarily on causes and general effects of space weather while addressing general impacts to Air Force systems. The Space Reference Text[15] used at the Army Command and General Staff College contains a similar subset of information.

Air Force Space Command Pamphlet 15-2 and the Handbook of Geophysics and the Space Environment collectively describe space weather types, effects, and impacts in the following areas: satellite operations, high frequency communications, satellite communications, ground-based space radar operations, Global Positioning System operations, and space-based surveillance operations.

Space weather can affect satellite operations by damaging satellites, inducing false readings in satellite sensors, causing anomalous (unexpected) behavior in satellite subsystems, and modifying a satellite's orbit. In most cases, these effects are caused by large disturbances of energetic electrically charged particles bombarding a satellite. These disturbances have caused several satellite failures and thousands of anomalies during the last two decades. In 1994, an abnormally intense space weather disturbance likely caused the complete failure of a Canadian communications satellite,[16] and in 1997, a United States commercial communications satellite, Telstar, permanently failed hours after the onset of a similarly intense disturbance.[17] Of course, temporary satellite anomalies are more common than permanent failures, and the Air Force Space Command maintains a classified database of Department of Defense satellite anomalies caused by space weather.

A second type of space weather effect caused by the direct interaction between space weather and system hardware is radio wave interference. As described in chapter one, the sun may emit a burst of electromagnetic radiation at several frequencies throughout the electromagnetic spectrum. If a ground- or space-based radio wave receiver is pointed toward the sun when the burst occurs, then the receiver will experience interference if the burst frequency is near the receiver's operating frequency.

Perhaps more importantly, space weather within the ionosphere can affect electromagnetic radio waves used in applications such as communications, navigation, and surveillance. Figure 4 depicts the range of radio waves and general effects caused by space weather. The type and intensity of the effect depend on the radio wave frequency.

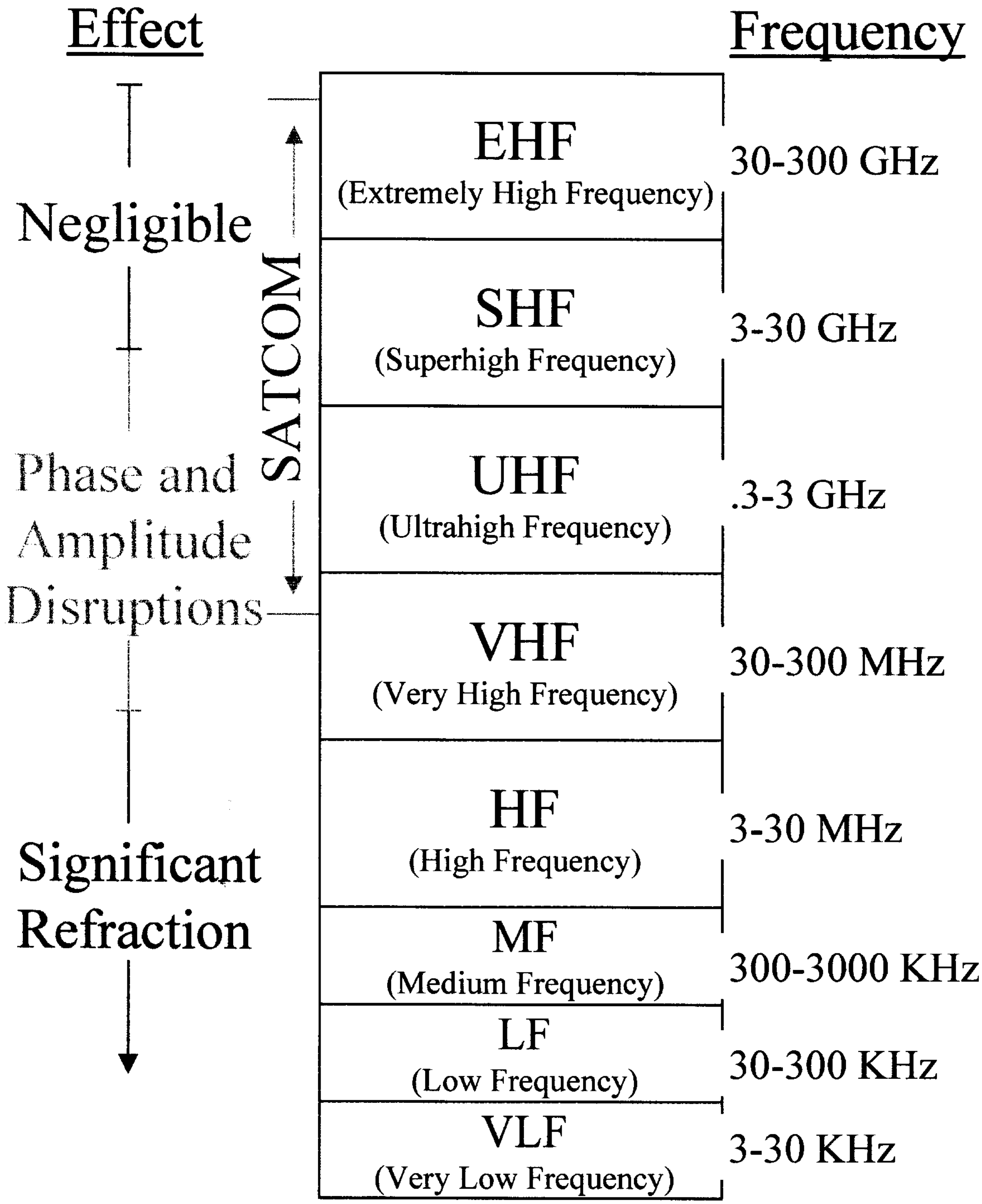

Fig. 4. Depiction of the types of radio signals within the radio wave portion of the electromagnetic spectrum, and the general ionospheric effects on those signals. (The bandwidths for each frequency band are not drawn to scale.)

High frequency signals and signals at lower frequencies used for over-the-horizon applications are literally controlled by the ionosphere; the properties of the ionosphere refract (bend) the radio waves back down to earth. Space weather disturbances within the ionosphere can degrade or completely interrupt applications at these frequencies.

Most very high and all ultrahigh frequency signals penetrate through the ionosphere, but as they move through the ionosphere they are slowed down and may be modulated or distorted by space weather disturbances. The severity of the effect is a further function of radio signal power at a given frequency, and the impact that this effect might cause, such as interrupting satellite communications, is also a function of the performance characteristics of the radio wave receiver being used.

Superhigh frequency signals are affected significantly less than the lower frequency signals. With the exception of the lower portion of the superhigh frequency band, the effects of space weather on these signals are mostly negligible for current Department of Defense communication applications. However, the effects of space weather on other military applications that use these frequencies are not trivial, such as causing positional tracking errors for space surveillance applications.

Extremely high frequency signals are virtually unaffected by space weather, although meteorological elements like heavy rain can absorb, reflect, and disrupt them.

With regard to these types of radio wave effects on Army operations, Army Field Manual 34-81, Weather Support for Army Tactical Operations, states that ionospheric disturbances (a broad category of space weather) may "degrade electronic collection and radio communication systems."[18] The space physics, communications, and intelligence communities have known about these effects for several years, but in many cases the specific effects have not been identified system by system. With few effects quantified, a potential impact can rarely be described more definitively than the generic description currently provided in Field Manual 34-81.

In addition to this thesis study, two other complementary efforts are currently underway which are designed to improve the understanding of space weather effects and impacts. The Air Force Space Command Directorate of Requirements is working on a Space Environment Capstone Requirements Document to assess the needs to observe and forecast space weather, and this effort focuses on Air Force Space Command operational needs. Although that effort does not specifically study Army applications, there are similarities in the systems used by the Air Force and Army even though the implications of the space weather effects may differ. Also, the Department of Defense Office of the Space Architect recently began a study on whether the current architecture used to collect space weather data needs improvement. The study includes an evaluation as to the relevance of space weather to the Department of Defense; the architect group has asked that the results of this thesis be made available to assist with their study.

The published literature describes a future in which the United States military will exploit advanced technologies and space systems. The literature also reflects the efforts of space physicists who have identified various space weather phenomena and continue to discover new causes and effects. Actions are underway, including this thesis study, to better specify the effects and then to apply these effects to specific military systems to determine the degree of degradation of system performance. The published literature is lacking with respect to these potential impacts, so analyses have not been possible which determine whether there is a nontrivial need for battlefield commanders to consider space weather in mission planning and execution.

Following this void, the research methods of this thesis aim to: identify United States Army systems (or those used by the Army) affected by space weather; quantify those effects, if possible, through technical analysis of system performance specifications; identify the subsequent potential impacts by analyzing the effects with respect to the concepts of operations (how the Army employs the systems); and determine whether the decision-making process is better served by including space weather information, such as observations and forecasts of the phenomena.

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2. Department of the Army, FM 100-18, Space Support to Army Operations (Washington, DC: Government Printing Office, July 1995), ii.

3. Department of the Army, Space Policy Letter (Washington, DC: HQ DA, July 1994), 1.

4. Department of the Army, TRADOC Pamphlet 525-5, Force XXI Operations (Washington, DC: Government Printing Office, August 1994), p. 1-2c.

5. Ibid., p. 4-3.

6. Department of Defense, Chairman of the Joint Chiefs of Staff, Joint Vision 2010 (Washington, DC: Government Printing Office), 3.

7. Department of Defense, Technical Information Center, Defense Technology Area Plan (Washington, DC: Government Printing Office, April 1997), chap. 7, p. 3.

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13. Department of Commerce, Office of the Federal Coordinator for Meteorological Services and Supporting Research, National Space Weather Program Implementation Plan (Washington, DC: OFCM, 1997), 1.

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15. United States Army Command and General Staff College, U.S. Army Space Reference Text (Fort Leavenworth: USA CGSC, January 1995), chap. 5, p. 1-23.

16. David Schultz, "Knock-out Punches From the Sun," Canadian Geographic, May/June 1994, 14.

17. Kathy A. Svitil, "It Came From the Sun," Discover, June 1997, 36.

18. Department of the Army, FM 34-81, Weather Support to Army Tactical Operations (Washington, DC: Government Printing Office, August 1989), 14.

CHAPTER THREE

RESEARCH METHODOLOGY

The research methodology of this thesis follows a five-step process to determine whether or not space weather information should be included in the United States Army Intelligence Preparation of the Battlefield process. The research begins by identifying systems that the Army uses which may be affected by space weather. In essence, this first step selects candidate systems that warrant further investigation as to whether space weather can affect them. After a system is chosen as one that is potentially susceptible to the effects of space weather, then a system-specific evaluation is performed to identify and, if possible, quantify the particular space weather effect. Next, the concept of operation for the system is investigated, leading to an understanding of how the Army employs the system on the battlefield. The space weather effect identified in step two is then considered in light of the system's concept of operation in order to project the potential operational impacts caused by space weather. Finally, using the information obtained from the preceding steps for each of the systems, the last step includes a subjective analysis of the utility of adding space weather information into the Army's military decision-making process.

The first research step includes identifying systems used by the Army which may be affected by space weather. Based on the fundamental properties of space weather commonly accepted within the space physics community, and as described in Air Force Space Command Pamphlet 15-2, Space Environmental Impacts on Department of Defense Operations,[1] and the Handbook of Geophysics and the Space Environment,[2] the following general criteria are used to select candidate systems that may be affected by space weather:

1. Does any part of the system operate in space?
2. Does any part of the system transmit or receive an electromagnetic wave that traverses through or within the ionosphere?
3. Does any part of the system include a radio wave signal receiver that points toward the Sun at any time during operation?
4. Does any part of the system measure magnetic fields or rely on the measurement of magnetic fields?

These criteria are evaluated against systems used by the following combat arms and combat support branches: air defense artillery, armor, aviation, engineer, field artillery, infantry, military intelligence, signal, and special forces. Tables of organization and equipment provide a baseline listing of systems, and multiple reference documents and other publications provide system descriptions. In addition, the knowledge and personal experiences of Army Command and General Staff College students and faculty are used to gain information concerning systems used by the Army. In this step and throughout the research process, information obtained from personnel is considered accurate if it is consistent among at least three qualified individuals from an appropriate branch.

Once systems have been evaluated using the criteria described in step one, the next step is to specify and, if possible, quantify the space weather effects on those systems that meet at least one of the candidate criteria. To specify the space weather effect, the properties of the specific type of space weather are analyzed against the performance characteristics of the system. For example, an ionospheric disturbance referred to as a short-wave fade can partially or completely absorb high frequency radio waves when they enter the lower ionosphere. The magnitude of the effect varies, ranging from complete absorption to negligible signal fading (weakening) because the intensity of the ionospheric disturbance can vary considerably. As noted in chapter two, the magnitude of the effect also varies as a function of the specific radio wave frequency. If a system includes a radio wave transmitter or receiver that operates within the high frequency band, then the space weather effect on the system (during the disturbance) would be the partial or full absorption of the radio wave; the effect prevents the radio wave from reflecting and/or propagating as designed by the system.

As previously discussed, the various space weather properties that are considered in this analysis are those properties that are generally accepted by the space physics community. In cases when the analysis is less obvious, discussions are conducted with Department of Defense space physicists assigned to the Air Force Research Laboratory, Hanscom Air Force Base, Massachusetts.

The performance specifications of a system being evaluated are obtained from military publications and other technical reference documents. Additionally, discussions are conducted with Army personnel who have operated the system or with contractor personnel who are knowledgeable with system design or operation.

Once a system has been identified as being susceptible to the effects of space weather in a nonnegligible quantity, an analysis is performed of how the Army uses that system throughout the various echelons and various levels of operations. The Army units that doctrinally use the system are identified, and how those units use the system as part of the combined arms team is evaluated. This information is necessary because the question of whether space weather information should be used in the operational decision-making process can only be answered as a function of how the systems are used in a particular operation. The data from this step is again taken primarily from discussions with Army Command and General Staff College students and faculty who have used the systems as well as from Army publications that describe how a system is typically employed. The concepts of operation are also needed to identify the potential operational impacts caused by space weather.

The effects of space weather, the magnitudes of those effects, and the concepts of operations for a particular system must be analyzed in concert with one another to determine the potential operational impacts of space weather. For example, a space weather effect might confuse a tactical intelligence collection sensor to such a degree in which the sensor may not be able to accurately collect on a target. If the concept of operation for this intelligence collection system is that a Military Intelligence battalion operates the system as the primary collector for a particular type of intelligence data within a maneuver brigade's area of operation, then a potential impact might be that the actions of an adversary would go either unnoticed or uncorroborated. The potential impacts postulated in this step are largely derived subjectively and are, necessarily, discussed with Army Command and General Staff students and faculty to ensure that the projected potential impacts are reasonable.

If, at any time during the research process, the effects or impacts of space weather are established as trivial based on parameters such as negligible magnitudes or unrelated concepts of operation, then the subsequent research steps are not performed for that particular system.

The final step builds directly toward answering the fundamental question of this thesis. Based on how a system is employed (concept of operation), and based on how the system can be affected by space weather, the utility of using space weather information in the planning and employment of a system is evaluated. The subordinate question within this final step is: what use, if any, would be served by providing space weather information to a commander or system operator? The utility is determined by whether or not a commander or operator would make any decision or take any action based on the receipt of space weather information. Although one of the delimitations of this thesis (see chapter one) is that the costs of providing space weather information would not be considered, this step takes into account the space weather information that is currently available from or could be provided by the Air Force Space Command's 55th Space Weather Squadron.[3] Moreover, the Department of Defense's current capability to provide space weather information is used as a baseline in this step; the analysis does not imagine some new or improved type of space weather information in determining the utility of the Army using the information.

The strengths of the research methodology exist in the sequential and interdependent stepping process that provides a clear map of how the study is performed. The thesis' five-step process allows for a systematic, bottom-up analysis of individual systems and then proceeds to a subsequent and interrelated step, building toward an answer to the fundamental question of the thesis. This process provides an easy opportunity for anyone to repeat parts or all of the research in order to critically review or build from the results; the process leaves little question as to the origins of a supposition or conclusion contained in the thesis. Also, the first three steps are relatively objective in nature and, therefore, decrease the chance for biases to control the process. Finally, to augment the published information and, in some cases, to fill the void of unpublished information, the methodology exploits the knowledge and personal experiences available from the pool of expertise at the Army Command and General Staff College.

The weaknesses of the research methodology exist primarily in the rigidity of the five-step process. Although the research structure is designed to rein in unfocused efforts as well as to provide the strengths already described, the rigid process may stifle the exploration of other approaches and could inhibit relevant information from entering the study's analysis.

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2. Department of the Air Force, Air Force Materiel Command, Phillips Laboratory, Handbook of Geophysics and the Space Environment (Hanscom AFB, MA: PL, 1985), 1 passim.

3. Department of the Air Force, Air Force Catalog 15-152, Space Environmental Products (Washington, DC: Government Printing Office, 1992), 1 passim.

CHAPTER FOUR

ANALYSIS

This chapter identifies systems used by the United States Army which are susceptible to nonnegligible effects of space weather as described in steps one and two of the thesis methodology. (Note: Although efforts were made to identify all systems adversely affected by space weather, the exclusion of a system in this chapter does not necessarily mean that the system is not affected; security sensitivities and classifications or a lack of information may have precluded a system from being described here.) The analysis includes: brief descriptions of each of the systems; a discussion of the applicable space weather effects; summaries of how the Army employs the systems; suppositions of potential operational impacts due to the effects; and statements of how space weather information could be used to mitigate the impacts.

The systems identified as being affected by space weather are categorized in five areas: communications systems that use ultrahigh and superhigh frequency satellite radio signals or high frequency over-the-horizon radio signals; intelligence collection systems, primarily those that intercept high frequency over-the-horizon radio signals; electronic attack systems that use high frequency over-the-horizon radio signals; intelligence dissemination systems that use a network of ultrahigh frequency satellite communications systems; and navigation systems that use the Global Positioning System for purposes ranging from basic ground navigation to precision-guided weapon delivery.

Communications

The communication systems operated by the Army which are affected by space weather are high frequency over-the-horizon systems, ultrahigh frequency satellite communication systems, and superhigh frequency satellite communication systems. The high frequency systems are designed to communicate over-the-horizon using the ionosphere as a reflecting media and are, therefore, virtually controlled by space weather. The ultrahigh frequency satellite communication systems send and receive radio waves that can be significantly disturbed as they traverse through the ionosphere, resulting in the intermittent disruption or prevention of communications. The superhigh frequency satellite communication systems can experience interference because they operate at radio wave frequencies in which the sun may emit bursts of radio waves.

High Frequency Communications

As briefly explained in chapter two, space weather conditions in the ionosphere virtually control high frequency radio signals used for over-the-horizon applications. The Army operates systems, each described below, which use high frequency radio signals to communicate beyond line of sight. Space weather affects all of the high frequency systems in the same ways.

There are three categories of space weather effects on these systems. First, space weather can cause the partial or total absorption of the high frequency radio waves that the systems attempt to transmit and/or receive. For example, a burst of X-ray radiation from the sun can generate an abnormally high number of free electrons (electrons that are not attached to an atom or molecule) within the lower regions of the ionosphere. When the high frequency radio signals enter the lower ionosphere, the signal is absorbed partially or fully because of interactions with the electrons, atoms, and molecules of this region. The remaining signal, if any, which is subsequently refracted back toward the ground where it is supposed to be received may be too weak or distorted for reception.

Another effect is that space weather can cause the high frequency radio signals to penetrate the ionosphere and continue out into space rather than be refracted back towards the ground for reception. For example, enhanced levels of electrically charged particles originating in the magnetosphere can subsequently heat the lower thermosphere and cause the upward expansion of atoms and molecules. When these atoms/molecules move up into the middle ionosphere, they combine with the free electrons that reside there and that normally serve to refract the high frequency radio signal. Once the electrons become attached to the atoms/molecules, the electrons are unable to refract the radio wave downward toward the earth.

Finally, space weather can cause the radio wave to take unusual paths before it is finally refracted back toward earth. For example, irregular regions of densely packed electrons in the ionosphere can trap the radio signal within the ionosphere and cause the signal to split in different directions. Eventually, the split signals may be refracted downward, but when they reach the earth's surface they can be well displaced from the intended receiver. On the other hand, the split signals might reach the intended receiver, but the signal reception can be difficult or impossible when the same portion of the signal is received twice, at two slightly different times, due to the signal taking different paths before ultimately reaching the receiver.

The intensity and frequency of occurrence of these effects depend on several variables including geographic location on earth, the time of day, and the solar cycle as described in chapter one. Summarily, in response to various solar phenomena such as sunspots, solar flares, coronal holes, and the resulting processes within the ionosphere, these effects can occur at all locations on earth during daytime or nighttime. Based on historical data and the current phase of the solar cycle, these types of effects will increase in frequency of occurrence and in intensity during the next four years. All of the following systems are susceptible to the effects just described.

AN/ARC-220/VRC-100 High-Frequency Radio

The AN/ARC-220 (airborne) and VRC-100 (vehicle-mounted) radio systems provide voice and data over-the-horizon communications using secure and nonsecure high frequency radio signals.

Ground and air forces assigned to United States Army Special Operations Command employ these systems to meet a wide variety of communications needs while conducting sensitive operations. In some cases, communications are executed via a high frequency, split-second transmission burst at a preplanned time in order to reduce security risks to friendly forces.

An operational impact caused by the effects of space weather on these systems could be the failure of special operations forces to communicate as planned.

Commanders and system operators could mitigate this impact by using space weather information in the following ways: identify periods when and locations where high frequency sky wave communications are expected to be poor and, if necessary, use other communications modes to satisfy the communication requirement; identify specific frequencies within the high frequency band which are most likely to provide successful communications; and identify the optimum angle of incidence with the ionosphere at which to focus the high frequency transmission in order to reach the intended receiver.

AN/GRC-193/GRC-213/PRC-104 Improved High-Frequency Radio Set

The AN/GRC-193 (vehicle-mounted), GRC-213 (vehicle-mounted or man-pack), and PRC-104 (man-pack) systems provide voice and data over-the-horizon communications using secure and nonsecure high frequency radio signals.

Corps and division long range surveillance units may use these systems, depending on the operation, as their primary mode of communications while positioned as far as 150 kilometers forward of the Friendly Line of Own Troops. In some cases, communications using these systems are executed via a high frequency, split-second transmission burst at a preplanned time in order to reduce security risks to friendly forces. Conventional combat and combat support forces throughout all echelons employ these systems as secondary communications modes.

An operational impact caused by the effects of space weather on these systems could be the failure of infantry surveillance units to communicate with their command and control centers.

The utility of using space weather information is as previously described for the high frequency radio communication systems.

AN/TRC-179 Regency Net System Terminal

The Regency Net system provides the Commander-in-Chief of United States European Command with an independent secure voice and data over-the-horizon communications system using high-frequency radio signals.[1]

Army units assigned at echelons above corps throughout United States European Command employ the system when directed.

The operational impacts and utility of using space weather information are as previously described for the high frequency radio communication systems.

Integrated Meteorological System

The Integrated Meteorological System (IMETS) is a weather data communication system that receives, processes, and disseminates weather observations (alpha-numeric and satellite imagery), forecasts, and weather effects decision aids in support of Army ground and air operations. One way IMETS receives weather data is via high frequency over-the-horizon radio signals.

Air Force weather teams assigned to echelons above corps, corps, divisions, armored cavalry regiments, special operations force units, separate brigades, and aviation brigades employ IMETS to inform combat forces of when meteorological conditions may adversely affect friendly and/or enemy operations.

The impacts caused by the effects of space weather on IMETS could include the failure of maneuver forces to be aware of adverse meteorological conditions that can affect friendly and/or enemy combat operations.

Commanders and system operators could use space weather information to identify periods when high frequency radio receipt of meteorological conditions will not be possible. They may, therefore, take action to secure meteorological data via other means, such as via satellite communications, if available. Space weather information could also be used to identify specific frequencies within the high frequency band that are most likely to provide successful receipt of meteorological data.

Ultrahigh Frequency Satellite Communications

As noted in chapter two, space weather conditions in the ionosphere affect ultrahigh frequency radio waves traversing through the ionosphere. The type and magnitude of the effect are a function of the particular frequency used within the ultrahigh frequency band. The Army operates satellite communications terminals, each described below, which operate at frequencies between 225-400 megahertz (see figure 4 in chapter two). Technically, the bandwidth between 225-299 megahertz falls within the very high frequency band, but the Department of Defense refers to the 225-400 megahertz bandwidth as ultrahigh frequency.[2] The terminals are relatively lightweight, readily available, and easy to use. Moreover, as described in the Army Satellite Communications Architecture, ultrahigh frequency satellite communications "has the advantage of low cost user terminals that are small and lightweight and can operate well with small, portable antennas. [Ultrahigh frequency satellite communications] can be used on the move under adverse [meteorological] conditions and in dense foliage."[3] Space weather affects each of these ultrahigh frequency satellite communications systems in virtually the same way.

The primary space weather effect on ultrahigh frequency radio waves between 225-400 megahertz which are traversing through the ionosphere is a weakening of the radio wave and a shifting of the radio wave's phase. This effect occurs when space weather processes create large gradients in the electron density within the ionosphere. An affected radio wave traverses through regions where, at one moment, fewer electrons exist, and a moment later, the radio wave abruptly encounters a large number of electrons. The result of this phenomenon is commonly referred to as scintillation. The

Army's Satellite Communication Architecture states, "Ultrahigh frequency signals are easily disrupted by natural scintillation."[4] The effect of scintillation at the lower frequencies within the ultrahigh frequency band can make the radio wave unrecognizable to a receiver, thereby preventing or interrupting communication.

Unlike the effects of space weather on high frequency radio waves, the scintillation effect on ultrahigh frequency radio waves does not occur at all times of day nor at all locations throughout the world. Instead, the scintillation effect of concern to Army ultrahigh frequency satellite communication applications is extremely dependent on location, time of day, and stage of the solar cycle. This dependence is due to interrelated processes involving the earth's magnetic field, the changing ionospheric properties after the sun sets (i.e., the sun's radiation does not reach the nighttime ionosphere), and the electric currents within the ionosphere.

There are two regions on earth where scintillation is known to commonly occur at levels that can affect ultrahigh frequency satellite communication systems, and the regions are determined by the earth's magnetic field. First, space weather processes at high magnetic latitudes can cause scintillation as a result of enhanced electric currents in the magnetosphere. The same phenomena that cause the northern lights (aurora borealis) can also cause the scintillation. For practical purposes, this effect occurs only at night and is typically confined to Alaska and the extreme northern Pacific Ocean, central and southern Canada, the northern Atlantic Ocean, and extreme northern Asia. This specific effect can extend further southward during the most intense space weather disturbances.

A larger, more intense, and more common region of scintillation that affects ultrahigh frequency radio waves traversing the ionosphere occurs at lower latitudes.

Again, the effect and its location are directly related to the earth's magnetic field. For practical purposes, this effect occurs at night and is confined to South America, the south-central Atlantic Ocean, Africa, southwest Asia, and the southern Far East. Of particular interest is that this effect is rarely experienced in the United States or in central Europe where most in-garrison and training operations are conducted.

These effects are intermittent for a few reasons: the scintillation-causing regions of the ionosphere move and change shape and intensity in response to various space weather processes; the communication satellites orbit around the earth above the scintillation-causing regions; and the ground terminals also move as the earth rotates below the regions. Based on historical data and the current phase of the solar cycle, these types of effects will increase in frequency of occurrence and in intensity during the next four years, occurring intermittently for several hours during the night. All of the following systems are susceptible to the effects just described.

AN/PSC-5 Enhanced Man-pack Ultrahigh Frequency Tactical Satellite Communications Terminal (Spitfire) and PSC-7 Miniature Satellite Transceiver

The Spitfire and Miniature Satellite Transceiver (MST-20) are lightweight, man-portable ultrahigh frequency transceivers that provide on-the-move voice and data satellite communications at frequencies between 225-400 megahertz.

The Army is currently fielding the Spitfire to combat and combat support units at all echelons; the system will eventually replace all of the Army's existing ultrahigh frequency man-portable and vehicle-mounted satellite communication radio terminals. The Spitfire and MST-20 are used as the sole satellite communications system in the Corps and Division Warfighter Nets. "The primary mission of the Warfighter Net is to provide the Corps and Division Commanders with an improved command and control system. The commander uses this net for tactical control, combat coordination, and tactical data reporting of combat forces, long range surveillance units, support units, ... and engineer units. The Commanders distribute terminals [to their subordinate units] based on mission and their preference for communications."[5] The Warfighter Net can interface with all of the other ultrahigh frequency satellite communication systems (described below) that are used in the corps and division areas. Additionally, special operations units operate the MST-20 to meet a variety of communication needs.

An operational impact caused by the space weather effects on these systems could include the failure of corps and division command and control elements to establish communications with their respective combat forces.

Commanders and tactical satellite communication system operators could mitigate space weather impacts by using space weather information in the following ways: identify periods when and locations where ultrahigh frequency satellite communications may be temporarily prevented and, if possible, use other modes to satisfy the communication requirement; and schedule ultrahigh frequency satellite communications at times less likely to be disrupted. Most importantly, combat forces could consider space weather conditions before deciding to rely on ultrahigh frequency satellite communications to meet an anticipated, time-sensitive communication need.

AN/PSC-3/VSC-7 Ultrahigh Frequency Satellite Communications Tactical Terminals, AN/PSC-10 Lightweight Satellite/Line-of-Sight Terminal, and HST-4A/C

The PSC-3 (man-portable), VSC-7 (vehicle-mounted), PSC-10 (portable man-pack, vehicle-mounted, airborne, and fixed station), and HST-4A/C (compact) are ultrahigh frequency transceivers that provide voice and data satellite communications using frequencies between 225-400 megahertz.

Special operations forces, Army ranger units, long range surveillance units, and other infantry units employ these systems, primarily in forward locations or behind enemy lines, in order to communicate with their command and control elements and other appropriate units. Users may communicate via an ultrahigh frequency split-second transmission burst at a preplanned time in order to reduce security risks to friendly forces. The VSC-7 may also serve to control a network of PSC-3 terminals. Additionally, combat, combat support, and combat service support units assigned throughout all echelons use these systems for communicating beyond line of sight.

An operational impact caused by the effects of space weather on these systems could be the inability of forward combat forces and other maneuver and combat support units to establish communications with command and control agencies. The utility of using space weather information to mitigate the impacts is as previously described.

AN/GSC-40/MSC-64 Ultrahigh Frequency Satellite Communications Terminal

The GSC-40 and MSC-64 are ultra-high frequency transceivers that provide voice and data satellite communications at frequencies between 225-400 megahertz.

Command posts at echelons above corps in Europe employ these systems to communicate with tactical forces and other command posts; the systems are used to transmit (GSC-40) and receive (MSC-64) Emergency Action Messages.[6]

The operational impacts and utility of using space weather information are as previously described.

AN/TRC-194 Milstar Ground Command Post Terminal

The TRC-194 command post terminal provides voice and data satellite communications primarily using extremely high frequencies not affected by space weather. However, the system includes an ultrahigh frequency transceiver to provide voice and data satellite communications at frequencies between 225-400 megahertz.

The system is employed in support of echelons above corps activities and National Command Authority communications to and from a theater. A National Command Authority communication may be made to the theater through the extremely high frequency satellite communication terminal, and then the communication may be forwarded to tactical forces using the ultrahigh frequency satellite communication terminal.

An operational impact caused by the effects of space weather on this system could be the inability to inform forward tactical forces of National Command Authority directives. The utility of using space weather information is as previously described.

Superhigh Frequency Communications

As noted in chapter two, the effects of space weather on superhigh frequency radio wave applications are typically less significant than on high frequency and ultrahigh frequency applications. The Army operates satellite communications terminals, each described below, which operate at frequencies throughout the superhigh frequency band. All of the systems communicate through the Defense Satellite Communication System, and some of the systems also operate through commercial communication satellites such as International Telecommunications Satellite Organization satellites. In contrast to the ultrahigh frequency satellite communication systems that are primarily used for in-theater communications, the superhigh frequency systems are primarily used for high-volume communications between the United States and a theater via either fixed or deployed satellite communication stations.

The primary space weather effect on superhigh frequency satellite communication systems used by the Army is signal interference caused by bursts of radio radiation by the sun. The sun can emit bursts of radiation at the same frequencies that the superhigh frequency systems operate at, and when a system's ground receiver is pointed toward the sun during the burst, then the sun's radio wave radiation reaches the receiver and causes interference.

This effect can occur only for a couple of hours when the sun enters a receiver's field of view while the receiver constantly points toward a geostationary communications satellite orbiting over the equator. Of course, the sun's burst must occur while the sun is within the field of view. The potential for interference is increased during the months near equinox since that is when the sun crosses over the equator and, therefore, is better positioned to enter into a receiver's field of view. Based on historical data and the current phase of the solar cycle, these types of effects will increase in frequency of occurrence and in intensity during the next four years due to an increase in solar radio wave bursts.

Because the effect is most often one of interference rather than complete interruption of communications, commanders and operators could more likely use space weather information to evaluate system performance, adjust signal gain, and determine the causes of interference and other signal abnormalities. The information could also be useful in system hardware and software troubleshooting analyses and in determining whether interference is being caused by environmental conditions, by equipment problems, or by enemy jamming efforts.

The effects and the utility of using space weather information described above apply to all of the following superhigh frequency satellite communication systems.

AN/TSC-85B/93B Tactical Satellite Terminals

The TSC-85B/93B are vehicle-mounted terminals that provide jam-resistant satellite communications at frequencies between 8-12 gigahertz using the Defense Satellite Communication System. These are the most tactical (mobile) of the Army's superhigh frequency satellite communication systems.

Signal battalions, companies, and brigades employ the systems to meet the high density tactical communication needs of divisions, echelons above corps, and corps, respectively.

AN/GSC-52 State-of-the-Art Medium Terminal and AN/GSC-49 Jam Resistant Secure Communications Terminals

The GSC-52 and GSC-49 systems are semi-fixed terminals that provide satellite communications at frequencies between 8-12 gigahertz using the Defense Satellite Communication System.

Signal units employ the systems worldwide to provide high density inter-theater communications.

AN/FSC-78/79/GSC-39 Defense Satellite Communication System Terminals

The FSC-78/79 (heavy) and GSC-39 (medium) are semi-fixed terminals that provide extremely high volume, jam-resistant satellite communications at frequencies between 8-12 gigahertz using the Defense Satellite Communication System.

Signal units employ the systems worldwide to provide high density inter-theater communications.

Super High-Frequency Tri-Band Advanced Range Extension Terminal

The Super High-Frequency Tri-Band Advanced Range Extension Terminal is a highly mobile vehicle-mounted system that provides satellite communications at frequencies between 8-12 gigahertz using the Defense Satellite Communication System. Additionally, the system can interface with commercial communication satellites using frequencies between 4-8 and 12-18 gigahertz.

The Army currently is acquiring this system to replace the TSC-85B/93C. Signal brigades, battalions, and companies will employ the systems in support of all echelons.

Light Multiband Satellite Terminal

The Light Multiband Satellite Terminal provides satellite communications at frequencies between 8-12 gigahertz using the Defense Satellite Communication System. Additionally, the system can interface with commercial communication satellites using frequencies between 4-8 and 12-18 gigahertz.

Signal battalions employ the system in support of echelons above corps.

Special Operations Forces Tactical Assured Connectivity System and Lightweight Satellite Terminal 8000

The Special Operations Forces Tactical Assured Connectivity System and Lightweight Satellite Terminal 8000 are vehicle-mounted systems that provide satellite communications at frequencies between 8-12 gigahertz using the Defense Satellite Communication System. Additionally, the systems can interface with commercial communication satellites using frequencies from 4-8 and 12-18 gigahertz.

Special operations signal units employ the systems to support special operations, and conventional signal companies employ the systems in support of echelons above corps.

Intelligence Collection

The Army operates ground and airborne systems that collect intelligence by intercepting electromagnetic signals at high frequency, very high frequency, ultrahigh frequency, and superhigh frequency wavelengths. The collection of these signals generates a type of intelligence referred to as signals intelligence. Space weather affects those systems that are designed to intercept high frequency signals. Additionally, the Army operates an intelligence collector that senses magnetic fields and may be, therefore, affected by space weather.

High Frequency Signal Collection

As already described in chapter two and earlier in this chapter, space weather conditions in the ionosphere control the propagation of high frequency sky wave radio waves. The Army operates several systems, each described below, which intercept high frequency radio waves and, in some cases, identify the location from where the emission is originating. All of these high frequency collection systems are affected in virtually the same way, and the potential operational impacts are similar.

There are three general categories of space weather effects on these systems. First, space weather can cause the partial or total absorption of the high frequency radio waves that the systems attempt to collect. When the high frequency radio signals that the systems are designed to intercept enter the ionosphere, the signals may be absorbed partially or fully. The remaining signal, if any, subsequently refracted back toward the ground where it may be intercepted can be too weak or distorted for reception.

Another effect is that space weather can cause the high frequency radio signals to penetrate the ionosphere and continue out into space rather than be refracted back towards the ground for interception. This occurs when not enough electrons exist in the ionosphere to refract the radio wave back toward earth.

Finally, space weather can cause the radio wave to take unusual paths before it is finally refracted back toward earth or escapes into space. After being trapped within the ionosphere, the high frequency radio signal may eventually propagate downward and be intercepted, but it can then appear to have originated from an area grossly different from where it was actually transmitted.

The potential operational impacts caused by the space weather effects on all of the high frequency signal collection systems include: complete inability to collect high frequency signal intelligence; incorrect interpretation that an adversary is not using high frequency radio; and incorrect determination of the location or region from where an intercepted signal originates.

Commanders and system operators may mitigate these impacts by considering space weather information in the following ways: identify periods when and areas where high frequency sky wave signal interception is unlikely or impossible and thus unable to satisfy intelligence-gathering requirements; identify when an adversary cannot successfully use high frequency radio signals for communications beyond line of sight; and identify conditions that allow an adversary to use high frequency successfully, but which may, at the same time, prevent friendly interception of those signals.

Actions that commanders may take as a result of this information include: positioning the collection systems in an optimum location for successful operation; directing other intelligence-collection assets to execute the mission when the high frequency collectors cannot operate due to space weather; and taking advantage of a period of time when an adversary cannot successfully use high frequency communications and may, therefore, be vulnerable depending on their dependence on high frequency communication systems.

AN/TSQ-152 Trackwolf and AN/TSQ-199 Enhanced Trackwolf

The Trackwolf and Enhanced Trackwolf are mobile, ground-based high frequency communications intelligence intercept systems that collect, process, and analyze high frequency sky wave radio signals and identify the location from which the radio signals are being emitted.

The Trackwolf and Enhanced Trackwolf support echelon above corps commanders by supplying communications intelligence and high frequency jammer and emitter location information. The information is then made available to a theater's All Source Analysis System. This analysis system serves as the Army's primary tactical intelligence analysis, fusion, and dissemination system; it provides a comprehensive intelligence picture that combat forces use to understand enemy deployments, capabilities, and potential courses of action.

AN/TRQ-32A(V)2 Teammate and AN/TSQ-138 Trailblazer

The Teammate and Trailblazer are ground-based tactical communications intercept systems that receive and record high frequency, very high frequency, and ultrahigh frequency radio signals and identify the directions from which the radio signals are being emitted. The effects of space weather on these systems act only on the high frequency sky wave intercept and direction finding functions; space weather does not affect the very high and ultrahigh frequency line-of-sight intercept or direction-finding functions, nor the high frequency line-of-sight applications.

Military intelligence battalions employ these systems primarily in support of divisions and armored cavalry regiments. The system collects and distributes signal intelligence data into the All Source Analysis System for use by forces throughout the division area.

AN/PRD-12 Lightweight Man-Transportable Radio Direction Finding System

The AN/PRD-12 is a lightweight, man-portable communications intercept system that receives and records high frequency, very high frequency, and ultrahigh frequency radio signals and identifies the direction from which very high frequency radio signals are being emitted. The AN/PRD-12 is a component of the Teammate; therefore, space weather affects the collection of high frequency sky waves in the same way.

Light, airborne, air assault, and special operations forces units may employ the systems as stand-alone to obtain intelligence data, and the information is again channeled into the All Source Analysis System for use by forces throughout an area of operations.

AN/ALQ-151 Quickfix and Advanced Quickfix

The Quickfix is an airborne (UH-60A helicopter) communications intercept and electronic attack system that intercepts ground wave and sky wave high frequency radio signals and very high frequency radio signals, identifies the direction from which the very high frequency radio signals are being emitted, and performs electronic attack jamming at very high frequencies. The Advanced Quickfix provides intercept and electronic jamming at ultrahigh and extremely high frequencies. The effect of space weather on the Quickfix involves only the high frequency sky wave intercept function; space weather does not affect any of the Quickfix line-of-sight high-frequency and very high frequency applications.

Elements of military intelligence battalions and companies that are attached to helicopter lift battalions employ the system to provide signals intelligence and countermeasures to divisions and armored cavalry regiments, and the intelligence data is made available through the All Source Analysis System. Several airborne Quickfix systems may work together simultaneously, and they may be integrated with the ground-based Trailblazer system.

Airborne Reconnaissance Low

Airborne Reconnaissance Low (ARL) is an airborne (modified DeHavilland DHC-7 aircraft) intelligence-collection system with both signal intelligence and imagery intelligence sensors. The signal intelligence system intercepts high frequency, very high frequency, and ultrahigh frequency radio waves. The DHC-7 aircraft also includes a high frequency radio system for its own over-the-horizon communications.

The effect of space weather on the ARL involves only the high frequency sky wave intercept system as well as the aircraft's high frequency communication radio system. For the same reasons that ARL may not be able to collect adversary high frequency signals, the aircraft may also not be able to communicate with friendly ground stations using its own high frequency radio. Space weather does not affect the ARL imagery intelligence applications.

The ARL currently supports echelon above corps reconnaissance and surveillance operations for United States Southern Command and United States Pacific Command. Military Intelligence companies perform on-board intelligence data analysis and disseminate the information to joint intelligence centers as appropriate. The data is also distributed into the All Source Analysis System.

RC-12 Guardrail

The Guardrail is an airborne (RC-12 aircraft) signals intercept and direction-finding system that has several designs and versions. In general, the system intercepts ground wave and sky wave high frequency radio signals, very high frequency radio signals, and ultrahigh frequency radio signals. The system also identifies the direction from which these signals are being emitted. A standard system consists of twelve aircraft that fly operational missions in sets of three. The effects of space weather on the Guardrail system involve only the high frequency sky wave collection function.

Aerial exploitation battalions employ the system to support corps-level signal intelligence collection. The system is flown 30-50 kilometers behind the Forward Line of Own Troops and provides signals intelligence and targeting information to tactical commanders within the corps area of responsibility. The data is sent directly from the aircraft to military intelligence companies supporting a corps. The data is also disseminated into the All Source Analysis System.

AN/MLQ-39 Ground Based Common Sensor

The Ground Based Common Sensor is a ground-based communications intercept and electronic-countermeasure system that receives and records high frequency, very high frequency, and ultrahigh frequency radio signals and identifies the location from which the radio signals are being emitted. It also performs jamming functions, discussed later in this chapter, against high frequency and very high frequency communications. The system is being fielded to replace the Traffic Jam, Trailblazer, and Teammate.

Military intelligence units at divisions, separate brigades, and armored cavalry regiments will employ various versions of the system.

Magnetic Field Collection

GSQ-187 Improved Remotely Monitored Battlefield System

The Remotely Monitored Battlefield System (REMBASS) and its upgraded version are unattended ground-based intelligence collection systems that detect, classify, and determine the direction of movement of personnel and vehicles by sensing seismic-acoustic energy, magnetic field changes, and changes in the infrared field.

One of the system's sensors is the DT-561/GSQ Magnetic Sensor Transducer that detects target activity by sensing a change of the earth's magnetic field induced by the passage of vehicles or armed personnel. Space weather affects the operation of this system by creating magnetic fields that are superimposed onto the earth's magnetic field. Under disturbed space weather conditions known as "geomagnetic storming," the vertical and/or horizontal component of the magnetic field as measured by REMBASS, depending on geomagnetic latitude, may be radically altered from the baseline magnetic field measured day to day. The effect varies because the magnitude and direction of the ionospheric currents that are generating the supplemental magnetic fields vary, but the effect can trigger the magnetic sensor to report spurious data. Based on historical data and the current stage of the solar cycle, the space weather phenomena that cause this effect will increase during the next four years.

Military intelligence battalions and companies employ the system to provide light divisions, separate brigades, and armored cavalry regiments with information about activities on or near the Forward Line of Own Troops as well as to provide protection within a division's rear zone. Special operations forces also use the Improved REMBASS for similar applications.

The potential operational impacts caused by the space weather effects on the REMBASS systems include: the inability to collect accurate magnetic sensor data in concert with and to corroborate thermal and acoustic measurements; an incorrect interpretation based on magnetic sensor data of the presence or absence of armored material in the area; and an erratic, erroneous triggering of the system.

Commanders and operators of the system could use space weather information to identify periods when the REMBASS magnetic sensor may be unreliable in operating as designed and to determine whether other collection assets should be used against designated targets. System technicians could use the information to assist in troubleshooting system problems; a REMBASS system may appear to be faulty in the presence of rapidly changing space weather conditions.

Electronic Attack

The Army operates ground-based and airborne systems that perform electronic attack against enemy electromagnetic systems using radio signals ranging from high frequency to extremely high frequency. Most of the targets of electronic attack operate at frequencies greater than high frequency, and the majority of Army electronic countermeasure systems focus on those threats. Space weather affects only those electronic attack systems operating in the high frequency band.

High Frequency Signal Jamming

Working in concert with the Army systems that attempt to collect high frequency radio signals and determine the region from which the signals are emanating, the Army also operates systems, each described below, that transmit high frequency radio signals designed to interrupt or prevent an adversary from using high frequency signals.

The effects of space weather on these systems are twofold: the effect on the ability of these systems to collect/intercept high frequency signals is the same as previously described in the intelligence collection section; and similarly, space weather affects the ability of these systems to successfully jam using sky wave transmissions because the system relies on the ionosphere to reflect its signal down toward the receivers in the targeted area of interest. Space weather conditions define the geographic areas where these high frequency signal attack systems, based on their ground position, can effectively interfere with high frequency radio applications. Because of changing space weather conditions, these high frequency attack signals may at one moment reach the targeted region and be effective against enemy activities, and then, a moment later, the jamming signal may not reach the target region. Instead, the jamming signal may move into a region where friendly high frequency communications are taking place.

The potential operational impacts caused by the space weather effects on these systems include: failing to effectively jam enemy high frequency signal applications; believing incorrectly that jamming operations are effective; and preventing friendly high frequency radio applications due to radio signal fratricide.

Commanders and operators could use space weather information in determining the best location to establish these systems and the best time to employ them, and in deciding whether or not to use the systems if conditions are likely to create risk of friendly interference.

AN/TLQ-33 Army High Frequency Electronic Warfare System

The Army High Frequency Electronic Warfare System (AHFEWS) is a ground-based intercept and electronic-countermeasure system that searches for high frequency radio transmissions, identifies assigned targets by signal type and frequency, and executes jamming attacks on those signals.

The 201st Military Intelligence Battalion employs the AHFEWS to support echelon above corps electronic warfare activities and is deployed as directed.

AN/TLQ-17A(V)4 Sandcrab

The Sandcrab is a ground-based electronic countermeasures system that provides high frequency sky wave electronic attack.

The 201st Military Intelligence Battalion employs the Sandcrab to support echelon above corps electronic warfare activities and is deployed to theaters as directed. The systems are in the process of transferring to an Army Reserve unit.

AN/MLQ-39 Ground Based Common Sensor

The Ground Based Common Sensor (GBCS) is a communications intercept and electronic-countermeasure system. In addition to its signals intelligence collection function, the GBCS performs jamming functions against high frequency and very high frequency communications. The system is currently being fielded to replace the Traffic Jam, Trailblazer, and Teammate. Space weather affects the high frequency collection and jamming functions of GBCS as previously described.

Military intelligence units at divisions, separate brigades, and armored cavalry regiments will employ various versions of the system.

Intelligence Dissemination

In addition to the intelligence data collected by Army units, the military intelligence community obtains a variety of other intelligence data from several ground, airborne, and space-based sources, processes that data, and then distributes the information to in-theater combat forces. The methods of disseminating the intelligence information rely heavily on ultrahigh frequency and superhigh frequency satellite communications; the Army Satellite Communication Architecture states, "Intelligence and Electronic Warfare satellite communications systems are vitally important to winning the information war and disseminating intelligence in near-real time to tactical commanders."[7] Of particular relevance to this thesis is that the majority of satellite communications used for intelligence dissemination within a theater of operations use the lowest frequencies within the ultrahigh frequency band.

As described earlier in this chapter, ultrahigh frequency and superhigh frequency signals used in satellite communications are affected in different ways. For in-theater dissemination of intelligence, ultrahigh frequency satellite communications are used; the signals may be distorted as they pass through the ionosphere on their way to and from a satellite, resulting in disruption or prevention of communications. For dissemination from the United States to a theater, superhigh frequency satellite communications are primarily used; these applications may experience radio wave interference. Moreover, the military intelligence satellite communication dissemination systems are affected by space weather in the same ways previously described for ultrahigh frequency and superhigh frequency satellite communication systems, to include the regions of the world where the ultrahigh frequency effects are most common.

These intelligence dissemination systems are designed as a network to support multiple echelons located in a given theater. The network largely includes a series of systems managed by the Army's Technical Exploitation of National Capability program.[8] Some systems receive intelligence data directly from reconnaissance and surveillance satellites and aircraft, while other systems receive intelligence data that has been processed and made ready for further dissemination. Finally, some of the systems transmit intelligence information to a satellite that subsequently transmits or broadcasts the information to friendly forces within an area of operation.

There are four intelligence dissemination broadcasts that provide signals and imagery intelligence to Army units, typically down to battalion level, that do not otherwise have access to many of the nation's intelligence collectors. All of the broadcasts use satellite communications at ultra-high frequencies between 225-400 megahertz. The Tactical Information Broadcast Service disseminates correlated data collected by aircraft such as Rivet Joint, Joint Stars, Airborne Warning and Control System, U-2s, and unmanned aerial vehicles, as well as intelligence collected by ground forces. This broadcast is classified secret. The Tactical Reconnaissance Intelligence Exchange System disseminates information collected by aircraft, such as the U-2 and the Guardrail Common Sensor, and also provides other intelligence including top secret and special compartmentalized information. The Tactical Related Applications system disseminates electronic intelligence and related reports and is classified secret. Finally, the Tactical Data Distribution System/Tactical Data Information Exchange System-

Broadcast disseminates intelligence that has been collected from multiple sources and then processed and distributed through a single source. National and strategic intelligence collectors are the primary sources of this intelligence, and the broadcast is classified Secret.

The Army operates a network of several intelligence communications systems, each described below, that collect and integrate intelligence data, generate intelligence reports, and send and receive intelligence broadcasts and other intelligence information using ultrahigh frequency satellite communications. Consequently, for each of the systems, the operational impacts caused by the effects of space weather could include the failure of command and control centers, maneuver units, and target planning groups to receive imagery and signals intelligence data and products.

Commanders and system operators could mitigate these space weather impacts by considering and acting on space weather information in the following ways: identify periods of time when and locations where intelligence broadcast transmissions or other satellite communication intelligence functions may be temporarily prevented or disrupted; direct other communications modes to satisfy intelligence dissemination requirements; and tailor intelligence broadcast sequences to reduce the likelihood of repeated disruptions. Most importantly, when anticipating or planning an operation that has a course-of-action which is driven by intelligence data, then combat forces could consider space weather conditions before deciding to rely on satellite communications to provide the needed intelligence data.

Modernized Imagery Exploitation System

The Modernized Imagery Exploitation System (MIES) is a ground-based system that receives and processes imagery taken from satellites and aircraft, integrates that imagery with other intelligence products, and then disseminates imagery intelligence and assessments.

Military Intelligence brigades employ the MIES in support of corps and echelons above corps. The system is used to build the imagery intelligence satellite broadcasts that support forces throughout a theater of operations. Some of the data is disseminated into the All Source Analysis System.

Mobile Integrated Tactical Terminal

The Mobile Integrated Tactical Terminal (MITT) is a highly mobile ground-based system that receives and processes imagery and signals intelligence from several sources, integrates and tailors the information as appropriate, and then disseminates this information as required by the tactical force commanders.

Military intelligence battalions and brigades employ the MITT at division and corps level. One system is generally allocated per division and is located at the division main command post. Targeting and other applicable intelligence is then disseminated via area communications to the maneuver forces as needed.

Forward Area Support Terminal

The Forward Area Support Terminal (FAST) is an extremely mobile ground-based system that receives and processes imagery and signals intelligence from several sources, integrates and tailors the information as appropriate, and then disseminates this information as required by the tactical force commanders. The FAST is essentially a smaller version of the MITT.

Military intelligence units supporting divisions, separate brigades, and armored cavalry regiments employ the FAST, and the system is also used to support corps and echelons above corps.

AN/TSQ-134(V) Electronic Processing and Dissemination System

The Electronic Processing and Dissemination System (EPDS) and its advanced version are ground-based systems that receive, process, correlate, and integrate signals intelligence data. The systems receive signal intelligence data that has been collected by national, theater, and corps sensors. The systems may also originate a signals intelligence satellite broadcast.

Military intelligence brigades primarily employ EPDS at corps level, correlate and integrate the signal intelligence data, and then forward the information to commanders in response to their requirements. The EPDS also processes signals intelligence for inclusion into the All Source Analysis System.

OE-95/TSQ-134(V) Enhanced Tactical Users Terminal

The Enhanced Tactical Users Terminal (ETUT) is a mobile ground-based system that collects intelligence data from multiple space and ground sensors and intelligence processing systems. The system interfaces with EPDS and MIES for signals and imagery intelligence, respectively, and builds signals intelligence satellite broadcasts.

Military intelligence brigades and companies employ the ETUT to support corps and echelons above corps, respectively. ETUT serves as the corps-level fusion center for signals and imagery intelligence and then distributes the data as necessary.

AN/TSQ-132/168/178 Joint Stars Ground Station Module

The Joint Stars Ground Station Module (GSM) is a mobile multi-sensor imagery intelligence tactical data processing center that is currently being fielded. It collects data from ground, airborne, and space-based intelligence collection sensors via various modes, including ultrahigh frequency satellite communications. The GSM also sends Joint Stars data via ultrahigh frequency satellite communications to other ground stations that are either on the move or not within the footprint of the Joint Stars transmission.[9]

Aerial exploitation battalions and various other military intelligence units will employ the system at echelons above corps, corps, divisions, armored cavalry regiments, separate brigades, and field artillery brigades.

Enhanced Tactical Radar Correlator

The Enhanced Tactical Radar Correlator (ETRAC) is a ground-based system that collects and integrates synthetic aperture radar imagery from airborne sources and then synthesizes that data with other intelligence data to describe the overall intelligence picture.

The effect of space weather on ETRAC does not involve the collection of the radar imagery, but rather on the ability to obtain other intelligence data needed for corroboration and on the broadcast transmission of a synthesized picture, both functions of which are performed via ultrahigh frequency satellite communications.

Military intelligence brigades employ the ETRAC at corps level and disseminate the information throughout the area of operation to meet various intelligence needs.

Commanders Tactical Terminal

The Commanders Tactical Terminal (CTT) is an intelligence processing system that fuses the data and information made available by all of the previously described systems and intelligence satellite broadcasts. The CTT is designed to focus on tactical intelligence and targeting data for use by maneuver and combat support forces and can interface with various tactical networks, including the Corps and Division Warfighter Nets previously described.

The CTT is used by air defense artillery, aviation, field artillery, and military intelligence units assigned at corps, divisions, armored cavalry regiments, and maneuver brigades.

Special Operations Forces Intelligence Vehicle and Scampi

The Special Operations Forces Intelligence Vehicle and Scampi (lightweight version) are deployable intelligence information support systems that receive, process, and disseminate intelligence. In addition to using ultrahigh and superhigh frequency satellite communications to send and receive intelligence, these systems also use high frequency over-the-horizon radio waves.

Special operations forces units employ these systems in support of echelons above corps activities.

Trojan Spirit

The Trojan Spirit, as defined here, represents a family of several intelligence satellite communication terminals in various versions which are used primarily to send and receive intelligence information in modes such as voice, data, and video between the United States and overseas theaters. The systems may thereby feed information into the in-theater intelligence-processing and dissemination systems. In the case of the Trojan Lite system (lightweight, highly-mobile), intelligence is passed from a maneuver battalion or brigade to the division or corps command post. The Trojan systems provide satellite communications at frequencies between 8-12 gigahertz using the Defense Satellite Communication System and between 4-8 and 12-18 gigahertz using commercial communication satellites.

Various military intelligence units employ the Trojan systems, primarily in support of echelons above corps, corps, and division.

Navigation

The Army uses the Global Positioning System to perform ground and airborne navigation functions. The Global Positioning System includes a network of satellites that continuously transmit ultrahigh frequency radio signals, and special receivers use these signals to calculate navigational data. The calculation is based on geometric principles that rely on knowing the exact amounts of time that it takes signals from multiple satellites to reach a single receiver. The overall performance (accuracy) of the system is affected by space weather conditions because the signals traverse through and are slowed down or distorted by the ionosphere.

The Army uses two general types of Global Positioning System receivers: single-frequency and dual-frequency. The single-frequency systems are used for ground navigation applications ranging from infantry navigation to artillery targeting, while the dual-frequency systems are used for aviation navigation as well as for in-flight guidance in some advanced artillery weapons. The primary effects of space weather differ depending on the type of Global Positioning System receiver used.

Single-Frequency Global Positioning System Navigation

Electrons in the ionosphere interact with radio signals traversing through the ionosphere, and the type and intensity of this interaction are a function of the radio wave frequency (see figure 4 in chapter two). For the Global Positioning System single-frequency signal transmission near 1.6 gigahertz, the most relevant effect is that the electrons slow down the speed of the radio wave. The total number of electrons through which the radio signal travels determines how much the radio signal will be slowed; the greater the number of electrons through which the radio signal travels, the longer it will take the radio wave to reach a receiver.

Because space weather processes cause the ionosphere to be horizontally and vertically inhomogeneous with respect to the number of electrons, a Global Positioning Satellite signal travels through a different number of electrons depending on what region of the ionosphere the signal is moving through. Therefore, the timing calculations and the resulting navigation data output are affected because different signals from different satellites will be slowed by varying magnitudes. For example, a Global Positioning System receiver positioned on the ground in the central United States uses four different radio signals to compute the receiver's latitude, longitude, altitude, and velocity. One of the signals that the receiver uses to calculate navigation data may come from a satellite directly overhead and thus traverses through the ionosphere directly overhead. The second, third, and fourth signals may come from satellites positioned west, north, and east, respectively, of the receiver's location, thus traveling through different regions of the ionosphere at different speeds. A single-frequency receiver calculates the navigation data without truly knowing the differing speeds.

In an attempt to lessen the ionospheric-induced navigation errors, the single-frequency radio signals transmitted by the satellites contain correction factors based on a model of the number of electrons expected in different regions of the ionosphere. In other words, the modeled correction factors attempt to inform the receiver of the differing speeds among the signals being used to compute the navigation data. When space weather conditions are relatively undisturbed, the correction factors are accurate enough to provide an overall accuracy within nominal receiver-specified performance. However, when disturbed space weather conditions exist, the modeled correction factors do not accurately represent the state of the ionosphere.

The practical result of the ionospheric-induced errors on Army single-frequency navigation applications is twofold. First, the Precise Positioning Service single-frequency receivers operated by the Army, each described below, may provide navigation data that is not within the error margins that the receiver normally provides. For instance, the positional data may be over seventy feet in error from true position during disturbed space weather conditions.[10] Second, and perhaps more importantly, the positional errors will change from one moment to the next in response to changes in the electron content of the ionosphere. For example, after providing positional data that is forty feet east of the true position, moments later the system may provide positional data that is thirty-five feet west of true position.

The recent proliferation of single-frequency Global Positioning System receivers in the Army has taken place during the stage of the solar cycle that leads to fewer and less severe ionospheric disturbances. Army forces have operated the systems under what could be considered as the best of space weather conditions, producing navigation data with relatively low and unchanging error margins. Based on historical data and the current stage of the solar cycle, the space weather conditions capable of generating large and changing errors to single-frequency receivers will increase in occurrence during the next four years.

AN/PSN-11 Precision Lightweight Global Positioning System Receiver and Stand Alone Global Positioning System Receiver

The Precision Lightweight Global Positioning System Receiver (PLGR) and Stand Alone Global Positioning System Receiver (SAGR) are self-contained passive systems that use Global Positioning System single-frequency signals to provide grid coordinates (latitude and longitude), altitude/elevation, velocity, time, and direction of movement. The systems may be handheld or mounted on a vehicle. Although the PLGR displays a numerical signal-quality designator, this feature does not recognize when space weather conditions are causing less accurate information.

The Army has acquired over 125,000 PLGRs and SAGRs during the last few years, and the systems are used by virtually all types of combat, combat support, and combat service support units operating at all echelons. The types of applications for the systems include: armor and infantry maneuver, special operations forces operations, airborne operations, field artillery setup and targeting, tactical reconnaissance, surveying, obstacle placement, and minefield navigation.

The potential operational impacts caused by the effects of space weather on these systems are only limited by the imagination of the user in determining how to exploit the systems' capabilities. The fundamental impact is that combat forces using the system to perform navigation functions will not always obtain navigation data within normal error margins. One sample impact could include Paladin (155 mm) artillery fire missing the designated target.

Commanders and system operators could use space weather information to identify periods of time when single-frequency applications are more likely to provide larger and/or frequently changing navigation errors. Action might then be taken to delay, cancel, or reschedule operations depending on the need for precise navigation data.

Dual-Frequency Global Positioning System Navigation

The errors produced by the ionosphere as described for the single-frequency applications are virtually eliminated by using dual-frequency systems that use two radio signals of different frequencies transmitted at the same time from each of the Global Positioning System satellites. A dual-frequency receiver is able to calculate and then correct for the ionospheric-caused errors because the degree in which a radio wave is slowed down by the ionosphere is a function of the radio wave's frequency; the two radio waves with different frequencies reach a receiver at slightly different times. Using the same geometrical methods of the single-frequency system to determine navigation data, and accounting for the two different frequencies (1.6 and 1.2 gigahertz) and how they are affected differently by electrons, the receiver "backs out" the ionospheric errors. Moreover, space weather-caused navigation errors are not an issue for dual-frequency applications as long as the receiver can lock onto the dual-frequency signals from four different satellites. Conversely, space weather can also disrupt a Global Positioning System signal and thereby adversely affect dual-frequency navigation applications.

The effect of the ionosphere on ultrahigh frequency satellite communication signals as described earlier in this chapter also applies, although to a lesser degree, to the ultrahigh frequency Global Positioning System radio signals. In summary, the scintillation effect occurs when space weather processes create large gradients in the electron density within the ionosphere. A Global Positioning System radio wave traversing through these regions of the ionosphere may be weakened or distorted such that it can be unrecognizable to a receiver and, therefore, useless in making a navigation calculation. As explained earlier, this effect is extremely dependent on location, time of day, and stage of the solar cycle. It occurs at higher and lower magnetic latitudes during the nighttime and is generally more common and intense during solar maximum.

The effect of disrupting a Global Positioning System signal is even more intermittent and more short-lived than that which was described for ultrahigh frequency satellite communications. The navigation satellites are constantly in motion, so the signals that are at one moment traversing through a scintillation region can soon be traversing through a different, nonscintillating region. Also, a receiver does not constantly lock onto the same signals; a receiver will use the best four sets of signals it can find to make its calculation. The number of satellite signals from which to choose is dependent on the altitude of the receiver and on the topography surrounding the receiver. At sea level in flat terrain, a receiver would typically have access to six or seven signals. In a hilly or mountainous region where lines of sight to a satellite may be limited, that number can quickly decrease. Therefore, the potential for a dual-frequency receiver to be unable to provide accurate navigation data because of ionospheric scintillation is also a function of the topography in which the receiver is being used. The following systems are susceptible to the effects just described.

Miniaturized Airborne Global Positioning System Receiver

The Miniaturized Airborne Global Positioning System Receiver (MAGR) is an aircraft-mounted passive system that uses a Global Positioning System dual-frequency signal to calculate grid coordinates (latitude and longitude), altitude/elevation, velocity, time, and direction of movement.

The MAGR is currently used on fixed- and rotary-wing aircraft as a supplementary navigation mode. Based on how the system is used today, there does not appear to be any significant operational impacts that could occur as a result of space weather. However, this is only true as long as the system is not used for precision navigation and landings without visual reference.

Army Tactical Missile Systems

The Army Tactical Missile Systems (ATACMS) is a surface-to-surface guided missile with an anti-personnel and anti-material warhead. Modification programs are also underway for enhanced capabilities. The missile guidance system includes a Global Positioning System dual-frequency receiver in order to achieve precision targeting accuracy. The effects of space weather on ATACMS are as described above for dual-frequency systems.

Corps artillery units employ the ATACMS to attack targets at extended ranges such as surface-to-surface missile sites, air defense systems, logistics elements, and command and control complexes.

An operational impact caused by the effects of space weather on the ATACMS could include the failure to obtain pinpoint accuracy and destroy a designated target.

Commanders and system operators could use space weather information to identify periods of time when the system may not be able to achieve pinpoint accuracy. The times of a planned attack or the use of additional or alternate weapons systems might be considered in response to this type of space weather information.

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CHAPTER FIVE

CONCLUSION AND RECOMMENDATIONS

Over fifty systems used by the Army have been identified as being susceptible to the effects of space weather to a degree in which the systems may not, during periods of disturbed space weather, operate as designed or required. These systems are used for communications, intelligence collection, electronic attack, intelligence dissemination, and navigation applications.

The communications systems affected are high frequency radio systems used for over-the-horizon communications, ultrahigh frequency satellite communications systems used primarily for in-theater tactical communications, and superhigh frequency satellite communications systems used primarily for inter-theater communications. Users of the high frequency systems include, but are not limited to, special operations forces and long range surveillance units. Users of the ultrahigh frequency satellite communications systems include tactical forces operating on the Corps Warfighter Net and Division Warfighter Net. Users of the superhigh frequency satellite communications systems, operated by signal units, are primarily divisions, corps, and echelons above corps.

The intelligence collection systems affected are systems, with one exception, that collect enemy high frequency radio signals. The one exception is a system that uses magnetic field measurements. Military intelligence units operate these systems in support of virtually all echelons.

The electronic attack systems affected are systems that transmit high frequency radio signals designed to interfere with enemy high frequency radio applications. Military Intelligence units operate these systems.

The intelligence dissemination systems affected are primarily systems that transmit and receive signals and imagery intelligence via ultrahigh frequency satellite communications, including the theater intelligence satellite broadcasts. Users of these systems include all combat arms units throughout all echelons at and above battalion level.

The navigation systems affected are Global Positioning System single- and dual-frequency systems. Users of the single-frequency systems include virtually all combat arms and combat support units at all echelons. Users of the dual-frequency systems include fixed- and rotary-wing aircraft units and corps artillery units.

Conclusion

Based on the current function of the Intelligence Preparation of the Battlefield (IPB) process, on the number of systems used by the United States Army which can be adversely affected by space weather, on the ways the Army employs those systems on the battlefield, and on the ways commanders and system operators could use space weather information to mitigate the adverse effects and improve overall effectiveness, this thesis concludes that space weather conditions should be formally considered as part of the IPB process. Observations and forecasts of the space weather phenomena that affect the systems identified in chapter four should be made available to commanders and their combat forces.

The IPB process is designed to make decision makers at all levels aware of environmental conditions that may limit friendly or enemy activities. After considering available environmental information, friendly forces may simply elect to cope with the conditions, avoid the conditions so as to mitigate the adverse effects and subsequent operational impacts, or exploit those conditions that may be more disadvantageous to the enemy.

Observations and forecasts of space weather may be used in the execution and planning stages of operations that employ those adversely affected systems. An observation can explain why a particular system is not operating as designed, or it may assist in determining whether system problems are due to equipment failure, hostile threats such as jamming, or space weather. A forecast can be used to determine how long a system will experience problems during a current operation, or it may be used to identify times or locations in which a particular system will not perform properly in a planned operation. In these and other ways, space weather information can better serve the military decision-making process.

Recommendations

Several Army and Air Force organizations should consider action based on the results of this thesis. The United States Army Intelligence Center and Fort Huachuca should consider formally including space weather information as an element of the IPB process. The Army Weather Office at the United States Army Intelligence Center should consider taking action to ensure weather support to Army forces includes those elements described herein. This action would, of course, be taken in coordination with the staff weather offices at Headquarters Army Training and Doctrine Command, Headquarters Army Forces Command, and Headquarters Air Combat Command. Finally, Air Force weather units that support the Army should consider contacting Air Force Space Command to establish support requirements in order to obtain space weather information from the 50th Space Wing's 55th Space Weather Squadron.

This thesis focused on systems that are currently operational and that will be employed during the next few years when solar maximum occurs. A follow-on study, focused on Army XXI and its digitization architecture, would be beneficial in determining the longer-term need to include space weather information as part of IPB. As a starting point, some of the battlefield awareness architecture currently planned includes using satellite communications using the lowest portions of the ultrahigh frequency band. Also, the effects of space weather will need to be monitored as theater defense systems continue to be developed.

Although this thesis alludes to space-based intelligence collection systems, it does not, for classification reasons, address how those systems are affected by space weather. As the Army continues to exploit these systems through the Tactical Exploitation of National Capabilities program, a study may be useful to determine whether information concerning the space weather effects on the intelligence collection portion of these systems would prove beneficial to Army combat forces.

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