CDC 1W051A

Weather Journeyman

Volume 3. METWATCH and Space Environment

Extension Course Program (A4L)

Air University

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CONTRATULATIONS on completing Volumes 1 and 2 of this career development course (CDC). This current volume is the last in the 3-volume set for CDC 1W051A. Volume 1 of this course was designed to strengthen your fundamental knowledge of general meteorology principles, synoptic scale weather systems, and weather observing principles. In Volume 2, you have acquired a wealth of knowledge on weather radar.

Volume 3 will now increase your knowledge on METWATCH/MISSIONWATCH concepts, and principles and concepts of the space environment and its impact on the Department of Defense.

Unit 1, METWATCH/Cooperative Weather Watch/MISSIONWATCH, describes the principles of watching the weather for an area, or specifically the weather for a mission. The concept knowledge contained in this unit is critical for success as a weather journeyman. As you may have already noticed, providing weather support is a demanding task that requires a responsibility to monitor changing weather conditions that is unmatched by our civilian counterparts.

Unit 2 of this volume contains fundamental information about the relationships and interactions between earth and our sun. The interactions between the sun's emissions and earth's atmosphere are responsible, in a sense, for a science all its own. After completing this unit, you will have fundamental knowledge that is necessary to support our space-sensitive customers. Moreover, you will understand the impact that solar and space anomalies have on national defense.

The background knowledge you receive in unit 2 is expounded on further in unit 3 by making a relationship between space weather and solar anomalies and their impact on military operations and national defense. The unit ends by identifying the key units requiring space weather support, the agencies providing space weather support, and how and where you can get the information. When being tasked to support such a mission, you will have an arsenal of information to guarantee mission success.

As this is the last volume of a 3-volume course, once you have completed this volume in its entirety, you should begin preparing for your course exam. Schedule, then take the exam, only when you are confident you have mastered all of the material in the course.

Code numbers on figures are for preparing agency identification only.

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To get a response to your questions concerning subject matter in this course, or to point out technical errors in the text, unit review exercises, or course examination, call or write the author using the contact information on the inside front cover of this volume.

NOTE: Do not use the IDEA Program to submit corrections for printing or typographical errors.

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This volume is valued at 9 hours and 3 points.

NOTE:

In this volume, the subject matter is divided into self-contained units. A unit menu begins each unit, identifying the lesson headings and numbers. After reading the unit menu page and unit introduction, study the section, answer the self-test questions, and compare your answers with those given at the end of the unit. Then complete the unit review exercises.

Unit 1. METWATCH/Cooperative Weather Watch/ MISSIONWATCH

NOW THAT YOU HAVE a knowledge of fundamental general meteorology principles, synoptic scale weather systems, weather principles and weather radar, it's time to turn our attention to the meteorological watch (*METWATCH) and Space Environment.*

If you research the terms METWATCH, Cooperative Weather Watch and MISSIONWATCH in *Webster's Dictionary*, you would be hard-pressed to find any such words. That's because these terms are exclusive to the military and relate to techniques used to watch the weather for changes. In military terms, METWATCH means to watch the weather while "MET," of course, stems from meteorology. A Cooperative Weather Watch utilizes a team effort to monitor weather conditions. Similarly, MISSIONWATCH means to watch the weather for a specific mission.

For weather folks, watching the weather is an inherent task, nearly impossible to neglect. It's simply not enough that we create forecast products and perform mission briefings. Once completed, we've got to follow up and make sure that the assumptions we've made are indeed correct. This unit covers the principles, procedures and tools that enable us to meet our responsibilities to conduct an effective METWATCH, Cooperative Weather Watch and MISSIONWATCH. First, let's examine the similarities and differences between these procedures and learn how they may apply to your job.

401. Principles

The concept of monitoring weather conditions is necessary to take appropriate actions anytime aerospace weather conditions may endanger life or property, pose a safety hazard, or adversely impact mission operations. However, it is difficult to watch the weather if you are not exactly sure what conditions have a negative impact on the mission. To conduct a METWATCH, we must understand its purpose.

Purpose of METWATCH

The purpose of a METWATCH is to provide a controlled and organized approach to ensure weather operators maintain situational awareness of the current and future meteorological situation, within a designated area. This approach pertains to ground, air, or space weather. Your particular focus is to detect unforecasted changes in the weather. For example, you may have forecasted the onset of lower ceilings moving over the target zone; however, now you find the lower ceilings are occurring sooner than anticipated. If you have conducted your METWATCH correctly, you'll notice the error in timing, and then take steps to amend the forecast product to reflect the change.

At a minimum, consider timing, location, and forecast values whenever you conduct a METWATCH. Timing is critical in almost anything you do as a weather forecaster. To have control over a timing situation, you will have to be extremely proactive and astute to changing conditions. Location, however, is a variable you can't control. You can, however, familiarize yourself with the terrain and its effects on weather conditions. More importantly, study the effects of the surrounding terrain in your area of responsibility (AOR), and its cause-and-effect relationship to forecast values such as ceilings and visibilities.

Depending on the level of support you are providing, conducting a METWATCH or MISSIONWATCH may lead to issuing, upgrading, downgrading, amending, or canceling one of the following:

- Mission execution forecast (MEF).

- Weather watch.
- Weather warning.
- Weather advisory.

NOTE: A MEF is a generic term for any type of forecast product, briefing, or customized product designed to support peacetime or combat operations (e.g., terminal aerodrome forecast (TAF), mission briefing, weather flight briefing, etc.).

Just because a weather unit performs a METWATCH does not necessarily mean they are required to issue a weather watch, weather warning or weather advisory, although these actions are often a result of the METWATCH. Many new weather personnel get confused with this concept. For example, a rapid change in weather conditions such as worsening ceiling and visibility conditions may require a forecast amendment, but not necessarily the issuance of a watch, warning, or advisory unless the specific change in the weather actually warrants it.

Purpose of Cooperative Weather Watch

A Cooperative Weather Watch is used to offset limitations of the Basic Weather Watch, as described in Air Force Manual (AFMAN) 15–111, *Surface Weather Observations*. A Cooperative Weather Watch uses a team concept to increase the METWATCH capability of the weather observer. This program increases the weather station's sensing capability through the cooperation of base agencies. At many sites, the point of observation has viewing restrictions across portions of the horizon. Weather-related damage can occur on these parts of the base that are not visible from the observation point. A well-coordinated Cooperative Weather Watch adds immensely to the weather station's effectiveness. It is important to enlist the aid of the right agencies. Ensure that non-weather agencies such as Air Traffic Control (ATC), Security Forces, Range Control, etc. know how to report important weather conditions, changes and reportable values. An effective training program is important in assuring the effectiveness of the Cooperative Weather Watch.

Purpose of MISSIONWATCH

When weather personnel conduct a MISSIONWATCH, they are essentially monitoring aerospace weather for a specific mission. In this regard, a MISSIONWATCH differs from METWATCH only in terms of focus. With a METWATCH, we're monitoring a broad area with general interest, whereas with a MISSIONWATCH, we're focusing on the specific areas and forecast times to ensure mission success.

402. Procedures and tools

Specific guidelines for conducting METWATCH procedures vary from one unit to the next, depending on the unit's mission and customer. Strategic weather centers, Operational Weather Squadrons (OWS), and Weather Flights (WF) develop procedures on how they will perform METWATCH tasks. Normally, Air Force instructions (AFI) and the support agreements that we've made with our customers help us establish criteria that require specific METWATCH actions.

METWATCH procedures

Weather units must identify all geographic areas, information, products, and services that require METWATCH actions. In other words, customer's needs vary, so not everyone requires the same METWATCH services. For example, a METWATCH for flying hazards such as turbulence may be just what a C–130 crew needs, but it is hardly applicable to a computer communications center. Therefore, units perform different METWATCH actions for different geographical areas and services. Accordingly, weather units often provide entirely different sets of METWATCH procedures for each set of customers.

Weather pattern consideration

Some weather patterns are notorious for causing poor weather conditions each time the pattern occurs. Weather units normally have a regional analysis and forecast program (RAFP) that identifies weather regimes and patterns that are most likely to cause problem areas. When a familiar pattern appears to be developing, forecasters can refer to the RAFP to effectively pinpoint problem areas within their AOR. A good RAFP takes most of the guesswork out of determining the problem areas within your AOR, and will help streamline METWATCH focus.

NOTE: For smaller-scale forecasting responsibilities, a local area forecast program (LAFP) serves forecasters similarly.

Mission-limiting parameters

In order to effectively METWATCH for an area, the supporting weather units establish a minimum set of air and ground parameters that apply to aerospace weather for each customer. Aerospace weather means all weather events from the troposphere through space—“mud to sun” so to speak. Focus your attention on mission-limiting parameters. Mission-limiting implies weather situations or parameters that impact the mission in some adverse way. To best accomplish this, start by understanding your customer’s needs. This is a place for asking questions. For example:

- What type of aircraft is my customer flying?
- What are the aircraft sensitivities?
- What are the minimum ceiling and visibility thresholds?
- Does weather along the mission route obscure the terrain?
- What surface weather parameters will limit mission success?

As you can imagine, the list of questions could be quite lengthy—just a few are listed here.

Mission-limiting parameters include go/no-go thresholds. For example, the weather parameters that cause a no-go decision for an F–15E may be merely a small adversity for rotary wing (helicopter) customers. To avoid broad-based or “blanket” METWATCHing from happening, tailor your METWATCH checklists for each different category of customer.

Watches, warnings, and advisories

For all practical purposes, weather units concentrate METWATCH efforts on the same criteria that relate to weather watches, warnings, and advisories—the exception is a MISSIONWATCH where focus is on the area or route of the mission from launch to recovery.

Weather warnings

Weather warnings are considered official notification and are issued to alert customers that weather conditions are expected to occur that may pose a hazard to life or property. Units are encouraged to limit warning criteria to intense weather phenomena that cause the customer to take protective actions. All other phenomena should be addressed via an advisory. The following are examples of some minimum suggested thresholds that warrant warning criteria:

- Tornadoes.
- Winds 35 knots or greater ($\geq$ 35 but $<$ 50).
- Winds greater than 50 knots.
- Hail (establish thresholds of less than or greater than ¾ inch).
- Heavy rain (2 inches or more within 12 hours).
- Heavy snow (2 inches or more within 12 hours).

- Freezing precipitation.
- Blizzard conditions (reducing visibility to ¼ mile or less).

Weather watches

Generally, weather watches are issued for the same criteria as weather warnings. A weather watch differs from a warning in that the term *watch* alludes that "the potential exists" for weather conditions that may pose a hazard to life or property. Watches are generally reserved for the potential for severe weather. Another point of interest is that while a watch may be a precursor to a warning, a warning may be issued at any time.

Weather advisories

A weather advisory is considered a special notice to supported customers that alerts them to weather conditions that could affect their operations. There are two types of advisories, observed weather advisories (OWA) and forecast weather advisories (FWA). OWAs are issued when the customer does not require advance notification of a particular weather event. FWAs are issued when a customer requires advance notification of an impending condition with sufficient time to allow protective actions to be taken.

Some examples of observed weather advisories are:

- Turbulence (in local flying area, light intensity or greater).
- Icing (in local flying area, any intensity).
- Thunderstorms (in local flying area, include coverage ISOLD [isolated], FEW, etc.).

Examples of forecast weather advisories are:

- Ceilings < 1,000 feet (terminal), desired lead time (DLT) 1 hour.
- Visibility < 3 miles (terminal), DLT 1 hour.
- Low-level wind shear (LLWS), DLT 1 hour.
- Crosswinds, DLT 1 hour.

Frequency and duration of weather checks

Once the mission-limiting parameters of warnings, watches, and advisories have been established, units should next consider how often they are going to check the weather for changes. The best way to monitor changes is to establish intervals that are reasonable and time-efficient. When weather changes are gradual, thirty-minute to one-hour intervals work well; however, fifteen-minute intervals may be necessary when rapid changes occur.

Action notification list

When forecasted conditions change appreciably during the METWATCH, units must have some outline on actions to take. The outline usually includes the primary and back-up methods of contacting the appropriate agencies that require notification. For example, the notification list may include means such as telephone, radios, e-mail, phone patch, and so forth. Separate notification lists may be required for different weather events. Keep in mind that these notification lists are separate from a weather watch or warning notification**.**

Minimum desired lead times

The term *lead time* equates to the amount of notice a customer wants *before* the event occurs. Desired lead times are required with weather warnings and forecast advisories. Through written agreements, customers must establish a minimum desired lead time for each forecast advisory and warning criteria. Weather units agree to the customer's need only when they have the realistic capability to meet the lead time demands. For example, while a customer may desire a minimum lead time of 3–hours notification for winds greater than 50 knots, the weather unit may only be realistically capable of meeting a 2–hour lead time for that phenomenon. In short, it's imperative to differentiate between what the customer wants and what your unit can realistically provide.

Weather phenomena that do not meet warning or forecast advisory criteria, but are considered a mission-limiting parameter, should be categorized as observed advisory criteria. For example, cloud ceilings less than 1,000 feet, which do not affect base resources, but instead apply to aviation missions, would be a practical event to add to your list of METWATCH phenomena.

Cooperative weather watch procedures and contributors

As you can see, the METWATCH is a critical process in any weather unit's daily operations. To increase the effectiveness and geographic scope of the METWATCH, units implement a Cooperative Weather Watch. Weather units will have locally developed procedures for their Cooperative Weather Watch program. The required support and details of the Cooperative Weather Watch should be annotated in the Weather Support Document. Let's take a look below at the supporting agencies who are typically contributors in the Cooperative Weather Watch.

ATC and Range Control

The primary concern is the occurrence of previously unreported conditions that affect safety of flight, the efficiency of flight and resources. ATC personnel are required to receive local weather phenomena training. Tower personnel should tour the observation site to get first-hand knowledge of observing limitations and clearly define the tower's role in overcoming these limitations.

Security Police

They may see unreported conditions and damage incidental to weather conditions.

Flightline personnel

They may also see unreported conditions that might affect flight line operations.

Field Personnel

They may see unreported conditions. This might be the only reliable source for off-station conditions.

Pilots

They provide pilot reports (PIREP) which might include unreported or unknown conditions and weather affecting flight operations.

MISSIONWATCH procedures

Weather units that issue an MEF are required to develop MISSIONWATCH procedures that cover the entire duration of the mission—from start to finish. The best way to develop MISSIONWATCH procedures is to use the same mission-limiting parameters that apply to the METWATCH. Apply the parameters to the MISSIONWATCH, making minor adjustments as necessary to tailor the parameters to your customer.

A MISSIONWATCH also has an action notification list that states who to contact if significant changes in the weather occur or if the MEF must be amended. The list differs from the METWATCH notification as only key persons, such as the mission director or commander, are notified.

METWATCH and MISSIONWATCH tools

A variety of tools are used to conduct a vigilant, watchful eye over your unit's AOR. The tools used to perform METWATCH for a region depend largely on the size of the organization and their capabilities. As you may have already guessed, many of the same tools you used to formulate the forecast are used to conduct the METWATCH and MISSIONWATCH.

Satellite and radar data

Meteorological satellite (METSAT) and radar data are the most valuable tools for conducting an effective METWATCH or MISSIONWATCH. Both offer the most current up-to-date data, and thus they are considered to be the most renewable data source; time is of the essence when monitoring changes in the weather. Moreover, the WSR–88D can be preprogrammed to alert the user of dramatic changes in the atmosphere, as they occur.

Real-time surface data

Surface data is also a reliable and renewable data source that is used to monitor changes in the weather. With surface observations that are updated at least once per hour, the data reflects changes rather quickly. Weather units can program weather computers to alert them of predetermined weather components that cross a given threshold. For example, the receipt of observations with a 300–foot ceiling will sound a visual and audible alarm. This proves invaluable when conducting a METWATCH or MISSIONWATCH.

Upper-air data

Weather data from PIREPs, air reports and significant meteorology reports (SIGMET) are excellent for monitoring changing weather conditions. These are especially valuable because aviators report weather phenomena that might otherwise be missed due to data coverage gaps.

Other technology

Weather units may also use any other weather data available to monitor changing weather conditions. Tower cameras, on-line weather resources, lightning detection data, and Mesoscale Weather Network (MESONET) data are just a few of the additional data sources that aid in conducting a thorough METWATCH or MISSIONWATCH. MESONET is a series of weather sensors, primarily in Midwestern states that are tied into university and National Weather Service computer systems. Though the data may not be readily available for forecasters in locations other than the Midwest, MESONET data, when available, is an invaluable heads-up for severe weather events.

403. Roles and responsibilities

The concept of performing a METWATCH or MISSIONWATCH successfully is largely dependent upon a three-tiered structure of responsibility. Strategic weather centers, OWSs, and Weather Flights make up the structure, and each plays a significant role in the process. While this lesson does not go into the specifics of warnings, watches, and advisories, we do examine the roles of each echelon of weather units and their responsibilities in terms of the process.

Strategic center support

The strategic centers responsible for weather support at the highest level are Air Force Weather Agency (AFWA), the 14th Weather Squadron, the 2d Weather Squadron Space Weather Operation Center, and Joint Typhoon Warning Center (JTWC). Strategic centers provide lower-level weather units with the data they need to perform effective METWATCH and MISSIONWATCH functions.

Of the strategic centers, AFWA is almost always involved in the day-to-day METWATCH and MISSIONWATCH process and is responsible for timely data transmission and expert advice concerning inclement and severe weather events. AFWA’s hemispheric-scale, upper-air, and severe weather analysis products are the first products used when performing the MEF, METWATCH, and MISSIONWATCH processes. These products help the lower-level OWS gain an understanding of the weather scenario at hand.

AFWA is responsible for issuing centrally produced, point weather warnings. Their role is to provide METWATCH support for weather units that have limited duty hours or have limited METWATCH capabilities. They are remotely responsible for monitoring weather conditions for warning-meeting criteria while weather units are closed and unmanned. The standardized point weather warnings help ensure human and resource protection during subordinate weather unit’s off duty hours.

AFWA Space Weather Flight and JTWC also play important roles as a starting point for monitoring weather conditions. For example, the Space Weather Flight would be the first source for solar anomalies and events that may impact a mission's communication ability. Similarly, JTWC is the authority for pacific region tropical events that may impact missions in the Pacific Command, such as for United States (US) bases in Japan.

Operational weather squadron support

When performing METWATCH and MISSIONWATCH duties, a large amount of responsibility lies with the OWS—and rightly so. In most cases, the OWS is the owner of the original issued forecast so it stands to reason that, "they, who create the product, are responsible for the product." Moreover, the OWS is most often the "lead unit" for weather customers that are assigned to each subordinate Weather Flight. The lead unit is responsible for defining the "problem of the day" and for briefing lower-level units on the overall weather situation. Having defined the "problem of the day," this puts the OWS in the best position to focus METWATCH techniques on specific problem areas.

Weather Flight support

The Weather Flight's role in monitoring the weather is to act as the "eyes forward" in monitoring weather changes for the higher-level OWS. Coordination and first-line communication with the weather customer occur here; thus it's critical that accurate upward- and downward-spiraling communications exist. 'Weather Flight's are front-line observers who notice a weather change first.

Equally important, is that although the OWS has overall responsibility for the METWATCH process, when the weather changes abruptly, the Weather Flight has the authority to amend forecasts to ensure immediate protection of lives, equipment, and resources. To wait for coordination otherwise, would cause more harm than good.

Self-Test Questions

After you complete these questions, you may check your answers at the end of the unit.

401. Principles

1. State the purpose of a METWATCH.

2. Why is it important to develop a Cooperative Weather Watch?

3. What is the major difference between a METWATCH and a MISSIONWATCH?

402. Procedures and tools

1. Can one set of METWATCH procedures be used for all of your customers? Why or why not?

2. Describe the term mission-limiting.

3. What product provides customers with advance notice of the potential for tornadoes?

4. What product provides your customers with advance notice of low-level wind shear?

5. What should be considered when we determine time frames for monitoring weather changes?

6. What elements should an action notification list contain?

7. Where do we document the details of the Cooperative Weather Watch?

8. Name three typical contributors and describe their role in the Cooperative Weather Watch.

9. How long should a MISSIONWATCH last?

10. What METWATCH/MISSIONWATCH tools are the most renewable?

11. Give examples of upper-air data that are useful for conducting a METWATCH or MISSIONWATCH.

403. Roles and responsibilities

1. Match the support agencies in column B with their appropriate roles in column A. The agencies in column B may be used once, more than once, or not at all.

Column A	*Column B*
____ (1) Most often the lead unit and defines the "problem of the day."	a. AFWA
____ (2) Issues centrally produced point weather warnings.	b. OWS
____ (3) Conducts hemispheric weather analysis.	c. WF
____ (4) Acts as the "eyes forward" in monitoring weather changes.	d. JTWC
____ (5) Responsible for tropical storms that impact US bases in Japan.	
____ (6) Strategic center that is most involved in the day-to-day METWATCH process.	

Answers to Self-Test Questions

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1. To provide a controlled and organized approach to ensure weather operators maintain situational awareness of the current and future meteorological situation, within a designated area.
2. To offset limitations of the Basic Weather Watch due to viewing restrictions across portions of the horizon.
3. They differ in terms of focus. A METWATCH focuses on a broad area with general interest. A MISSIONWATCH focuses on specific areas and forecast times to ensure mission success.

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1. No. Not every customer has the same METWATCH requirements.
2. Weather situations or parameters that impact the mission in some adverse way.
3. Weather watch.
4. Forecast weather advisory.
5. Ensure that you establish time intervals that are reasonable and time-efficient.
6. Primary and back-up method of contacting appropriate agencies. Examples are telephone, radios, e-mail, phone patch, and so forth.
7. The Weather Support Document.
8. (1) ATC and Range Control. The primary concern is the occurrence of previously unreported conditions that affect safety of flight, the efficiency of flight and resources.
   (2) Security Police. They may see unreported conditions and damage incidental to weather conditions.
   (3) Flightline personnel. They may also see unreported conditions that might affect flight line operations.
   (4) Field Personnel. They may see unreported conditions. This might be the only reliable source for off-station conditions.
   (5) Pilots. They provide PIREPs which might include unreported or unknown conditions and weather affecting flight operations.
9. The entire duration of the mission—from start to finish.
10. METSAT and radar data are the most renewable data types.
11. PIREPs and SIGMETs.

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1. (1) b.
   (2) a.
   (3) a.
   (4) c.
   (5) d.
   (6) a.

Complete the unit review exercises before going to the next unit.

Unit Review Exercises

Note to Student: Consider all choices carefully, select the *best* answer to each question, and *circle* the corresponding letter. When you have completed all unit review exercises, transfer your answers to the Field Scoring Answer Sheet.

1. (401) When conducting a METWATCH, as a minimum you must consider timing,
   a. location, and forecast values.
   b. terrain, and forecast values.
   c. error, location, and hazards.
   d. error, terrain, and hazards.

2. (401) A major difference between a METWATCH and MISSIONWATCH is that a
   a. MISSIONWATCH focuses on a broad area, with general interest.
   b. METWATCH focuses on a broad area, with general interest.
   c. MISSIONWATCH focuses on ground-based weather only.
   d. METWATCH focuses on a specific area and forecast time.

3. (402) When a weather flight conducts a METWATCH, which of the following tools *best* identifies weather patterns that normally cause poor weather conditions?
   a. Area of responsibility (AOR).
   b. 500 millibar hemispheric chart.
   c. Regional Analysis and Forecast Program (RAFP).
   d. National Weather Service, Weekly Weather Digests.

4. (402) Regarding a weather warning for winds greater than 50 knots, which of the following statements best defines the term *minimum desired lead time*?
   a. Difference between the valid time of the warning and time of occurrence.
   b. The amount of advanced notice a customer requires before the event occurs.
   c. Difference between the issue time of the warning and the time of occurrence.
   d. The amount of advance notice a customer must have between valid time of the warning and time of occurrence.

5. (403) Which organization is responsible for monitoring weather conditions for warning-meeting criteria while weather units are closed and unmanned?
   a. Joint Typhoon Warning Center (JWTC)
   b. Operational Support Squadron (OWS).
   c. Air Force Weather Agency (AFWA).
   d. Weather Flight; (WF).

Please read the unit menu for unit 2 and continue ➔

Unit 2. The Sun, Its Emissions, and the Earth

SPACE ENVIRONMENTAL effects or "space weather," as it is commonly referred to, is growing in importance as the Department of Defense (DOD) accelerates the exploitation of space to conduct communications, command and control, navigation, weapon delivery, surveillance, reconnaissance, theater defense, and other operations. Space environmental anomalies adversely affect ground, sea, air, and space operations, and though the types of effects differ from the weather types you are familiar with in the tropopause (rain, clouds, etc.), the impacts on military operations can be similar and just as significant.

Sample impacts:

- Disrupts tactical and operational communication signals.
- Degrades accuracy of global positioning system (GPS) navigation signals.
- Causes anomalous (unexpected) behavior and damage in satellite sensors/subsystems.
- Induces interference and false targets in space tracking and missile defense radars.
- Impedes intelligence collection efforts.

Air Force Weather (AFW) is responsible for measuring and predicting environmental impacts from earth's surface through outer space, commonly referred to as "mud to sun." Whether you forecast for Army ground operations, strategic airlift, tactical air or space systems, the bottom line is that space environmental effects can have a significant effect on your customer's mission in ways that you don't realize.

The evolution of our knowledge about the space environment is uncertain. New technologies may eliminate some adverse effects experienced today, while increasingly sophisticated and electronically sensitive systems planned for the near future may be affected by space environmental impacts in ways that are unprecedented. Also, the severity of the effects is peaking during a period called "solar maximum" that started in 1999 and lasts until 2002.

The Air Force's role in space can be seen throughout Air Force doctrine. Space weather is an important component in all facets of doctrine and is critical at all levels of the doctrine concept funnel. Examples of the impact space weather are clearly seen throughout the Air Force's core competencies, distinctive capabilities, and operational functions of air and space power.

2–1. The Sun

Space environmental effects essentially refers to electromagnetic radiation and electrically charged particles emitted primarily by the sun, and the environmental phenomena they create as a result of their interactions with earth's upper atmosphere and magnetic field. Figure 2–1 depicts the electromagnetic radiation and electrically charged particles streaming outward from the sun and engulfing earth. The relevant interactions occur generally above 60 kilometers (~ 200,000 feet) or above the stratosphere. These interactions cause complex and rapidly changing space environmental effects phenomena. The three main players in space environmental effects are the sun, earth, and the interplanetary medium between them. Let's start our journey at the sun.

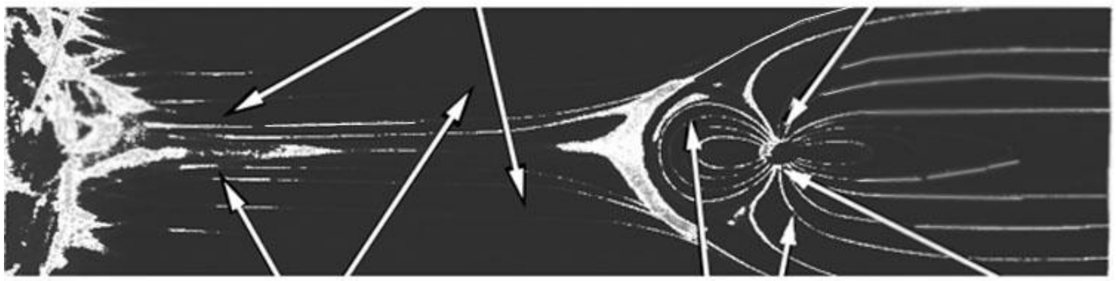

Figure 2–1. Depiction of the sun-earth environment.

404. Our star, the sun

We all know the sun is overwhelmingly important to life on earth; however, as laypersons, few of us have been given a detailed description of our star and its variations.

Some Facts About Our Sun	
Property	**Value**
Radius	6.96×10^5 kilometers (km)
Volume	1.41×10^{27} cubic meters (m^3)
Surface area	6.1×10^{18} square meters (m^2)
Mass	1.99×10^{30} kilograms (kg)
Distance from earth	1.49×10^8 km
Angular diameter from earth	0.53 degrees of arc
Acceleration due to gravity at the surface	274 meters/second/second (m/s^2)
Escape velocity at surface	6.18×10^5 meters/second (m/s)
Average density	1410 kilograms/cubic meter (kg/m^3)
Luminosity (total energy radiated per second)	3.85×10^{26} watts (W)
Solar radiant energy received per second at top of earth's atmosphere	1370 watts/square meter (W/m^2)
Effective temperature	5778 Kelvin (K)
Apparent rotation period	27 days (varies with latitude)
Age	4,600 billion years (approximately)

The sun is an average star, similar to millions of others in the universe and is located approximately 150 million kilometers from earth (see table above). It takes sunlight 8 minutes and 20 seconds to reach earth. The sun is an impressive energy machine, manufacturing about 3.85×10^{26} watts of energy per second (see table above). In other words, if the total output of the sun were gathered for one second, it would provide the United States (US) with enough energy at its current usage rate for the next 9,000,000 years. Each square meter of earth that faces the sun receives the equivalent of 700 megawatts of solar energy. The basic energy source for the sun is nuclear fusion, which uses the high temperatures and densities within the sun's core to fuse hydrogen into helium and releasing energy in the process. The core is so dense and the size of the sun so great, that it takes an estimated 10,000–170,000 years for radiation emitted from the core to reach the sun's surface.

The sun has been producing its radiant and thermal energies for the past four to five billion years. It has enough hydrogen (in the core and just outside of the core) to continue producing energy for another ten to eleven billion years. However, in about five to six billion years the surface of the sun will begin to expand, enveloping Mercury in the process. Scientists have dubbed such an occurrence as a "red giant." In this event, life on earth as we know it will cease to exist. If the sun were more massive, it would collapse and reignite as a helium-burning star. Due to its average size, however, the sun is expected to merely contract into a relatively small, cool star known as a "white dwarf."

It has long been known that the sun is neither featureless, nor steady. Although physician and scientist Theophrastus first identified sunspots in the year 325 B.C., we've learned a great deal more about the sun since then. Some of the key discoveries of solar features are explained in the following lessons.

405. Physical structure and characteristics of the sun

The sun is so immense when compared to earth, that 1,300,000 earths could be held inside the sun. The radius of the sun is 6.96×10^{5} meters (m), which is 109 times that of earth. The average density of the sun is only about one-fourth that of earth, but has over 333,000 times its mass, or approximately 1.99×10^{30} grams (g).

The sun consists of several distinct layers from the dense central core to the relatively thin corona. Direct observations of the solar interior can't be made since all of the emitted radiation comes from the photosphere. Initially, we could only observe the sun in the visible part of the spectrum, allowing us to study only the photosphere. However, a technology called helioseismology now provides us with a means to study the solar interior indirectly, by measuring sound waves propagating through the interior of the sun. We can determine activity in the interior by studying the propagation of radio, UV, X-ray, and other parts of the spectrum through the interior and observing oscillations on the photosphere. The launch of *Skylab* in 1973 and solar observing satellites in the last four decades have increased our observations and knowledge of the sun significantly. Over the last 50 years, new sensing devices such as radio telescopes, X-ray, and ultraviolet (UV) imagers and spectrometers have enabled observations of the photosphere, chromosphere, and the corona to be made. Let's examine each layer, as shown in figure 2–2, starting with the core.

Core

Although the core contains only $^{1}/_{64}$ of the sun's volume, it contains $^{1}/_{2}$ of the solar mass. Under the force of gravity, solar material is so compressed and heated that nuclear reactions take place. The temperature at the center is over 15,000,000K, which keeps the core in a gaseous state. Interestingly, nearly all the sun's emitted energy is generated in the core. Hydrogen atoms are transformed to helium at a rate of approximately 5 billion kilograms every second. This energy is slowly transferred into the photosphere by radiation.

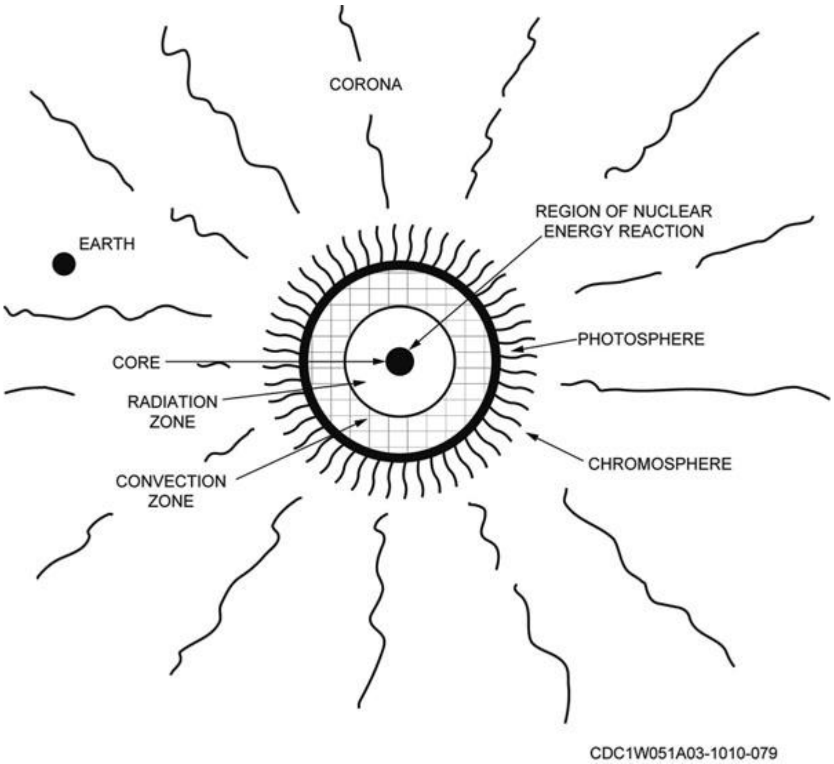

Figure 2–2. Structure of the sun.

Radiation zone

Radiation leaves the core as high-energy gamma rays. These rays are absorbed within the radiation zone and emitted again as lower energy photons. This process continues as the photons diffuse outward from the core and the energy of the average photon decreases. In this way, energy radiating from the core as gamma rays are gradually changed to X-rays, then to extreme UV (EUV) rays, UV, and finally into the lower energy visible light that is most characteristic of the solar energy radiated into space. However, radiation is not the only means by which energy is transported to the surface. Geometrically, at 0.86 of the solar radius, gas properties evolve to such an extent that turbulent convection occurs.

Convection zone

The temperature in the convection zone is considerably lower than in the core, allowing nuclear particles to acquire orbiting electrons and form atoms. Since atoms can easily absorb energy, the gas becomes more opaque to radiation—hence, large temperature gradients form. Because of these temperature gradients, elements of the convection zone become less dense than their surroundings and turbulent convection occurs. The energetic boiling and bubbling (granulation) seen in the photosphere is visible evidence of the convection in layers below.

Photosphere

Visually, what we see when we look at the sun is a glowing white sphere. This visible sphere is called the photosphere. The photosphere is considered the "surface" layer of the sun. This "surface" is a gaseous shell that forms a 500 km thick boundary between the dense interior gases in the core and the more diffuse, cooler gases in the inner layer of the sun's "atmosphere." The average temperature in the photosphere is 6,000 K.

In the photosphere, the emission of energy reaches its peak in the visible spectrum, extending from the near UV to the infrared; this is the range in which our eyes can sense light. Our eyes perceive the spectrum in its entirety so that the photosphere appears white. This white light, however, can be broken down into distinct colors of the visible spectrum, which represents radiation at various wavelengths.

The next two layers of the sun's atmosphere are the chromosphere and corona. They make up the outermost portion of the solar atmosphere and not able to be seen visibly because of the blinding light of the photosphere. Special filtering techniques must be used in order to view and study them.

Chromosphere

We call the next layer outward, the chromosphere. The chromosphere is the innermost layer of the solar "atmosphere," (which is not normally visible) and extends outward from the photosphere for approximately 2,500 km until it gradually merges with the outer layer of the solar "atmosphere." Temperatures in the chromosphere rise from 4,300K at the top of the photosphere to 1,000,000K at the base of corona. It's in this thin layer, only 30–40 km thick, that most solar activity occurs, such as solar flares (fig. 2–3). A solar flare is a sudden, short-lived, explosive release of energy, consisting of both electromagnetic and charged particles from a localized region in the chromosphere. We'll examine solar flares more closely later in the lesson.

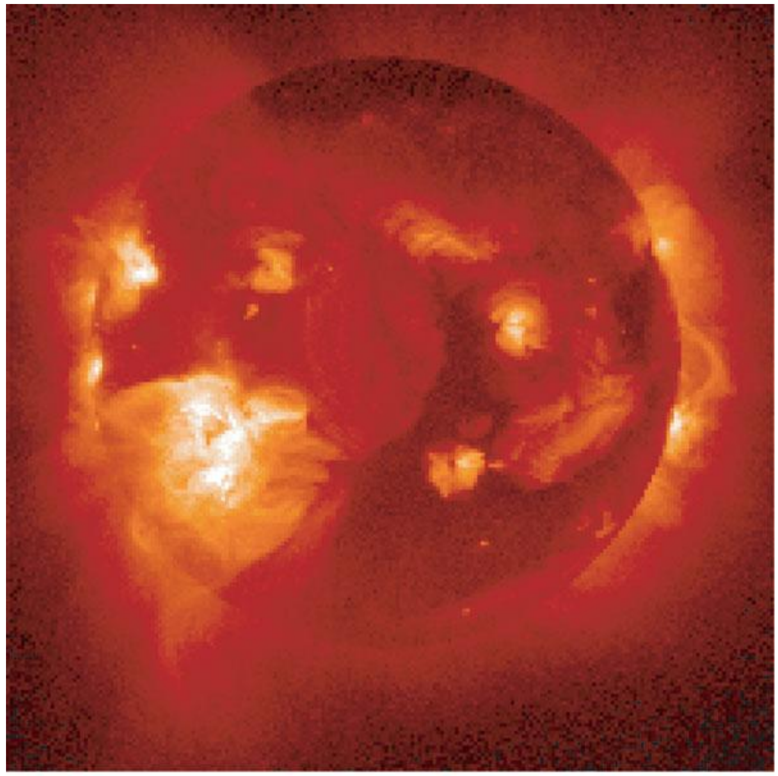

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Figure 2–3. The sun filtered by X-ray light.

Corona

The outermost portion of the solar "atmosphere," the corona, extends outward from the top of the chromosphere, as shown in figure 2–2. The temperatures in this region can range up to 2,000,000 K. The corona is less dense than the chromosphere and because of the brightness of the photosphere behind it, is not normally visible except during a total solar eclipse. The corona extends out great distances from the sun and extends to earth and beyond, so that it immerses the earth. This continual, outward flow of energetic charged particles from the sun is called the solar wind. Due to its high temperature, the corona emits high-energy photons in the form of X-rays. Observations of the corona through visible, UV, and X-ray wavelengths reveal that the brightest portions of the corona are located in the vicinity of sunspots and the darkest portions of the corona are located in the vicinity of "coronal holes." Incidentally, these variations in the brightness of the corona are caused by differences in the local magnetic fields.

It's obvious thus far, that some portions in the structure of the sun are more responsible than others for solar activity. As we move further into the lesson, you'll gain a better understanding of how solar activity impacts earth and why we're so interested in space weather. First, let's briefly look at composition of elements that make up the sun.

Composition of the sun

Without delving too deeply into the chemistry and physics involved, let's consider the composition of the sun. The sun is composed of approximately 75 percent hydrogen, 23 percent helium and traces of all other elements making up the remaining 2 percent. In terms of the states of matter—solid, liquid, gas—the sun is described as being in the fourth state, that of plasma. In the plasma state, the individual atoms are in various states of ionization, which means that some electrons surrounding the atom's nucleus have been stripped away. Deep within the very hot core of the sun, the hydrogen atoms are completely ionized. These ionized atoms are packed tightly together, creating the very dense core of the sun.

Core temperatures of about 10,000,000 to over 15,000,000K and the relative abundance of ionized hydrogen, carbon, and other elements provide the means for the thermonuclear processes that transform hydrogen into helium. This thermonuclear reaction, producing helium from hydrogen fuel, represents a nearly constant release of energy from the sun into space. This implies that the sun will eventually “burn up” its hydrogen fuel after another five to six billion years.

The sun’s activity is constantly monitored from earth by both military and civilian personnel using telescopes and other instrumentation at locations on earth and from space. The sun has a few observable features that can indicate changes in the sun’s internal and external dynamics that have a direct effect on space environmental effects.

406. Solar features

Just as weather observations play a crucial role in forecasting weather in the troposphere, observations of the sun’s activity play an equally valuable role in predicting space environment events. The sun has distinct features that can be observed by earth-based optical and radio telescopes and by space-based sensors. Two satellites, jointly operated by the National Aeronautics and Space Administration (NASA) and the European Space Agency (ESA) are the Solar and Heliospheric Observatory (SOHO) and the Solar Dynamics Observatory (SDO). These spacecraft, together with other satellites, constitute an international cooperative scientific satellite project whose goal is to gain an improved understanding of the sun. The spacecraft use their array of sensors to continually provide new information about the sun’s composition, the electromagnetic energy emitted into space, and its’ interactions with earth’s atmosphere. SOHO has identified plasma flows on the surface of the sun that resemble jetstreams and tradewinds in earth’s atmosphere. The advanced composition explorer (ACE) also provides near-real-time observations of the solar wind over short time periods. The changes in these features over time can provide valuable information indicating what effects earth’s atmosphere will experience in the future.

Because sunlight is so bright, scientists use various techniques to filter the sun down to a specific color or band of colors to look at one particular feature. Photographs taken of the sun in such filtered light show much more detail than pictures taken in plain sunlight and contain more detailed information about the sun’s structure. Such filtered light photographs revealed the magnetic structure of sunspots.

Changes in magnetic fields on the sun’s surface play a crucial role in causing many of the solar features that scientists observe on a daily basis. Let’s look at some of those features now.

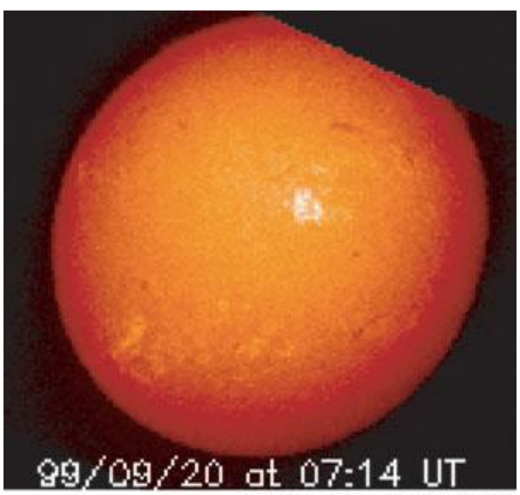

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Figure 2–4. Sun filtered by hydrogen alpha light.

Plage

Active regions on the sun show up as bright “plage” regions (fig. 2–4) located in the sun’s lower atmosphere (also known as the chromosphere). Plage are regions of high magnetic field strengths and are somewhat denser, hotter, and thus brighter, than the surrounding areas (fig. 2–5). Plage is best observed through a filter that passes only the monochromatic red light of the hydrogen-alpha wavelength (6563 Angstroms). Growth in both plage area and brightness can significantly increase the total output of portions of the solar electromagnetic spectrum, particularly in X-ray, EUV, and radio wave-lengths. Since plage can be produced by smaller magnetic field strength than required for sunspot production, plage is a precursor of sunspots and persists longer than any related sunspots. Most solar flares occur in the vicinity of these “active” regions.

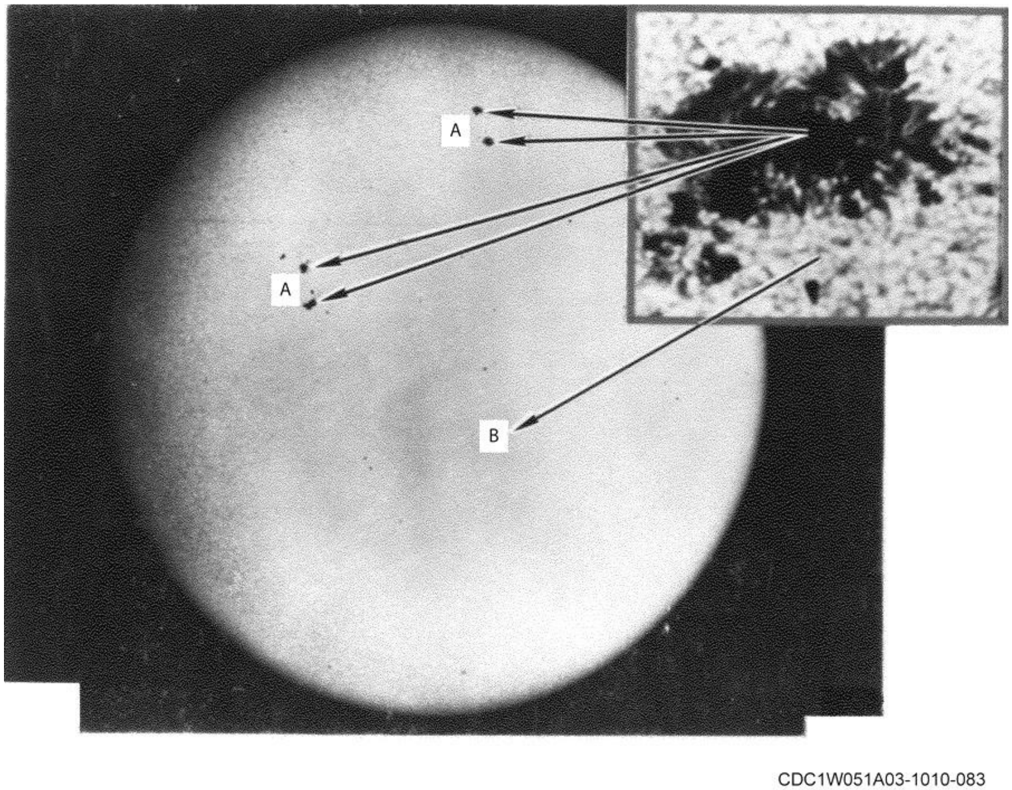

Figure 2–5. Sunspot groups.

Sunspots

Sunspots, as shown in figure 2–5, appear as dark areas against the hotter and brighter solar surface (also known as the photosphere). They are transient, concentrated, localized regions of plasma located in areas of intense magnetic fields in the photosphere. Sunspots are the most prominent visible features on the sun; a moderate-sized sunspot is about as large as the earth. Sunspots form and dissipate over periods of hours to weeks, or even months.

Sunspots usually occur in pairs with one being larger than the other. The first spot of a pair observed during the rotation of the sun is called the “leading spot.” The second spot observed of the pair is called the “trailing” spot. Sunspots occur when strong magnetic fields emerge through the solar surface and allow the area to cool slightly, from a background value of 6,000K down to about 4,200K. This area appears as a dark spot in contrast to the sun. The darkest area at the center of a sunspot is called the umbra; it is here that the magnetic field strengths are the highest. The less-dark area of light filaments surrounding the umbra is called the penumbra.

It is believed that sunspots, through their magnetic field lines arching above the solar surface, hamper the outflow of solar wind. Sunspots rotate with the solar surface, taking about 27 days to make a complete rotation as seen from earth. Sunspots near the sun’s equator rotate at a faster rate than those near the solar poles. Groups of sunspots, especially those with complex magnetic field configurations, are often the sites of flares (fig. 2–5).

Over the last 300 years, the average number of sunspots has regularly waxed and waned in 11-year cycles. This cycle is referred to as the “sunspot or solar cycle.” Past sunspot cycles have lasted 8–15 years. It is also interesting to note that every 11 years the overall magnetic polarity of the sun’s northern and southern hemispheres reverses itself. A return to the original polarity requires another eleven years—hence the sun also has a 22–year solar magnetic cycle.

Solar bursts

There are various causes of sudden bursts of radiation and/or electrically charged particles, and there are different names assigned to these bursts depending on their nature and cause. The "solar flare," originating from sunspot regions, is the most common type of burst and emits radiation and electrically charged particles. Generally, bursts are most common during solar maximum, though there are other solar phenomena that occur more often during solar minimum. Whether it's solar flares, steady-state radiation emissions, or daily changes in the solar wind, they all combine to form space environmental processes that can affect military operations.

Solar flares

Solar flares are intense, temporary releases of energy which occur in the vicinity of sunspots and/or plages. Solar flares are the primary cause of the solar activity. They are seen by ground-based observatories as bright areas on the sun (fig. 2–6) and are viewed as optical wavelengths. They are detected as bursts of noise through radio wavelengths. Solar flares can last from a few minutes to several hours and are our solar system's largest explosive events. Scientists estimate that a solar flare is equivalent to approximately 40 billion Hiroshima-size atomic bombs.

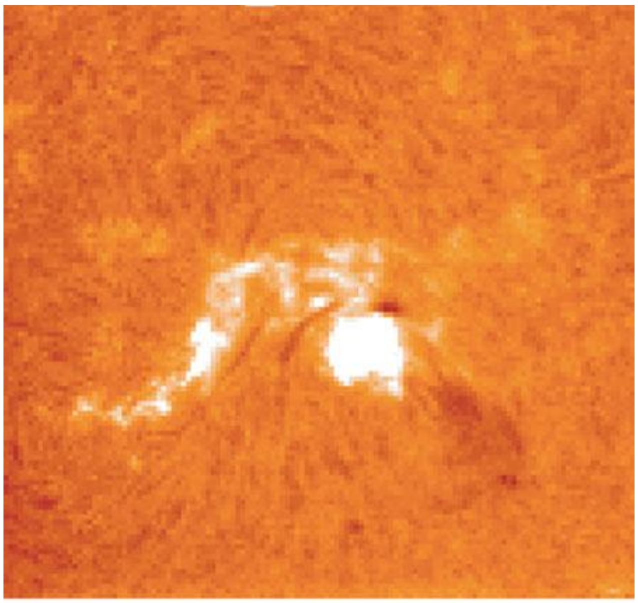

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Figure 2–6. Solar flare viewed from earth.

The solar flare is an explosive release of energy (both electromagnetic and charged particles) within a relatively small (but greater than earth-sized) region of the lower solar atmosphere. While the energy released during a flare is very substantial, it represents only 1/100,000 of the total solar output at most. Hence, our daily lives appear to be unaffected. However, a flare's enhanced X-ray, EUV, radio wave, and particle emissions are sufficient enough to adversely affect DOD radar, communications, and space systems.

Flare occurrence

Flares usually occur in the vicinity of sunspots or their precursors; the bright active regions called plages. Scientists believe that energy released by a flare is the energy stored in the intense, complex magnetic fields that produce those plages and sunspots. Flares are also a triggering mechanism for eruptive prominences or disappearing filaments, which are outward ejections of material (charged particles) which had been suspended, like clouds, in the solar atmosphere.

Unfortunately, on a case-by-case basis, it is almost impossible to predict exactly when a large flare will occur. However, the close correlation with flares, sunspots and plages do permit reasonable forecasts of the likelihood of flare occurrences and probable flare characteristics (size, duration, X-ray and particle emissions, etc.). The strength of a flare, and thus its potential to cause system impacts, is often correlated with the size and complexity of the associated sunspot group or plage active region. Interestingly, flares are classified according to their optical or X-ray characteristics.

Optical flare classification

The optical classification of a flare (as seen in Hydrogen-alpha light) is made using a two-character designation based on flare area and brightness. Example: a 1B designation indicates a "brilliant" intensity flare covering a corrected area between 100 and 249 millionths of the solar hemisphere (fig. 2–7).

NOTE: Flare areas are corrected for geometric foreshortening caused by projection of a spherical object on a flat viewing plane.

SIZE CATEGORY	CORRECTED FLARE AREA (Millionths of the Solar Hemisphere)	TYPICAL DURATION	PERCENTAGE OF ALL FLARES
0	10 to 99	Several minutes	75
1	100 to 249	Tens of minutes	19
2	250 to 599	An hour	5
3	600 to 1200	An hour or more	Less than 1
4	Greater than 1200	An hour or more	Less than 1

BRIGHTNESS CATEGORIES: F: Faint N: Normal B: Brilliant

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Figure 2–7. Optical flare classification.

X-ray flare classification

Flares are also classified by the peak X-ray energy flux emitted in the 1 to 8 Angstrom wavelength band, as measured by a geosynchronous operational environmental satellite (GOES) satellite (fig. 2–8). These measurements must be made from space, since earth's atmosphere absorbs all solar X-rays before they reach earth's surface.

CLASS	X–RAY PEAK FLUX
A	Greater than or equal to 10^{-5}, but less than 10^{-4} ergs/cm^2/sec
B	Greater than or equal to 10^{-4}, but less than 10^{-3} ergs/cm^2/sec
C	Greater than or equal to 10^{-3}, but less than 10^{-2} ergs/cm^2/sec
M	Greater than or equal to 10^{-2}, but less than 10^{-1} ergs/cm^2/sec
X	Greater than or equal to 10^{-1} ergs/cm^2/sec

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Figure 2–8. X-ray flare classification.

Filaments and prominences

Filaments are ribbon-like features suspended above the chromosphere by the magnetic field; they can be compared to clouds on earth. Filaments have a higher density and a lower temperature than the rest of the sun's atmosphere and so appear dark when seen against the brighter solar background. However, when filaments are seen on the sun's limb, they appear as bright features against the darkness of space and are then called prominences. A prominence is a large, bright feature extending outward from the Sun's surface, often in a loop shape. Some filaments/prominences exhibit rapid changes in shape or brightness, or show movement. These features are termed as active. An example of an active prominence is a loop prominence system, which is associated with energetic flares (fig. 2–9). Active filaments/prominences usually erupt at some point in their lifetime (fig. 2–9), releasing large amounts of solar material into space.

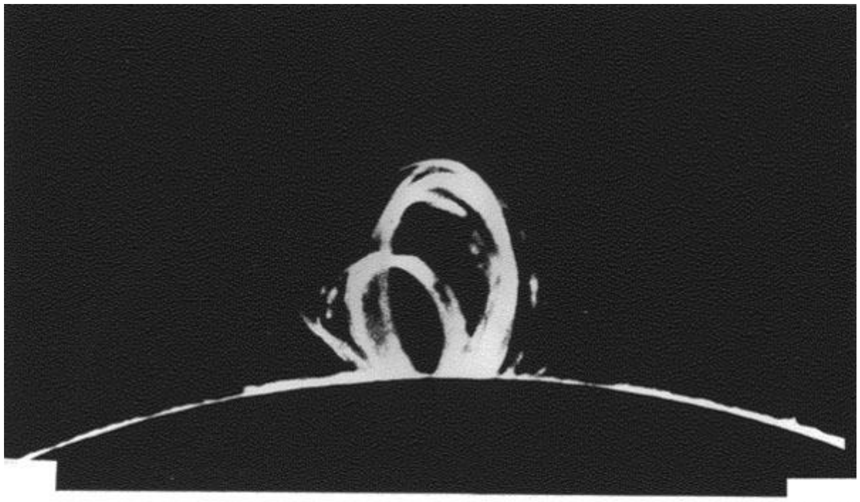

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Figure 2–9. A loop prominence.

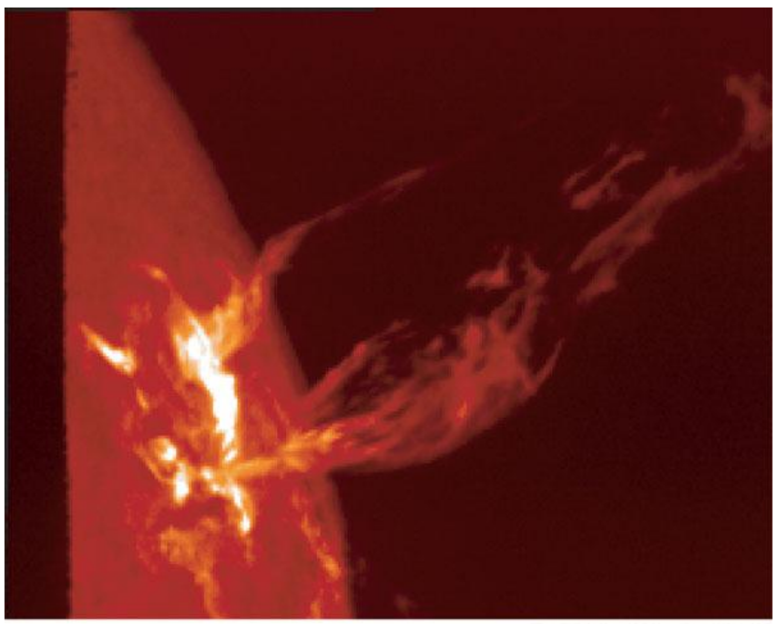

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Figure 2–10. An eruptive prominence.

Certain conditions can cause the supporting magnetic field to fling a filament or prominence outward. This outward eruption of material forms a charged particle stream, which could possibly reach earth and cause a geomagnetic disturbance about 72 hours after the eruption.

Coronal mass ejections

The outer solar atmosphere, the corona, is structured by strong, localized, magnetic fields. The magnetic fields usually are shaped like the letter "S," parallel each other, and don't touch. In 1999, using the Solar Vector Magnetograph (SVMG), an X-ray telescope, scientists Richard Canfield, David McKenzie, and Hugh Hudson discovered that when these magnetic fields reverse, like laying a figure "2" on the letter "S," the field lines cross each (referred to as globally twisted). When this happens the reaction is similar to two live electrical wires being crossed and a "short circuit" occurs. When these field lines cross, often above sunspot groups, the confined solar atmosphere can suddenly and violently release bubbles (or tongues) of gas and magnetic fields called coronal mass ejections

(CME). CMEs are huge, bubble-shaped disturbances rising and expanding above active sunspot regions. CMEs expand in size as they rise.

CMEs were first observed in 1973 from telescopes aboard the space station *Skylab*. Though a singular cause of CMEs is unclear, the SVMG allows scientists to measure the intensity and direction of a magnetic field in the hot gas. They can then predict which magnetic fields are more likely to erupt into a CME. A smaller version of the SVMG, the Solar X-ray Imager (SXI) now exists and is incorporated into a new version of a GOES weather satellite. This new GOES satellite serves a dual function—monitoring earth's weather as well as the sun's atmosphere.

CMEs heading straight for earth aren't easy to observe because they're masked when viewed against the background of the bright sun. Space-based sensors are used to identify CMEs. A large CME can contain a billion tons of matter that can be accelerated to several million miles per hour in a spectacular explosion. Solar material streaks out through the interplanetary medium, affecting any planets or spacecraft in its path. If the CME goes off in the right location on the sun it can intercept earth's atmosphere in four days causing geomagnetic storms in earth's atmosphere. CMEs are sometimes associated with flares but usually occur independently.

Coronal holes

Coronal holes are variable solar features that can last for months to years. They appear as large, dark holes when the sun is viewed in X-ray wavelengths. These holes are rooted in large cells of unipolar magnetic field structures on the sun's surface; their field lines extend far out into the solar system. The open field lines allow plasma to escape freely in the form of a continuous outflow of high-velocity solar wind. Coronal holes have a long-term cycle, but it doesn't correspond exactly to the sunspot cycle; these holes tend to be most numerous in the years following sunspot maximum. At some stages of the solar cycle, the holes are continuously visible at the solar north and south poles.

Now that we've defined some specific types of anomalies, let's tie these solar occurrences into the solar cycle so we get a better idea of which years of a solar cycle are likely to produce more or less solar activity.

407. The solar cycle

Western sunspot records begin with the first telescopic observations by Galileo in 1611. Over 200 years later the sunspot cycle (fig. 2–11) was discovered in 1843 by Heinrich Schwabe. Schwabe observed that the times when the maximum numbers and the minimum numbers of sunspots are observed follows an average of 11 years. This 11–year cycle is called the "sunspot or solar cycle." This doesn't necessarily mean that each cycle is exactly 11 years. Some cycles have lasted as short as 8 years and as long as 15 years, but most cycles are very close to the average of 11.1 years. Each sunspot cycle (from 1954 onward) is labeled in figure 2–11 by cycle number. The maximum of the last cycle (#23) was in 2000.

Solar cycle characteristics

Generally, cycles show a rapid, roughly 4–year rise to a "solar maximum," followed by a gradual 7–year decline to a "solar minimum." Since solar activity is closely correlated with the number of sunspots, solar events and operational impacts also

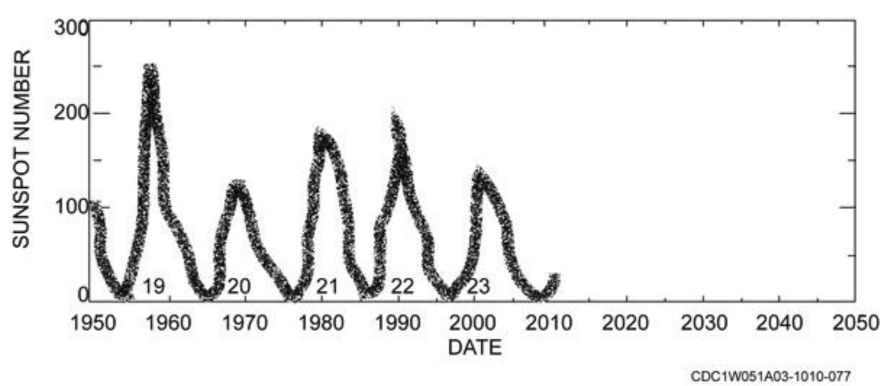

Figure 2–11. Sunspot cycle.

tend to follow an 11–year cycle as shown in figure 2–11. Predicting the time and magnitude of future sunspot cycles is a relatively difficult, uncertain process, normally involving the use of a variety of statistical and precursor methods. However, the real operational problem with the solar cycle is that solar minimum tends to lull system designers, operators, and users into a state of complacency. Interestingly, the rapid rise to solar maximum that follows the minimum creates some unexpected and unpleasant surprises. Overall, both maximums and minimums create cause-and-effect relationships that permit some type of solar activity to occur.

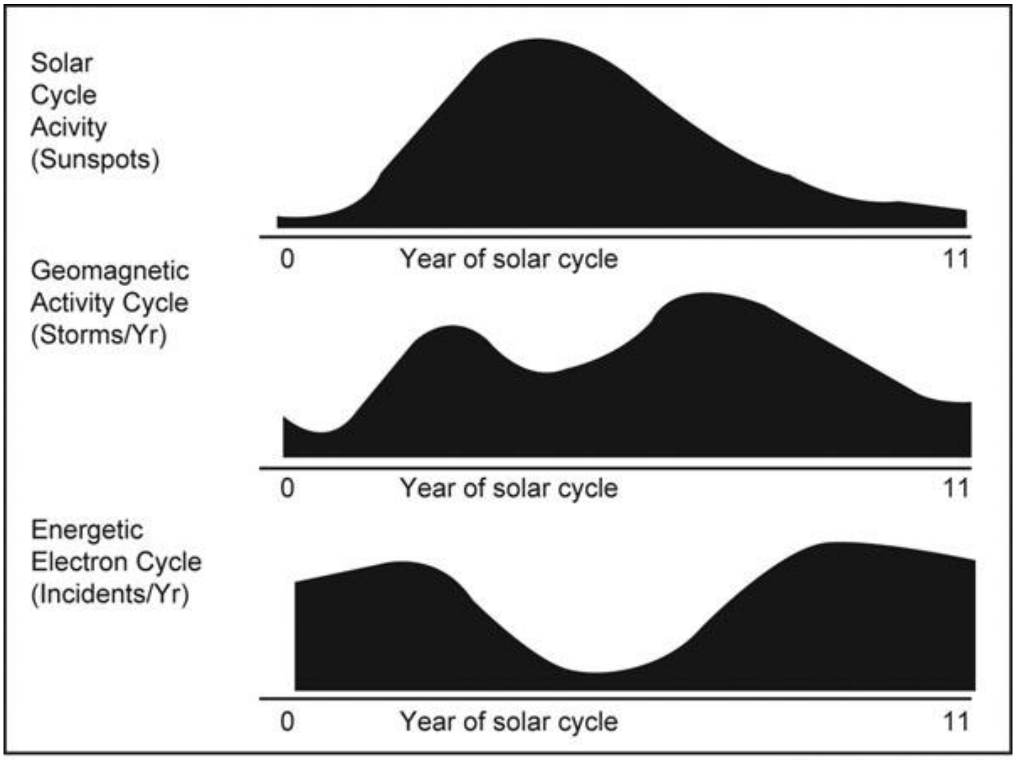

Figure 2–12. Solar activity and its effects on earth.

The cyclic nature of solar activity

There are several methods for measuring numbers of sunspots; however, the method most used is the "Zurich sunspot number." The Zurich number ranges from zero to 200 and usually is published as a monthly average. Operators should not be fooled into thinking they are "out of the woods" when a solar maximum has passed. The greatest potential for large solar flares is actually during the two to three years immediately following a solar maximum. The reason for this situation is that a decline in the number of sunspots and active regions (or plages) permits solar magnetic fields in those regions that exist to build in intensity and complexity without being prematurely disturbed by neighboring flare events.

Furthermore, solar and geophysical activity can and does occur even during solar minimum, because not all solar activity (and system impact) is solar flare induced. Flares are the primary cause; however, other causes include coronal mass ejections, disappearing filaments (also known as eruptive prominences), solar wind sector boundaries, high-speed particle streams emanating from coronal holes, and cosmic rays of nonsolar origin. Not all of these phenomena are directly tied to sunspots and plages; in fact, some (like coronal holes and nonsolar galactic cosmic rays) are actually more common problems during solar minimum!

Besides the amount of sunspots varying during a sunspot cycle, their location or position on the sun changes as well. Soon after the sunspot minimum occurs, new sunspots appear at latitudes 40–50 degrees north and south. These sunspots disappear over time without changing location. As newer sunspots or groups of sunspots appear, they form closer to the equator of the sun and stay in that relative location until disappearing. Each subsequent spot emerges somewhat closer to the solar equator and roughly 11 years later; at the time of solar maximum, most spots are located within 10 degrees north or south of the equator.

Magnetic polarity shift

Along with the 11–year solar cycle, there is an increasingly important property of the sunspot cycle related to the magnetic character of a sunspot pair. Recall that sunspots occur in pairs with a leading spot and a trailing spot. Looking at pairs of sunspots on the sun you will find that most pairs of sunspots are aligned in an east-west direction. At any one time, all the leading spots in the sun's northern hemisphere have the same magnetic polarity, and all the leading spots in the southern hemisphere have the opposite magnetic polarity. The same is true of the trailing spots in each hemisphere; their polarity is reversed from one hemisphere to the other. Every 11 years the overall magnetic polarity of the sun's northern and southern hemispheres reverses. If we had solar compasses a shift of 180° would then be observed every 11 years. A return to the original polarity requires another 11 years—hence the 22–year cycle. This 22–year cycle is also known as the Hale cycle. During the reversal the leading and trailing spots in the northern and southern hemispheres reverse polarity. The magnetic polarity reversal is preceded by a rise in the occurrence of magnetic storms on the surface of the sun. The cause of these storms is believed to be from the shearing of plasma flows along with other gases in the solar atmosphere.

The science of the anomalies of the sun is remarkable in its own right. Even more remarkable are the instruments used to observe the sun which help us learn as much as possible. Without the advancement in technology we have today, we'd be extremely limited in understanding our sun.

408. Solar optical observations

Solar optical observations are taken by certain AFW units using Solar Observing Optical Network (SOON) telescopes. These telescopes provide visual observations of the features in the sun's photosphere and chromosphere. Visual observations of the corona are taken using a coronagraph, which blocks out the solar disk so that only emissions in the corona may be examined. Observations of regions deeper than the photosphere are not possible due to the opacity of the photosphere. This lesson concentrates on the optical observations.

White-light observations

Essentially, the observations of features in the photosphere are termed white-light observations and the observations of features in the chromosphere are called monochromatic light observations. Because of the intensity of light from the photosphere, this type of observation is accomplished by photographic techniques or by projection methods rather than by direct observation. Solar observatories produce drawings of sunspots by projecting the image of the sun onto a sheet of paper attached to a board mounted on the telescope. The observer draws the sunspots by carefully tracing their projected images. But what are sunspots?

Sunspots are the oldest form of solar features observed and rendered by humans. They appear as dark splotches against the solar disk because their temperature is cooler than that of the surrounding photosphere by as much as 2,000 K. The temperature difference is produced by a strong local magnetic field that impedes the transfer of heat to part of the photosphere.

The insert of figure 2–5 illustrates that sunspots have a dark center, or umbra (A), surrounded by a brighter ring, or penumbra (B). The umbra may reach a size of 75,000 km (47,000 miles) across, and the entire spot, including the penumbra, up to 100,000 km (62,000 miles). Near a spot, material circulates inward toward the center in the upper layers and outward in the lower layers. Again, sunspots appear mainly in pairs or groups—the groups occasionally contain several dozen spots. Groups may persist for several solar rotations (the sun as observed from earth rotates on its axis approximately every 27 days), but sometimes change significantly from one day to the next, particularly in the early stages of development and late stages of decline.

The sun, like earth, possesses a magnetic field with north and south polarities. Unlike earth, however, the polarities of the northern and southern hemispheres reverse themselves from one 11-year solar cycle to the next. The undisturbed solar magnetic field has a field strength of one gauss. (The gauss is a unit of magnetic field intensity measurement. The mean field strength of earth is half a gauss.) However, active solar regions marked by sunspots have strong local fields of up to 4,000 gauss. These intense local fields with their sharp magnetic gradients are strongly influential in producing the eruptive energy, characteristic of solar flares.

Most sunspot groups are bipolar, with a dominant spot having opposite polarity from the other (or others). However, some spot groups have a single polarity or multiple polarities. A few complex spot groups develop a tight, chaotic pattern or polarities that often precede energetic solar flare activity. Sunspots, then, offer an important source of solar observational data for analysis purposes.

White-light observations, however, are limited to the photosphere. Just as with our terrestrial atmosphere, information of the solar atmosphere above the "surface" is necessary to develop an understanding of the interrelated phenomena.

Monochromatic light observations

We mentioned previously that observations of the chromosphere were made in monochromatic light. Filters have been developed that capitalize on the optical properties of quartz and calcite. Filtering the incident light from the sun through a series of alternate segments of polaroid and quartz (or calcite) results in light restricted to a particular wavelength. This represents the emission of a particular chemical element in the chromosphere.

One such element abundantly evident in the chromosphere is hydrogen. The radiation in the chromosphere is produced by a transition of the hydrogen atom's electron from the third to the second orbital shell. This emission is called the hydrogen alpha (Hα) line of the electromagnetic spectrum at a wavelength of 6,562.8 angstroms (A). (One angstrom unit is equal to 10^{-8} cm or 10^{-4} micrometers.) Since the Hα line is a red line of hydrogen emission, all features observed at the eyepiece of the telescope appear in various intensities of red. Photographs in Hα are sometimes produced in black and white. What do these observations and photographs display?

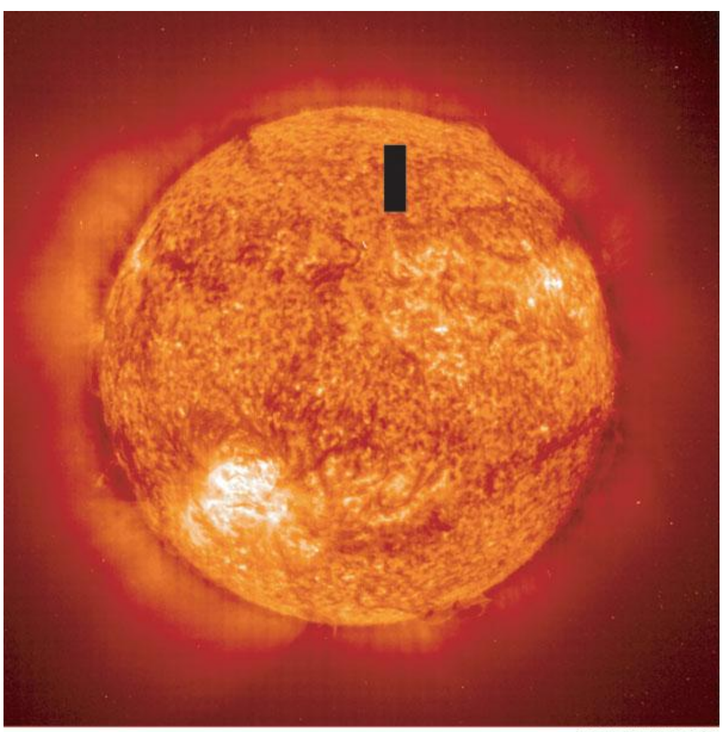

Figure 2–13. Plage regions on the sun.

Figure 2–13 is an Hα image of the sun. The bright regions on the solar disk are called plage regions, which appear above and in close association with sunspot groups of the photosphere. The plages are clouds of ionized gas that indicate relatively dense regions in the chromosphere. The brightness of the plage elements represents increased atomic reaction that results in areas of enhanced chromospheric intensity.

Recall that the dark ribbon-like features on the solar disk are called filaments, clouds of plasma suspended above the chromosphere. They normally extend to greater heights in the solar atmosphere than plage and appear dark because they are cooler than the other chromospheric features. Conversely, the same feature when viewed at the edge (or the limb) of the solar disk, against the darker "sky," appears light. Such features are then called limb prominences. Both filaments and prominences can be active or inactive with respect to the apparent motions of the filamentary material.

Motions along the line of sight within disk features can be determined by shifting the filter on the telescope slightly "off-band" toward either shorter or longer wavelengths. These off-band portions of the bandpass of the filter are called the wings. The shift toward shorter wavelengths is the blue wing, and the shift toward longer wavelengths is the red wing. Normally, inactive chromospheric features will be far less intense in the wings if they are discernible at all. A strong feature in one wing or the other indicates motion either toward or away from the observer, or a "Doppler" shift. Strong blue-wing emission indicates a radial motion outward (toward the observer), while a strong red-wing emission represents motion downward toward the photosphere. Motions within prominences can be observed directly on-band. The reason for this is that in limb features, the radial motions are perpendicular to the line of sight.

Generally, filaments, and plages, are often relatively long-lived solar features that persist for several solar rotations. Most are inactive throughout their life cycles, but a few undergo dramatic and dynamic changes. One vivid example is the eruption of a prominence on the limb. Figure 2–14 shows such an eruptive prominence, with the relative size of earth indicated.

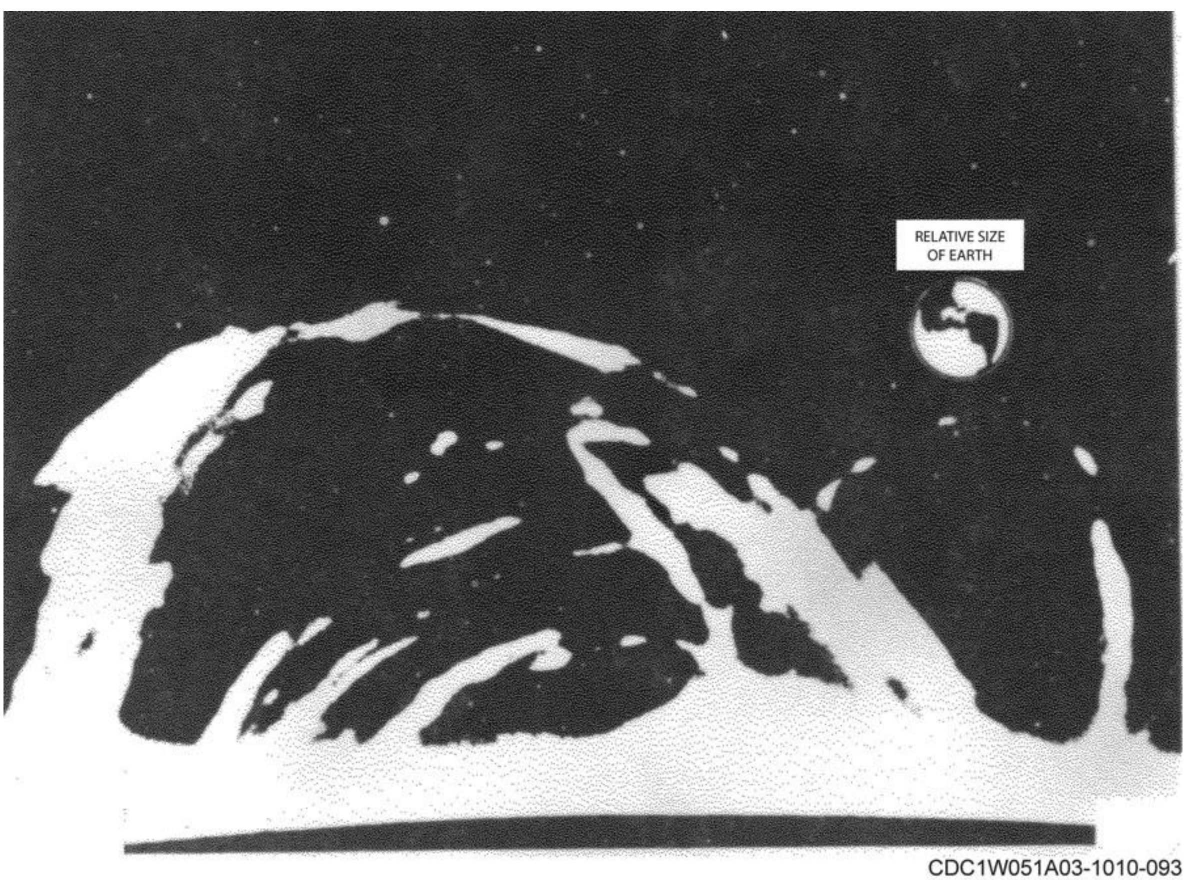

Figure 2–14. Eruptive limb prominence.

Limb activity is characterized by several phenomena that take different forms, the most common of which is the active prominence region (APR). These APRs usually take the form of a low arch and display brightness fluctuations and visible motion of matter along the length of the prominence. Frequently, at the bases of the prominence, bright surges on the limb occur in flame-like tongues in which matter briefly surges outward and falls back to the limb. When a large surge occurs in which the motions exceed escape velocity (approximately 618 km/sec in the photosphere or 400 km/sec in the lower corona), the material is ejected and does not return to the sun. This type of eruptive limb activity is called spray.

As you previously learned, another significant form of limb activity is the loop prominence, a spectacular example of which is shown in figure 2–9. Scientists believe the loop is formed by the condensation of material from the hot corona. Bright, condensed material (called bright knots) is often visible at the top of the loops, and downward motion is observed along both legs of the loop, believed to represent lines of magnetic force. An empirical relationship exists between the loop phenomena and the occurrence of flares. The loops generally form as a post-flare phenomenon, and have been correlated with those flares that release sufficient energy to propel charged particles into space.

While optical observations reveal a great deal of information about the sun, solar radio instruments reveal even more data regarding solar activity. The next lesson describes the capabilities and terms associated with such observations.

409. Solar radio instruments

Besides solar optical observations, observations are also taken of radio emissions from the sun. Air Force Weather's Radio Solar Telescope Network (RSTN) uses the AN/FRR–95 radio interference monitoring set (RIMS) to analyze solar radio data. The RIMS consists of two types of radio telescopes—the discrete frequency radiometer and the solar radio spectrograph (SRS).

Discrete frequency radiometer

This radio telescope is instrumented so that it can simultaneously sample solar radio emissions from the chromosphere and corona at eight discrete (fixed) frequencies: 245; 410; 610; 1,415; 2,695; 4,995; 8,800; and 15,400 megahertz (MHz).

Solar radio emissions received here at earth are described in terms of solar flux units (SFU). Each frequency has its reference standard in SFUs based on years of climatological data. These radio emissions normally represent a constant background level that varies as a function of the general activity level of the sun. Superimposed on this background flux, are bursts of radio energy produced in association with solar activity, such as a solar flare.

Solar Radio Spectrograph

Besides the data available at the eight discrete frequencies, the SRS also monitors solar emissions over a frequency range of 25–180 MHz. These low frequencies are associated with radiation that emanates from the coronal region of the sun.

Because a range of frequencies is involved, the type of data printout takes a slightly different form than that of the single-stylus, strip-chart traces for each of the discrete frequencies. On the discrete frequency recorders, the flux at each frequency is easily determined from the number of chart divisions above the background trace, much like the strip-chart printout from a lie-detector test, thus measuring flux density versus time. The printout for the SRS, however, is in terms of frequency versus time, rather than flux density versus time. The SRS recorder gives indications as to the range of frequencies involved with the radio burst, and by contrast with the background, a quantitative idea of the intensity of the burst.

Radio burst data at discrete and sweep frequencies, then, offers us information on the energy density and special characteristics of a solar event in the radio portion of the spectrum. This radio emission is coincident with the event and has predictive value in terms of the consequences on earth, but it obviously is not a predictor of the event itself.

Self-Test Questions

After you complete these questions, you may check your answers at the end of the unit.

404. Our star, the sun

1. How long does it take for sunlight to reach earth?

2. What is the basic energy source for the sun?

405. Physical structure and characteristics of the sun

1. Which layer of the sun contains one-half of its mass?

2. Where is nearly all the sun’s emitted energy generated?

3. In which layer of the sun do large temperature gradients form?

4. What is the “surface” layer of the sun called?

5. Give the name of the innermost layer of the sun’s atmosphere.

6. In which layer of the atmosphere does most solar activity occur including solar flares?

7. Which layer of the sun is not normally visible except during a total solar eclipse?

8. Name the layer of the sun that immerses earth.

9. What is the source of the sun’s energy?

10. What physical reaction represents a nearly constant release of energy from the sun into space?

406. Solar features

1. What is plage?

2. Describe sunspots.

3. Describe solar flares.

4. Near what solar features do solar flares usually occur?

5. What are solar prominences?

6. What are coronal mass ejections?

407. The solar cycle

1. What is the average duration of a solar cycle?

2. What numerical method is used the most to measure sunspots?

3. How is the magnetic field of the sun affected from one solar cycle to the next?

408. Solar optical observations

1. State the purpose a coronograph serves.

2. White light observations provide information on features in what part of the sun?

3. What type of solar observation uses a projection method rather than a direct method?

4. What is the darker interior of a sunspot called?

5. What type of solar observation uses a process where light is filtered through a series of segments of polaroid, quartz, and calcite?

6. What are plages and what do they indicate?

7. What information do monochromatic light observations provide?

8. What are filaments viewed at the limb of the solar disk called?

9. What does the strong, blue-wing emission of a filament indicate?

409. Solar radio instruments

1. What type of radio frequencies are associated with radiation that emanates from the coronal region of the sun?

2. What type of data collected by the SRS offers information on the energy density and special characteristics of a solar event in the radio portion of the spectrum?

3. Match the solar radio instruments in column B with their appropriate functions in column A. Items in column B may be used more than once.

Column A	*Column B*
____ (1) Monitors solar emissions over a frequency range of 25–180 MHz.	a. Discrete frequency radiometer.
____ (2) Provides a printout in terms of flux density versus time.	b. Solar Radio Spectrograph.
____ (3) Monitors solar emissions at eight fixed frequencies.	
____ (4) Provides a printout in terms of frequency versus time.	

2–2. Solar Emissions and Earth

Now that you acquired some information about the sun you are probably still asking, “But what impact does space environmental effects have on my customer’s mission?” Let’s go the next step and look at the geophysical processes that happen as the sun releases energy into the interplanetary medium between the sun and earth. The energy, whether radiation or particulate matter, flows outward from the sun and interacts with the atmospheres of all planets in the solar system including earth’s atmosphere. The interaction of these solar emissions with earth’s atmosphere and near atmosphere and the resultant effects is one of the primary objectives of this course. So, let's see what happens in the interplanetary medium as the emitted energy from the sun travels toward earth.

410. Electromagnetic radiation

As stated in the beginning of this unit, space environmental effects refer to electromagnetic radiation (EMR) and electrically charged particles emitted primarily by the sun, and the environmental phenomena they create as a result of their interactions with earth's upper atmosphere and magnetic field. Let's look at the part electromagnetic radiation plays in causing space environmental impacts in earth's atmosphere.

The sun emits different types of electromagnetic radiation that make up what is known as the "electromagnetic spectrum" (fig. 2–15). Radiation may be thought of as "energy moving as a wave."

- Gamma ray radiation—the most "energetic" of radiation types; often emitted by radioactive substances.
- X-ray radiation—(you guessed it) the same type of radiation used to take medical X-rays that are radiated by gases having temperatures of one million degrees K or more.
- UV radiation—radiation commonly reported as causing skin cancer.
- Visible radiation—radiation that we "see" with our eyes (i.e., light).
- Infrared radiation—radiation that causes several meteorological processes such as atmospheric heating and water vapor interactions.
- Radio-wave radiation—type of radiation used in radio communications.

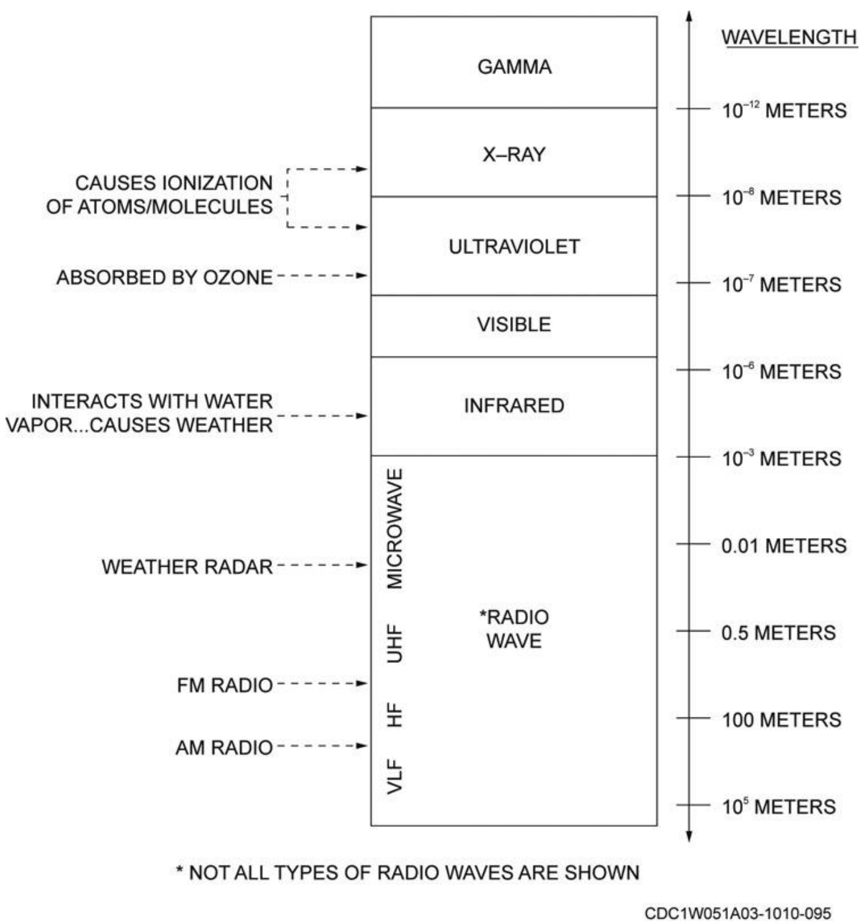

Figure 2–15. Depiction of electromagnetic spectrum.

The sun continuously emits all of these types of radiation at various intensities, and sometimes emits a "burst" of one or more of the radiation types. Our interest includes the continuous radiation as well as the bursts of radiation.

The sun emits radiation over the entire electromagnetic spectrum. The distribution of energy is such that the most intense portion of it falls in the visible part of the spectrum. Substantial amounts also lie in the near UV and infrared portions. Less than one percent of the sun's total emitted electromagnetic radiation lies in the EUV, X-ray, and radio-wave wings. However, we still have a twofold problem. First, solar activity can cause the amount of emitted EUV and x-ray energy to be enhanced by a factor of 100, and radio-wave energy by a factor of tens of thousands, over the normal solar output at these wavelengths. Secondly, it is exactly these wavelengths that affect DOD radar, communications, and space systems and make them the most vulnerable.

Electrically charged particle radiation

Aside from the emission of electromagnetic radiation, there is an additional flow of electrically charged particles from the sun. Of primary interest in the space environment are electrons and protons. They stream continuously outward from the sun to form what is known as the "solar wind." Like bursts of radiation, the sun can also emit a burst of electrically charged particles along with the continuous solar wind. Several types of solar activity can cause energetic particle streams to be superimposed on this background solar wind. Again, our interest includes both the solar wind and the bursts of electrically charged particles. The resultant enhancements and discontinuities in solar wind particle speed and/or density can disturb earth's magnetosphere as they sweep by.

The magnetosphere is that volume of space where earth's own magnetic field can exclude the sun's interplanetary magnetic field (IMF) and control the motion of charged particles. The magnetosphere is distorted by the pressure of the outward flowing solar wind. Its geomagnetic field lines are compressed on the sunward side, and drawn out in the direction of the dark side of earth. While the magnetosphere does provide some shielding from solar charged particles (except at the funnel-like cusps over the polar caps), the shielding is not enough to avoid some unpleasant system impacts that will be discussed later.

Variability in the sun's emissions

Because of the sun's internal processes, the radiation and electrically charged particles are not emitted at equal rates from all locations on the sun. In other words, some regions of the sun emit more radiation and/or electrically charged particles than others. (Regions that emit relatively greater amounts of radiation/charged particles are referred to as "active regions.")

Recall that during the 11-year solar cycle, the emissions rise and fall, and sunspots indicate the stage of the cycle. This cycle significantly affects the amount of emissions.

The space environment

The origin of space environmental impacts on radar, communications, and space systems lies with the sun. As profound as the statement may seem, if the sun continuously emits electromagnetic energy and electrically charged particles, the secret to understanding the impact on communications lies in understanding the energy flow. Within these normal (or background) emissions produced by the sun are enhancements in the electromagnetic radiation. The X-ray, EUV, and radio wavelengths are particularly interesting as these charged particle streams emitted by the sun impact us the most.

Sun's rotation

Because we know that the sun rotates, the emissions experienced in the near-earth environment can vary as the sun's active regions rotate around to the "other side of the sun." As observed from Earth, a full rotation is completed about every 27 days; consequently, active regions that "disappear" from our perspective on earth may reappear a couple of weeks later as they move into our view. However, these active regions grow and dissipate with great variability.

411. Interactions with earth's atmosphere

As previously noted, space environmental effects not only includes the radiation and electrically charged particles coming directly from the sun but also a variety of phenomena that result due to the interactions of the radiation and charged particles with earth's upper atmosphere, near atmosphere and magnetic field.

Radiation from the sun interacts with the atoms and molecules of earth's atmosphere. The following are the different types of radiation previously mentioned; however, this time the information is presented with the primary space environmental effects applications:

- Gamma ray radiation—interaction has little practical space environment application.
- X-ray radiation—interaction causes ionization of upper-atmospheric molecules. Ionization refers to an electron being separated (taken away) from the atom or molecule that the electron was originally attached to. This process creates a layer of electrons within earth's atmosphere known as the ionosphere, a region that causes many of today's space environmental effects. X-rays don't penetrate earth's atmosphere.
- UV radiation—interaction causes (1) ionization of upper-atmospheric atoms and molecules and (2) heating of the upper atmosphere, causing expansion.
- Visible radiation—interaction with earth's atmosphere is significant (such as clouds reflecting light or atoms/molecules scattering light to cause a blue sky), but the interaction has negligible effect on space environmental effects.
- Infrared radiation—interaction with earth's atmosphere is significant to meteorological processes, but the interaction has little effect on space environmental effects.
- Radio-wave radiation—interaction with earth's atmosphere is negligible for some of the sun's radio-wave radiation (i.e., it moves right through our atmosphere) and significant for others (e.g., atmospheric water droplets reflect some radio-wave radiation—i.e., microwaves used in weather radar). The primary relevance to space environmental effects is the portion of the sun's radio-wave radiation that penetrates the entire atmosphere and therefore occurs at earth's surface.

Like radiation, electrically charged particles (typically electrons) can also interact with the atoms and molecules of earth's upper atmosphere, causing (1) ionization and (2) heating of the upper atmosphere causing expansion of the upper atmosphere. Charged-particle interactions with earth's upper atmosphere also cause the northern and southern lights.

412. Between sun and earth

The area between the sun and the planets is termed the interplanetary medium. Although sometimes considered a perfect vacuum, this is actually a turbulent area dominated by the solar wind, flowing at velocities of approximately 250–1,000 km/s (about 600,000–2,000,000 miles per hour). Other characteristics of the solar wind (density, composition, and magnetic field strength, among others) vary with changing conditions on the sun. The effect of the solar wind can be seen in the tails of comets (which always point away from the sun).

The solar wind flows around obstacles such as planets, but those planets with their own magnetic fields respond in specific ways. Earth's magnetic field is very similar to the pattern formed when iron filings align around a bar magnet. Under the influence of the solar wind, these magnetic field lines are compressed in the sunward direction and stretched out in the downwind direction. This creates the magnetosphere, a complex, teardrop-shaped cavity around earth. The Van Allen radiation belts are within this cavity, as is the ionosphere, a layer of earth's upper atmosphere where photo ionization by solar X-rays and EUV rays creates free electrons.

Earth's magnetic field interfaces with the solar windspeed, density, and magnetic field. Because the solar wind varies over time scales as short as seconds, the interface that separates interplanetary space from the magnetosphere is very dynamic. Normally this interface (called the magnetopause), lies at a distance equivalent to about 10 earth radii in the direction of the sun. However, during episodes of elevated solar wind density or velocity, the magnetopause can be pushed inward to within 6.6 earth radii (the altitude of geosynchronous satellites). As the magnetosphere extracts energy from the solar wind, internal processes produce geomagnetic storms.

Additional sources of space environmental activity, which can strike at anytime during the solar cycle, are enhancements or discontinuities in the outward flow of the energetic charged particles that make up the solar wind. The IMF emanating from the sun normally has 4 to 6 sectors of alternating positive (+) and negative (–) polarity and a spiral structure near the plane of earth's orbit due to the 27–day rotation period of the sun. Charged solar wind particles are guided by the IMF (fig. 2–16), and those particles in one IMF sector do not normally penetrate into another sector. Since particles tend to move faster in the forward portion of a sector than in the trailing portion, particle density tends to increase and become irregular just behind a solar sector boundary (SSB), leading to a high-speed stream (HSS) of particles.

HSSs of particles can also exist within a sector because there are regions in the sun's atmosphere (called coronal holes) where magnetic field lines are open to space and do not impede the outward flow of particles. These coronal holes are most effective in causing HSSs near the plane of earth's orbit and during solar minimum periods. Both SSB and HSS enhancements and discontinuities can disrupt earth's magnetosphere as the sun's rotation causes them to sweep past earth.

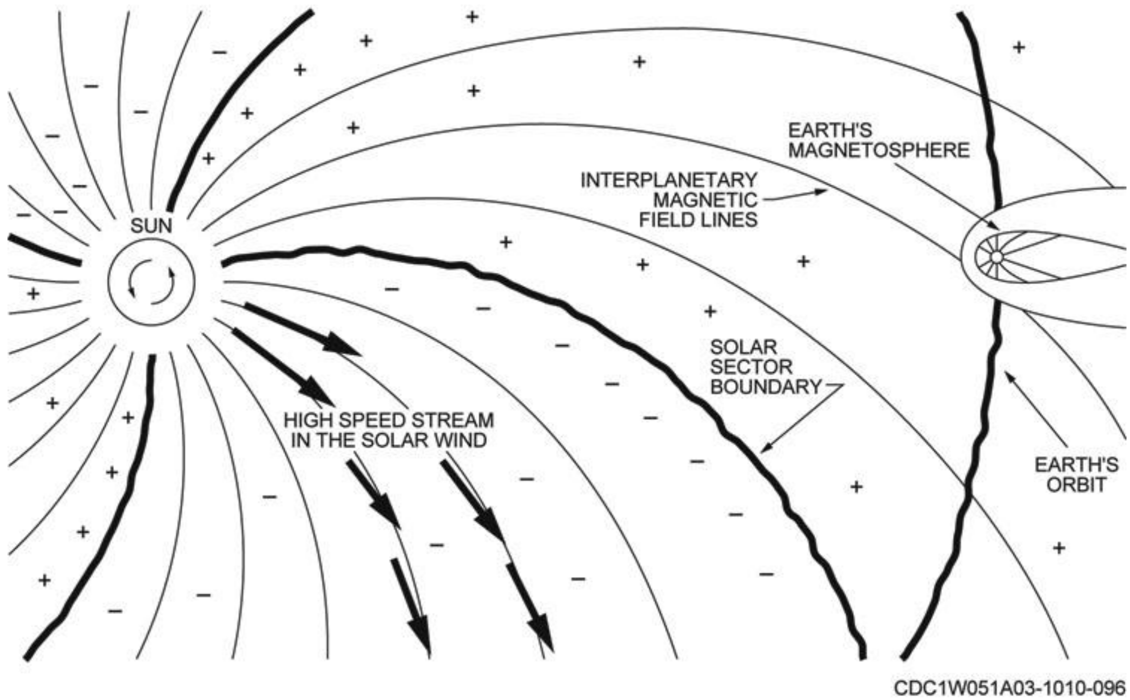

Figure 2–16. Solar wind and interplanetary magnetic field.

Solar wind enhancements and discontinuities occur throughout the solar cycle, even during solar minimum. Fortunately, the magnitude of the disruptions they cause in earth's magnetosphere (and thus the severity of their DOD system impacts) tends to be less than those disruptions caused by solar flares. Moreover, since these solar wind enhancements and discontinuities are tied to solar features that persist for longer than the sun's 27–day rotation period, they tend to be recurrent, and thus the geomagnetic storms they produce are somewhat easier to forecast than the sporadic geomagnetic storms produced by flares.

413. The near-earth environment

Space environmental effects occur virtually everywhere: at the sun, in interplanetary space, and in the near-earth environment. Since earth's atmosphere and magnetic field play such critical roles in forming the space environmental effects that affects DOD operations, our primary region of interest is the near-earth environment. Figure 2–17 depicts the key environmental regions surrounding earth along with examples of satellites currently orbiting earth. Space environmental effects occurs in all the layers, but is most pronounced above the mesosphere. It occurs all the time and with varying intensities. Let's begin by looking at the impact of space weather in the troposphere.

Troposphere

The troposphere extends from the surface to 11 km (35,000 feet). For operational purposes, the only space environmental effects that occurs within the troposphere is that portion of the sun's radio-wave radiation that penetrates all layers of earth's atmosphere. The radio-wave radiation can be at the same radio frequencies used in various communication and ground-based space tracking systems, causing impacts such as interference. Just above the troposphere is the stratosphere.

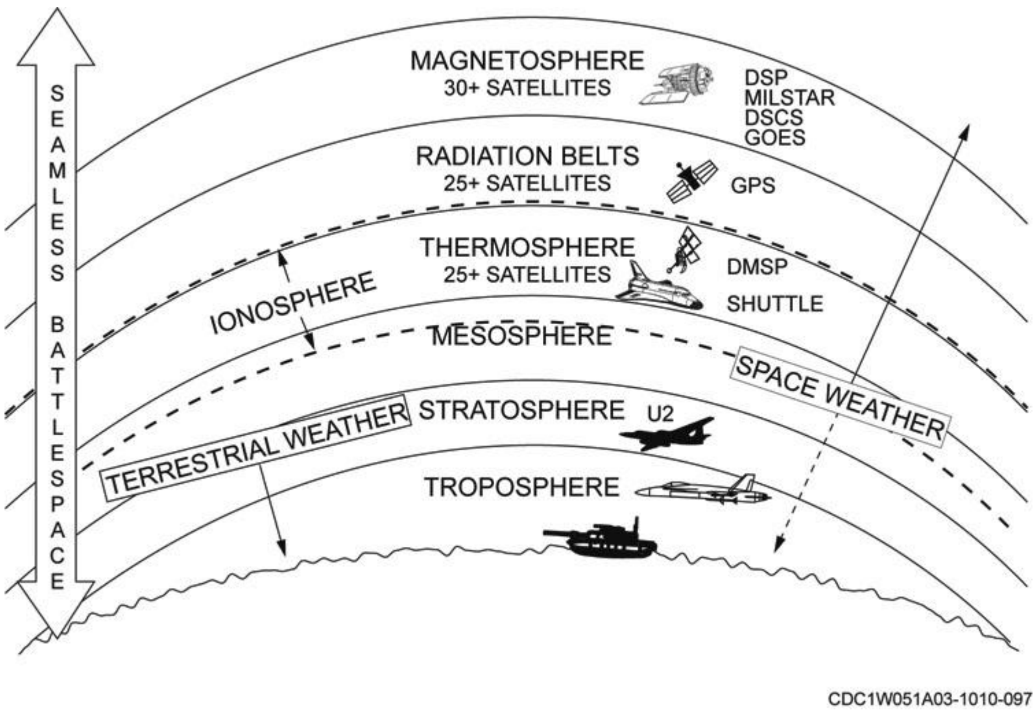

Figure 2–17. Depiction of key environmental regions and Deparment of Defense satellites in orbit.

Stratosphere

The stratosphere extends from 11 to 50 km (35,000–165,000 feet). Other than the sun's radio-wave radiation that penetrates into the troposphere, operationally relevant space environmental effects occur primarily above the stratosphere. However, there is one exception. Electrically charged particles emitted by the sun during the most extreme of bursts can reach the near-earth environment and penetrate into the stratosphere. These phenomena can increase risk for high-altitude flight operations. The next layer of our atmosphere is our mesosphere.

Mesosphere

Mesosphere extends from 50–85 km (165,000–275,000 feet). Ionization and heating are the primary space environmental effects processes taking place in the mesosphere, particularly in the upper parts of the layer. In figure 2–17, note that satellites and airframes are depicted above and below the mesosphere. There isn't enough air (atoms and molecules) in the mesosphere to allow traditional flight, and conversely, there is too much air for a satellite to sustain an orbit. Too many atoms and molecules create drag and force a satellite to lose altitude and eventually "burn up" due to frictional heating.

Thermosphere

The thermosphere extends from 85–1500+ km or from 50–900+ miles. The thermosphere serves as the primary reservoir of atoms/molecules that may be heated and/or ionized by the sun's UV radiation. Contrary to popular belief, space is not empty. For example, there are one million atoms per cubic centimeter at the altitude where Defense Meteorological Satellite Program (DMSP) satellites orbit. The interaction between the atoms/molecules and the UV radiation is more pronounced in the thermosphere than in any other layer. Winds in the thermosphere interact with electrically charged particles of the ionosphere, creating other space environmental effects phenomena.

Ionosphere

The ionosphere extends from an altitude of 60–1500+ km (~ 35–900+ miles). The ionosphere is a layer of floating electrons created within the mesosphere and thermosphere primarily as a result of the sun's X-ray and UV radiation ionizing the atoms and molecules located there. The ionization strips electrons from their original atom/molecule and results in large volumes of electrons that "float" in the ionosphere. The ionosphere is often described by how many electrons (such as density) exist within the layer. Figure 2–18 depicts an average, smoothed vertical electron density profile.

NOTE: Besides the one million atoms per cm^3 at DMSP altitudes, there are also about 50,000 "floating" electrons per cm^3.)

The ionosphere is not homogenous from one location to another—it is very irregular, having large numbers of electrons in some locations while having fewer in other locations. Sharp horizontal and vertical electron density gradients exist, and different layers within the ionosphere are created in response to different levels of radiation and various other processes.

Note that the satellites shown in figure 2–18 are located at the top or above the ionosphere. This means that any radio-wave signals a satellite sends to or receives from earth must go through the ionosphere.

The ionosphere is divided into three regions or layers identified as "D," "E," and "F." Each of these layers has a different ion population or ionization characteristic. The D layer extends from 50 to 90 kilometers. The E layer lies between 90 and 150 kilometers and the F layer extends from 150 kilometers to 1,000 kilometers above earth's surface. The F region is further divided into the F1 and F2 layers. The highest concentration of electrons is in the F2 layer, which is important from the standpoint of navigation and communication users.

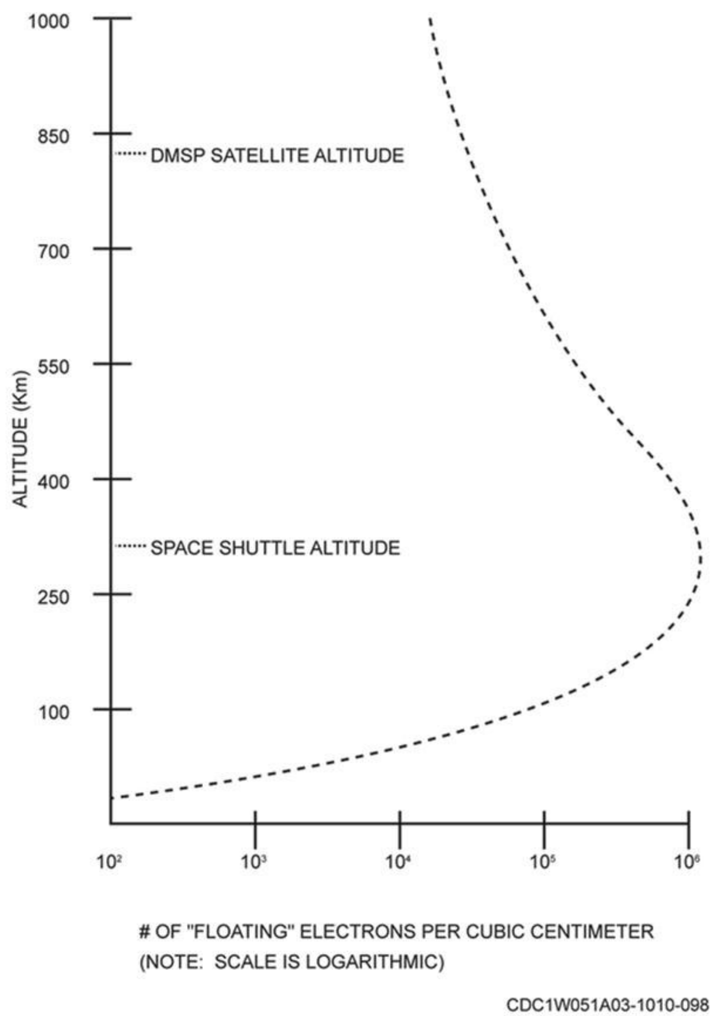

Figure 2–18. Depiction of average (smoothed) daytime electron density profile of the ionosphere.

Now that we've briefly looked at the layers of earth's atmosphere, let's look a boundary in our atmosphere that exists because of the solar wind and earth's interaction with the sun.

414. Earth's magnetopause and magnetosphere

The magnetic boundary between earth's magnetic field and the solar wind is the magnetopause. The magnetopause is shaped like a comet as shown in figure 2–19. A cross section of the magnetopause is circular in shape. Earth radii (Re) are used to measure distances in the magnetopause and magnetosphere instead of measuring distance in miles or kilometers. One earth radius is equal to 6371 kilometers or 3960 miles. The distance between earth's center to the "nose" of the magnetosphere is approximately 10.5 earth radii. The pressure of the solar wind rises and falls as it flows around the magnetopause causing the magnetopause to shrink or expand.

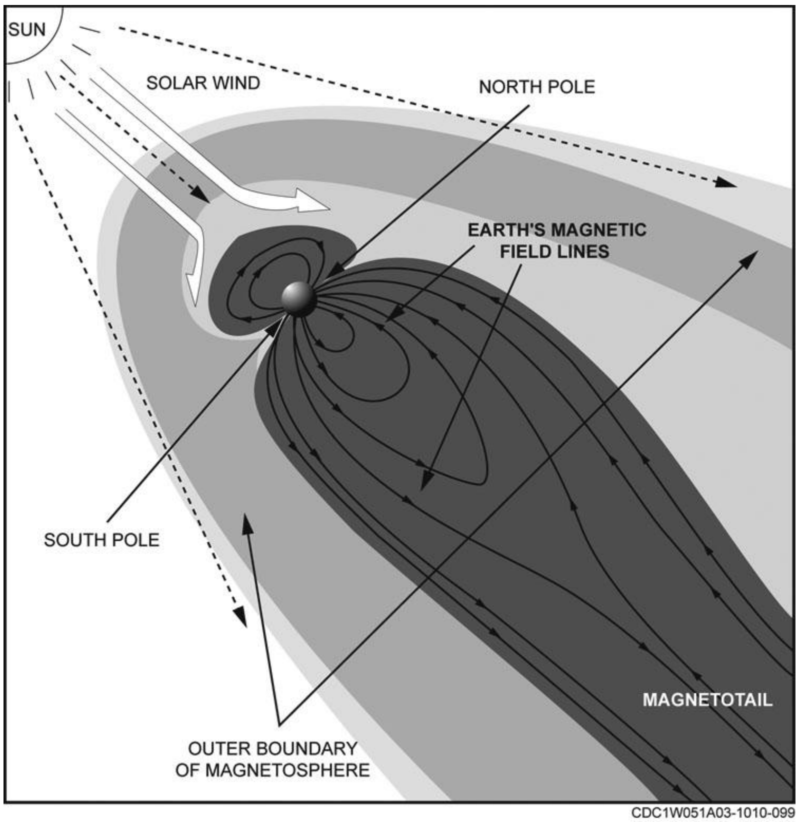

Figure 2–19. Depiction of earth's magnetosphere.

Magnetic fields deflect electrically charged particles that are moving, and the amount of deflection is determined by the magnetic field's strength and the charged particles' velocity (speed and direction of travel). Therefore, electrically charged particles in motion near earth are steered by earth's magnetic field. To complicate matters, electrically charged particles in motion create their own magnetic field (charged particles in motion represent an electric current, and an electric current generates its own magnetic field). So, not only does earth's magnetic field play a key role in space environmental effects, but so does the magnetic field generated by the moving electrically charged particles.

In figure 2–20, note that the magnetic field lines are directed toward and feed into the northern and southern polar regions. Electrically charged particles in motion are sometimes deflected so much that they funnel into the high-latitude regions where they interact with earth's upper atmosphere.

One result of this interaction is the "northern and southern lights," formally known as the aurora borealis (northern hemisphere) and aurora australis (southern hemisphere). The electrons that are being guided into the higher latitudes interact with the atoms or molecules of the upper atmosphere and cause the atoms or molecules to emit light (visible radiation).

Now that we have learned about the magnetopause let's look at the region inside. The region inside the magnetopause may be divided into several broad regions.

Magnetosphere

The inner magnetosphere extends from the nose of the magnetopause to a distance of about 8 Re, to the side of earth away from the sun. The magnetosphere is a shell-like region where earth's magnetic field is the predominant magnetic force. The inner and outer radiation belts are also located inside this region (fig. 2–20). Outside the magnetosphere, the magnetic field generated by the sun and solar wind (referred to as the “interplanetary magnetic field”) represents the predominant magnetic force. The solar wind interacts with earth’s magnetic field to form the outer boundary of the magnetosphere.

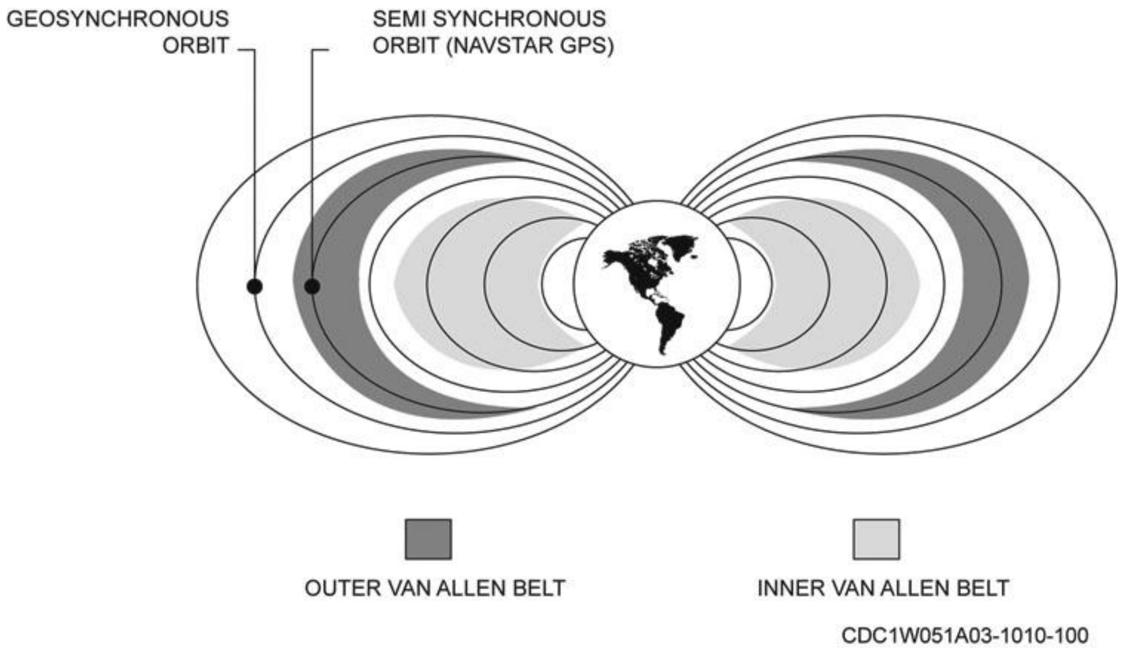

Figure 2–20. The inner and outer Van Allen radiation belts.

Note that the solar wind compresses the magnetosphere’s leading edge while the rest of the magnetosphere extends in the direction away from the sun. The altitude of the leading edge of the magnetosphere’s outer boundary is approximately 55,000 km (though highly variable), while the “magnetotail” extends several hundred thousand kilometers away from the sun. Geostationary satellites such as the GOES weather satellites orbit at 36,000 km, normally inside the magnetosphere.

A complex network of electrical currents exists inside the magnetosphere (fig. 2–21). Some of the solar wind’s electrically charged particles enter into the magnetosphere where they become part of this network. The electric currents send electrically charged particles into earth’s thermosphere and mesosphere, causing heating, ionization, and phenomena such as the previously mentioned, northern lights. Satellites orbiting in the magnetosphere can be affected as these currents (electrically charged particles in motion) bombard the satellite.

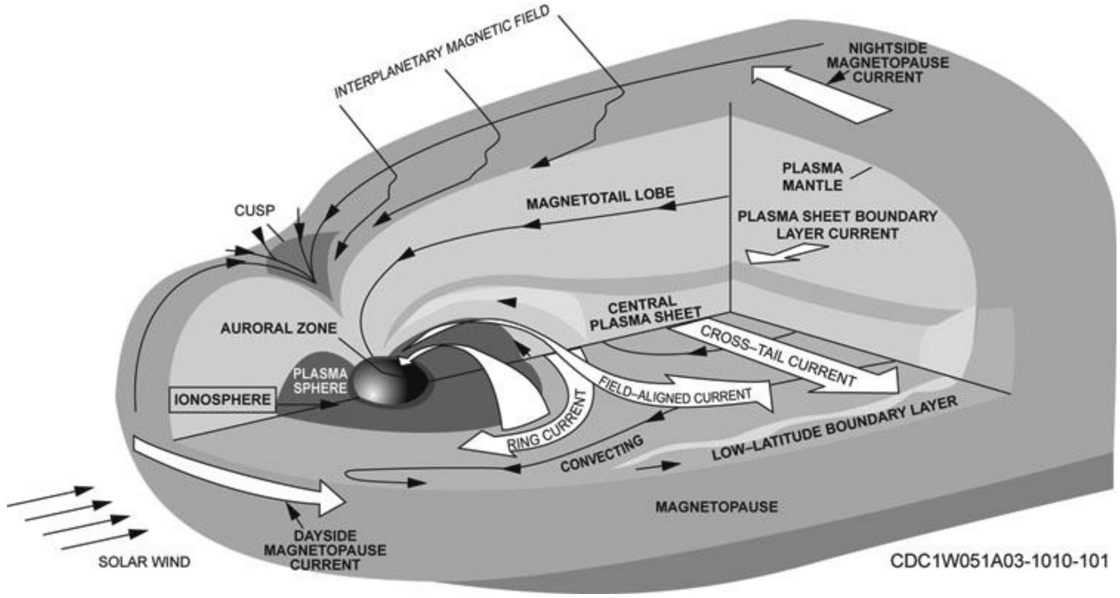

Figure 2–21. Depiction of components within earth's magnetosphere.

Finally, the electric-current network increases in intensity in response to changes in the solar wind and to bursts of electrically charged particles from the sun. The phrase "geomagnetic storming" is used to describe significant increases in the electric currents (electrically charged particles in motion) in the near-earth environment.

Radiation belts

Earth has two radiation belts; commonly referred to as the Van Allen radiation belts. There is an inner belt and an outer belt that were positively identified by sensors on the *Explorer* spacecraft in the late 1950s. The radiation belts represent regions of electrically charged particles "trapped" by the earth's magnetic field. The radiation belts surrounding the earth are located at approximately 1,000–25,000 kilometers. These altitudes are highly variable. Though there are fewer charged particles in the radiation belts than in the ionosphere, the radiation belt particles are much more energetic—for example, they move very quickly. These energetic electrically charged particles can bombard with satellites and cause unexpected satellite behavior.

Inner belt

The inner radiation belt is narrower than the outer belt, is strongest over the equator, and begins at an approximate altitude of 1,000 kilometers. The inner radiation belt originates from cosmic rays which are fast moving, positively charged, ions striking earth from all directions. Although the number of these ions is relatively small, the energy contained in each particle is quite high, with energy exceeding 30 million electron volts.

When the high-energy ions from cosmic rays collide with the nuclei of atmospheric gases, the nuclei split into fragments. Recall from basic physics that neutrons, protons, and electrons make up the nucleus of an atom. Scientists believe that the protons of the inner belt originate from the decay of neutrons after the collision occurs. While some of the post-collision neutrons are ejected from the atmosphere, back into space, it's the decay of the remaining protons and electrons that make up the inner belt. As the particles approach either of the magnetic poles, the increase in the magnetic field repels the particles away from the poles. This magnetic mirror effect causes the particles to bounce back and forth between the poles. The result of this interaction makes the area over the equator the most intense, with minimal energy near the poles. Comparatively speaking, the outer belt is significantly more stable.

Outer belt

The outer radiation belt is much wider than the inner belt and is also energy-centered over the equator. Data from space sensors suggest the outer belt surrounds much of earth except for over the polar regions.

The ions and electrons contained in the outer belt are believed to be a result from earth's magneto tail as seen in figure 2–21.

Occasionally, a violent outburst, known as a magnetic storm, drives energy known as tail plasma earthward into the near-earth magnetosphere. After the outburst is over some radioactive particles remain, trapped by electric fields.

Solar effects at earth

Van Allen radiation belts are not the only resultant anomaly caused by solar variations. Some major terrestrial by-products of solar variations are the aurora, proton events, and geomagnetic storms.

Aurora

The aurora is a dynamic and delicate visual manifestation of solar-induced geomagnetic storms. The origin of the aurora is, of course, at the sun. Energetic particles from the sun are propagated toward earth along with the solar wind. The solar wind moves at speeds ranging from 300 to over 1,000 km per second carrying with it a solar magnetic field. The solar wind strikes the magnetosphere and energizes electrons and ions in the magnetosphere. These particles usually enter Earth's upper atmosphere near the polar regions. When the particles strike the molecules and atoms of the thin, high atmosphere, some of them start to glow in different colors. Previously mentioned, this aurora is called the aurora borealis or northern lights in the northern hemisphere, and aurora austrailis in the southern hemisphere.

Auroras begin between 60–70 degrees latitude. As a storm intensifies, the aurora spreads toward the equator. During an unusually large storm in 1909, an aurora was visible at Singapore, on the geomagnetic equator. Most of the auroral features are greenish yellow; however, sometimes the tall rays will turn red at their tops and along their lower edge. On rare occasions, sunlight will hit the top part of the auroral rays creating a faint blue color. In addition to producing light, the energetic particles of the aurora produce heat that is dissipated by infrared radiation or transported away by strong tropospheric winds. Although the auroras provide a spectacular light show, they are merely a visible sign of atmospheric changes that wreak havoc on satellites and other technological systems.

To go into further detail of how high-energy particles are generated during geomagnetic storms, would exceed the purpose and desired knowledge level of this course. The basic concept, however, is that Earth's magnetic field or geomagnetic field as it is sometimes referred to is responding to an outwardly propagating disturbance from the sun. As the geomagnetic field adjusts to this disturbance, various components of earth's field change form, releasing magnetic energy and thereby accelerating charged particles to high energies. The charged particles flow along the magnetic field lines where they end up in earth's upper atmosphere causing the aurora.

Proton events

Energetic protons can reach earth within 30 minutes of a major flare's peak. During such an event, earth is showered with highly energetic solar particles (primarily protons) released from the flare site. Some of these particles spiral down earth's magnetic field lines, reaching the upper layers of our atmosphere.

Geomagnetic storms

One to four days after a flare or eruptive prominence occurs, a slower cloud of solar material and magnetic fields reaches earth, buffeting the magnetosphere and resulting in a geomagnetic storm. These storms are extraordinary variations in earth's surface magnetic field. During a geomagnetic storm, portions of the solar wind's energy are transferred to the magnetosphere, causing earth's magnetic field to change rapidly in direction and intensity.

Disturbances within the geomagnetic field are measured by an instrument called a magnetometer. In order to use the data collected, the magnetometer data is converted into what is referred to as the K-index. K-index values then indicate to customers what equipment may be affected by geomagnetic storms. Several K-indices can be averaged and processed through an algorithm that derives the Kp index. Figure 2–22 shows a map of the Kp index over the CONUS. The Kp index indicates the approximate latitude where the edge of the aurora will be located based on the strength of geomagnetic activity.

Disrupted systems

Solar activity can have a great impact on systems. These impacts can adversely affect systems in the terrestrial, near earth, and space environment.

Communications

Many communication systems use the ionosphere to reflect radio signals over long distances. Ionospheric storms can affect radio communication at all latitudes. Some radio frequencies are absorbed and others are reflected, leading rapidly fluctuating signals and unexpected propagation paths. TV and commercial radio stations are least affected by solar activity, but ground-to-air, ship-to-shore, and amateur radios are frequently disrupted. Radio operators using high frequencies rely heavily upon solar and geomagnetic alerts to keep their communication circuits up and running.

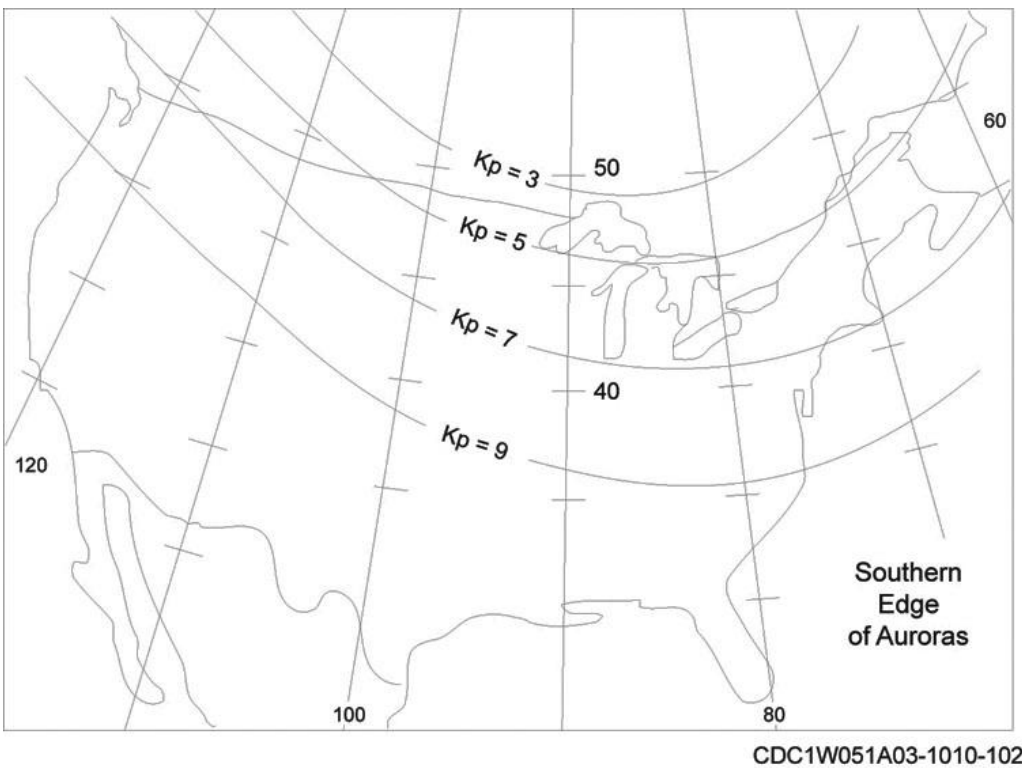

Figure 2–22. Kp index over the continental United States.

Some military detection or early warning systems are also affected by solar activity. The over-the-horizon radar bounces signals off the ionosphere to monitor the launch of aircraft and missiles from long distances. During geomagnetic storms, this system can be severely hampered by radio clutter. Additionally, some submarine detection systems use the magnetic signatures of submarines as a tool for locating other vessels. Geomagnetic storms can mask and distort these signals.

The Federal Aviation Administration (FAA) routinely receives alerts of solar radio bursts so they can recognize communication problems and forego unnecessary maintenance. When an aircraft and a ground station are aligned with the sun, air-control radio frequencies are often jammed. This can also occur when an earth station, a satellite, and the sun are in alignment.

Navigation systems

GPS satellites provide reliable navigation and greater coverage to personnel, aircraft, ships, and vehicles. Global positioning satellite signals are affected when solar activity causes sudden variations in the density of the ionosphere.

Solar flares and the resultant release of large amounts of radiant energy, disturb the ionosphere on the sunlit side of earth. As flares are usually associated with the strong magnetic fields that manifest themselves in sunspots, their occurrence rate increases and decreases in step with the sunspot cycle. Solar x-rays *DO NOT* affect GPS users. Thus, GPS signals are not affected by ionospheric changes in response to large influxes of solar x-rays.

Satellites

Geomagnetic storms and increased solar UV emission heat earth's upper atmosphere, causing it to expand. As the heated air rises, density levels in the satellite's orbital plane (up to about 1,000 km) increases significantly. The result is an increased drag for satellites in space, causing them to slow and change orbit slightly. Unless low earth-orbit satellites are routinely boosted to higher orbits, they slowly fall, and eventually burn up in earth's atmosphere.

Skylab is an example of a spacecraft reentering earth's atmosphere prematurely as a result of higher-than-expected solar activity. In another example, during the great geomagnetic storm of March 1989, four of the Navy's navigational satellites were taken out of service for up to a week.

As advances in technology have allowed spacecraft components to become smaller, their miniaturized systems have become increasingly vulnerable to the more energetic solar particles. The point here is that energetic particles can and do cause physical damage to microchips, and can change software commands in satellite-borne computers.

Differential charging

Differential charging is another concern and problem for satellite operators. During geomagnetic storms, the number and energy of electrons and ions increase. When a satellite travels through this energized environment, the charged particles striking the spacecraft cause different portions of the spacecraft to be differentially charged. Eventually, electrical discharges can arc across spacecraft components, harming and possibly disabling them.

Bulk charging

Bulk charging (also called deep charging) occurs when energetic particles, primarily electrons, penetrate the outer covering of a satellite and deposit their charge in its internal parts. If sufficient charge accumulates in any one component, it may attempt to neutralize by discharging to other components. This discharge is potentially hazardous to the satellite's electronic systems.

Radiation hazards to humans

Intense solar flares release very-high-energy particles that can be as harmful to humans as the low-energy radiation from nuclear blasts. Earth's atmosphere and magnetosphere allow adequate protection for us on the ground, but astronauts in space are subject to potentially lethal dosages of radiation. The penetration of high-energy particles into living cells, measured as radiation dose, leads to chromosome damage and, potentially, cancer. Large doses can be fatal immediately. Solar protons with energies greater than 30 million electron volts (MeV) are particularly hazardous. In October 1989, the sun produced enough energetic particles that an astronaut on the moon, wearing only a space suit and caught out in the brunt of the storm, would probably have died. (Astronauts who had time to gain safety in a shelter beneath moon soil would have absorbed only slight amounts of radiation.)

Solar proton events can also produce elevated radiation aboard supersonic aircraft flying at high altitudes over the polar caps. To minimize this risk, routine forecasts and alerts are sent through the FAA so that a flight in potential danger can alter its course and reduce altitude to minimize radiation exposure.

Geologic exploration

Geologists use earth's magnetic field to determine subterranean rock structures. For the most part, these geodetic surveyors are searching for oil, gas, or mineral deposits. However, they can accomplish this only when earth's field is quiet, so true magnetic signatures can be detected. Other surveyors prefer to work during the geomagnetic storms, when the variations of earth's normal subsurface electric currents help them to see subsurface oil structures. For these reasons, many surveyors use geomagnetic alerts and predictions to schedule their mapping activities.

Electric power

When magnetic fields move about near a conductor such as a wire, an electric current is induced into the conductor. Interestingly, this happens on a grand scale during geomagnetic storms. Power companies transmit alternating current to their customers through long transmission lines. The nearly direct currents induced in these lines from geomagnetic storms are harmful to electrical transmission equipment. For example, on March 13, 1989, in Montreal, Quebec, six million people were without commercial electric power for nine hours as a result of a huge geomagnetic storm. The event was so intense, that some areas in the northeastern US and in Sweden also lost power. Geomagnetic storm alerts and warnings are the key to help power companies minimize damage and power outages.

Pipelines

Rapidly fluctuating geomagnetic fields can induce currents into pipelines. Such occurrences cause several problems for pipeline engineers. Flow meters in the pipeline can transmit erroneous flow information, and the corrosion rate of the pipeline is dramatically increased. Even worse, if engineers unwittingly attempt to balance the current during a geomagnetic storm, corrosion rates may increase even more. Pipeline managers routinely receive alerts and warnings to help them provide an efficient and long-lived system.

Climate

The sun is the heat engine that drives the circulation of our atmosphere. Although it has long been assumed to be a constant source of energy, recent measurements of this solar constant have shown that the base output of the sun can vary by up to two tenths of a percent over the 11-year solar cycle. Temporary decreases of up to one-half percent have been observed. Atmospheric scientists believe that this variation is significant enough that it can modify climate over time. Plant growth has been shown to vary over the 11–year sunspot and 22–year magnetic cycles of the sun, as evidenced in tree-ring records.

While the solar cycle has been nearly regular during the last 300 years, there was a period of 70 years during the 17th and 18th centuries when very few sunspots were seen (even though telescopes were widely used). This drop in sunspot number coincided with the timing of the little ice age in Europe, implying a sun to climate connection. Recently, a more direct link between climate and solar variability has been speculated. Stratospheric winds near the equator have been correlated to blow in different directions, depending on the time in the solar cycle. Studies are under way to determine how this wind reversal affects global circulation patterns and weather.

Scientists have also made correlations of solar activity to the ozone layer. During proton events, many more energetic particles reach earth's middle atmosphere. There they cause molecular ionization, creating chemicals that destroy atmospheric ozone and allow increased amounts of harmful solar UV radiation to reach earth's surface. A solar proton event in 1982 resulted in a temporary 70 percent decrease in ozone densities.

Biology

There is an increasing amount of evidence that changes in the geomagnetic field affect biological life. Studies indicate that physically stressed human biological systems may respond to fluctuations in the geomagnetic field. Interest and concern in this subject have led the Union of Radio Science International to create a new commission entitled *Electromagnetics in Biology and Medicine.*

Possibly the most closely studied of the variable sun's biological effects, has been the degradation of homing pigeons' navigational abilities during geomagnetic storms. Pigeons and other migratory animals, such as dolphins and whales, have internal biological compasses composed of the mineral magnetite wrapped in bundles of nerve cells. While this probably is not their primary method of navigation, there have been many pigeon race smashes; a term used when only a small percentage of birds return home from a release site. Because these losses have occurred during geomagnetic storms, pigeon handlers have learned to ask for geomagnetic alerts and warnings as an aid to scheduling races.

Identifying other potential impacts

The most fundamental way to determine whether a system is potentially affected by space environmental effects is to evaluate the following criteria:

- Does the system send or receive a radio-wave signal that traverses the ionosphere?
- Does the system include a radio-wave receiver that points toward the sun at any time during operation?
- Does the system physically operate in space?

If the answer to any of these questions is yes, then the specific system should be evaluated further through the assistance of space environment operations personnel at Air Force Space Command, 14th Air Force, and/or Air Force Weather Agency (AFWA) Space Weather Operation Center. These agencies manage and perform the space environment observing, analyzing, forecasting, and alerting functions that are critical to resource protection and mission success.

Geomagnetic storms

The geomagnetic storm is the mechanism that allows charged solar particle streams (whatever their origin) to disrupt our magnetosphere and adversely affect radar, communications, and space operations.

Except for the funnel-like cusps above the polar caps, solar particles do not have direct access to the near-earth environment (fig. 2–23). Instead, when a particle stream enhancement or discontinuity in the solar wind sweeps past earth, its impact sends a shock wave rippling through the magnetosphere. Out in the magnetosphere's tail, drawn-out magnetic field lines reconnect and, like a snapping rubber band, shoot trapped particles towards earth's night side. Some of these particles stay near the equatorial plane and feed into the Van Allen radiation belts. Others follow geomagnetic field lines and penetrate into the atmosphere at high north and south latitudes (the auroral zones). Geomagnetic and ionospheric storms result from these conditions. Later, trapped particles in the magnetotail are replenished by the slow diffusion of solar wind particles into the magnetosphere's tail.

The night side particle injection mechanism, just described, makes sense when one looks at where DOD system impacts occur. The majority of radar, communications, spacecraft, and satellite problems occur in the *night* sector, *not* the daylight sector!

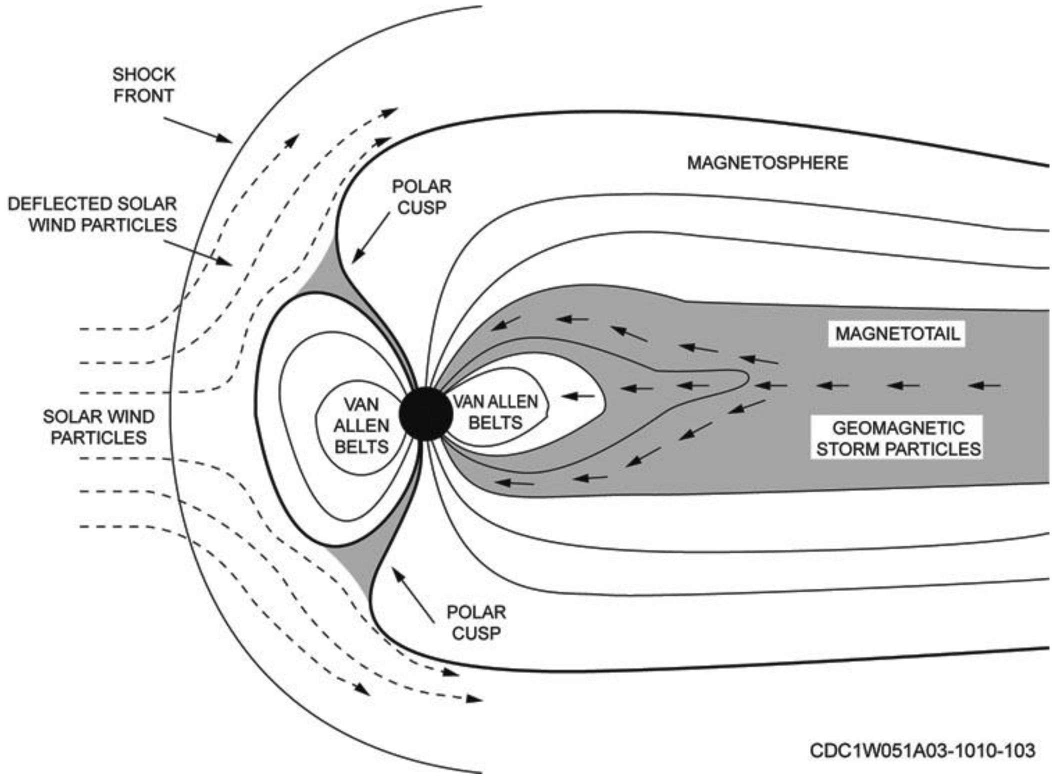

Figure 2–23. Geomagnetic storm mechanism.

Aurora

As just mentioned, some of these charged particles follow geomagnetic field lines, as shown in figure 2–24, and primarily reach earth at high northern and southern latitudes (i.e., in the auroral zones). As these particles penetrate earth's upper atmosphere, they collide with atmospheric atoms and molecules, causing them to become excited or ionized (fig. 2–25). When these atoms and molecules deexcite or recombine, they emit electromagnetic energy—from the EUV to radio waves.

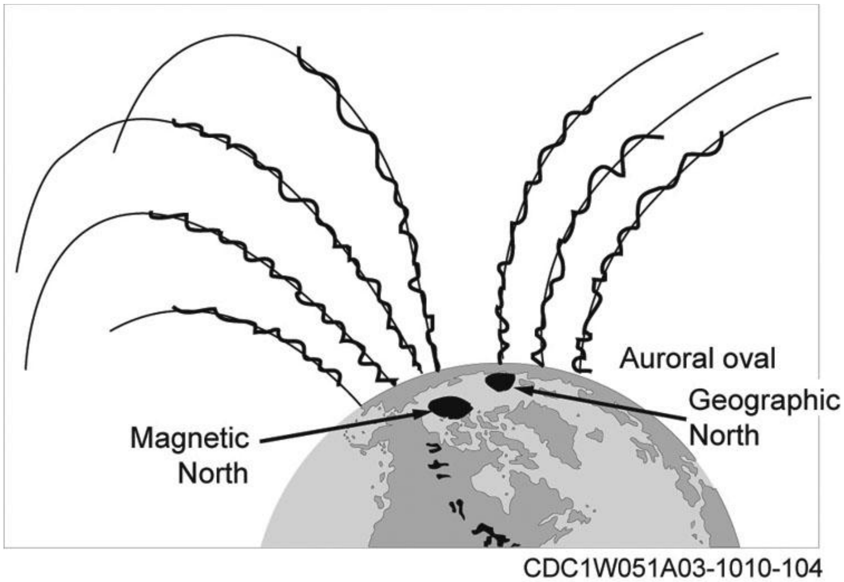

Figure 2–24. Energetic electrons are guided by geomagnetic field lines.

During the enhanced particle bombardment associated with a geomagnetic and ionospheric storm, the auroral oval intensifies, broadens, and moves equatorward. The enhanced and very irregular degree of ionization caused by this variable particle bombardment will cause problems like spacecraft charging, satellite drag, radar interference and clutter, space track errors, and anomalous propagation of high frequency (HF) and satellite communications (SATCOM) radio signals.

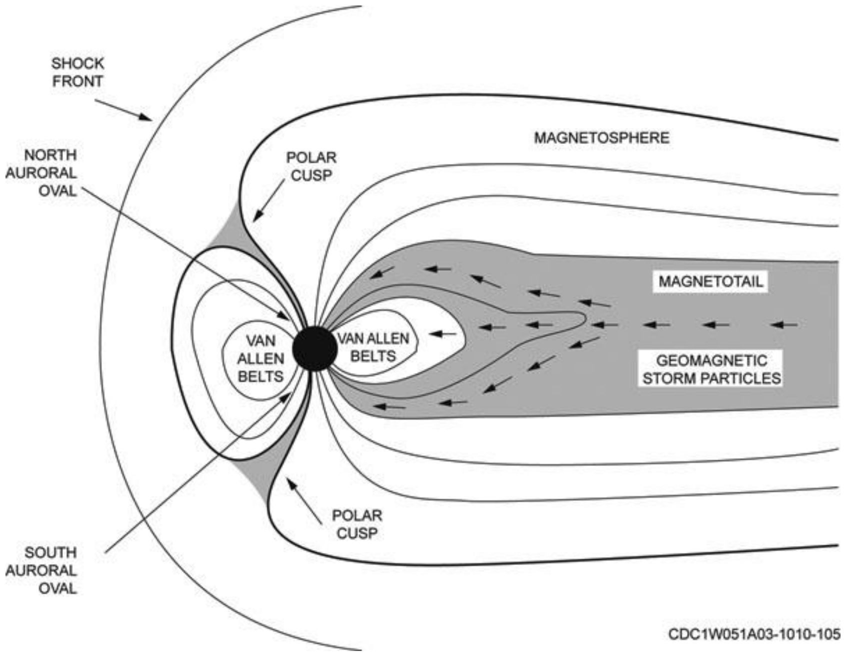

Figure 2–25. Aurora ovals.

Variability of space environmental effects

Space environmental effects continually occur because the sun's radiation and electrically charged particles continuously blanket the near-earth environment. Besides earth's upper atmosphere and magnetic field that affect the "energy" distribution, its rotation also causes irregular distribution. Furthermore, the sun does not emit radiation and electrically charged particles at constant intensities. Consequently:

- Earth's magnetosphere and its electric-current network are constantly responding to changes in the solar wind and to bursts of electrically charged particles.
- Earth's mesosphere and thermosphere and their reservoir of atoms/molecules for the ionosphere are constantly responding to changes in the sun's radiation.
- Earth's ionosphere and its "floating" electrons are constantly responding to changes in the sun's radiation and electrically charged particles, and are also constantly responding to the electric currents originating in the magnetosphere.

415. Solar-geophysical sensing devices

In addition to optical and radio observations, solar-geophysical observations are taken to provide data related to the ionosphere and the geomagnetic field. The ionosphere is that portion of earth's upper atmosphere where ions and electrons are present in sufficient quantities to allow the propagation of radio waves by reflecting them back to earth. The sensing devices used to make these observations include the neutron monitor, magnetometer, riometer, ionospheric sounder, polarimeter, and transionospheric sensor.

Neutron monitor

Neutron monitors sense the arrival at earth's surface of uncharged (neutral) atomic particles called neutrons. The neutrons form when the high-energy protons and alpha particles from the sun interact with the atmospheric atoms. The energies of the original particles penetrating earth's atmosphere may be inferred, since the neutron monitors respond to secondary particles having energies over 500 MeV (500,000,000 electron volts). Such a response is called a ground level event (GLE). However, only the most energetic solar flares cause an increase in neutron monitor counts above background level. The vast majority of events have energy levels far below the neutron monitor thresholds.

Magnetometer

The magnetometer measures the strengths and variations of earth's magnetic field, data that is necessary to fully evaluate ionospheric radio propagation conditions. Eruptions on the sun can inject large amounts of high-energy particles into the solar wind. Scientists have discovered the solar wind originates from magnetic fields on the surface of the sun. There is a high-speed solar wind with speeds as high as 3 million kilometers per hour and a low speed variety with speeds at only 1.5 million kilometers per hour. The increased solar particle flux may conflict on earth's magnetic field causing large variations in field intensity. Such occurrences are termed magnetic storms and are often the precursors to disruptions in communications and even electrical power systems.

Riometer

The riometer (relative ionospheric opacity meter) consists of a vertically directed antenna that detects cosmic radio noise at a typical frequency of 30 MHz. By "cosmic radio noise" we mean the fairly constant radio noise signals received from outside the solar system. This noise is absorbed or attenuated as it passes through the ionosphere. The amount of attenuation depends on the density of charged particles in the ionosphere. The riometer responds to increases in ionization caused by either protons or electrons deposited in the ionosphere. The presence of these charged particles makes the ionosphere more opaque to cosmic radio noise so that the riometer registers a corresponding loss of signal (absorption) that is measured in decibels.

Ionospheric sounder

The vertical incidence (VI) sounder transmits radio energy vertically with a frequency sweep over the range of about 2–30 MHz, or between any two selected frequencies in this range. The equipment works like radar to determine (as a function of frequency) the virtual heights and electron densities of reflecting layers in the ionosphere up to the level of maximum electron density. These data are used in evaluating the existing state of the ionosphere and in the prediction of future conditions. Ionospheric soundings provide information concerning the optimum propagation frequencies for HF radio communications systems in the region sampled. The oblique ionospheric sounder operates on much the same principle as the VI sounder. However, the state of the ionosphere is sampled over the whole path between two widely separated points on earth corresponding to locations of the transmitter and receiver.

Polarimeter

Polarimeters measure the total electron count (TEC) of the ionosphere along a path from the location of the polarimeter on the ground to a geostationary weather satellite equipped with a VHF beacon, which emits a continuous polarized radio signal. As the signal penetrates the ionosphere, its angle of polarization changes due to the effects of free electrons interacting with earth's magnetic field. The polarimeter measures the polarization of the radio beam after it has passed completely through the ionosphere, thus indicating the TEC along the path. Strictly speaking, the polarimeter can only measure the relative changes in TEC as the polarization measurements change. The measurements must be periodically calibrated with a nearby ionosonde in order for the polarimeter to produce absolute TEC measurements.

Transionospheric sensor

The transionospheric sensing system (TISS) measures absolute TEC by analyzing the signals from GPS satellites. The TISS is an improvement over the polarimeter in that it can sample multiple regions of the ionosphere, whereas the polarimeter is limited to only one. The TISS can also measure variations in GPS signal strength caused by variations in ion density along its path, a phenomenon called ionospheric scintillation.

Self-Test Questions

After you complete these questions, you may check your answers at the end of the unit.

410. Electromagnetic radiation

1. Where in the EM spectrum does the most intense portion of the sun's emitted energy fall?

2. Name two types of energetic charged particles of primary interest in the space environment.

3. Define solar wind.

4. How long does it take for the sun to complete a full rotation?

5. What may happen to an active region due to the sun's rotation?

411. Interactions with earth's atmosphere

1. Which forms of electromagnetic radiation are the most applicable to space environmental effects?

2. What causes the formation of the ionosphere?

3. Name the forms of electromagnetic radiation that are relatively negligible to space environmental effects.

412. Between sun and earth

1. How fast does the solar wind flow between the sun and earth?

2. What is formed by the interaction between the earth's magnetic field and the solar wind?

3. What is the magnetosphere?

4. What solar feature causes a high speed stream (HSS) of particles near the plane of earth's orbit?

5. Why are solar wind enhancement effects somewhat easier to forecast than geomagnetic storms associated with solar flares?

413. The near-earth environment

1. What space environmental effects occur in the troposphere?

2. What space environmental effects can occur in the stratosphere?

3. What space environmental effects occur in the mesosphere?

4. What environmental layer has the most interaction between atoms/molecules and UV radiation?

5. What environmental layer has a significant impact on a satellite being sent radio signals from earth?

414. Earth's magnetopause and magnetosphere

1. What steers electrically charged particles in motion near earth?

2. What is a visible result of earth's magnetic field lines being deflected to the point that they funnel into the high-latitude regions?

3. Define magnetosphere.

4. What compresses the leading edge of the magnetosphere?

5. How many radiation belts does earth have?

6. Define an aurora.

7. How soon can energetic protons from a major solar flare reach earth?

8. What is a geomagnetic storm?

9. What is differential charging?

10. How does bulk charging affect satellites?

11. What space environmental effects hazard can affect astronauts?

12. In which earth sector do DOD systems experience more problems?

415. Solar-geophysical sensing devices

1. What is the purpose of a neutron monitor?

2. Explain what the magnetometer measures.

3. What does the transionospheric sensing system (TISS) measure?

4. Match the solar-geophysical sensing device in column B with its function in column A. Items in column B may be used once.

Column A

____ (1) Detects radio noise signals received from outside the solar system.

____ (2) Measures the strengths and variations of earth’s magnetic field.

____ (3) Detects the arrival at the surface of electrically neutral particles.

____ (4) Measures the relative total electron content by analyzing the signals from GPS satellites.

____ (5) Determines the virtual heights and electron densities of reflecting layers in the ionosphere up to the level of maximum.

____ (6) Measures absolute total electron count by analyzing a VHF signal from a geostationary weather satellite.

Column B

a. Neutron monitor.
b. Magnetometer.
c. Riometer.
d. Ionospheric sounder.
e. Polarimeter.
f. Transionospheric sensor system.

Answers to Self-Test Questions

404

1. 8 minutes and 20 seconds.
2. Nuclear fusion.

405

1. The core.
2. In the core.
3. Convection zone.
4. Photosphere.
5. Chromosphere.
6. Chromosphere.
7. Corona.
8. Corona.
9. The thermonuclear reaction which produces helium from hydrogen fuel.
10. Transformation of hydrogen into helium.

406

1. Regions of high magnetic field strengths that are denser, hotter, and thus brighter, than the surrounding areas.
2. Transient, concentrated, localized regions of plasma located in areas of intense magnetic fields in the photosphere. They appear as dask areas against the photosphere.
3. Intense, temporary releases of energy.
4. Sunspots or plages.
5. A large, bright feature extending outward from the Sun’s surface, often in a loop shape.
6. Violent release of bubbles or tongues of gas and magnetic fields which rise and expand above the sunspot regions.

407

1. 11.1 years.
2. Zurich sunspot number.
3. It reverses polarity from one solar cycle to the next.

408

1. It blocks out the solar disk during visual observations of the corona, so that only emissions in the corona may be examined.
2. Photosphere.
3. White-light observations.
4. Umbra.
5. Monochromatic light observation of the chromosphere.
6. Clouds of ionized gas indicating relatively dense regions in the chromospheres; their brightness represents increased atomic reaction results in areas of enhanced chromospheric intensity.
7. They appear as bright regions on the solar disk due to increased atomic reaction that results in areas of greater chromospheric intensity.
8. Prominences.
9. A motion outward toward the observer.

409

1. Low frequencies from 25 to 180 MHz.
2. Radio burst data at discrete and sweep frequencies.

3. (1) b.
   (2) a.
   (3) a.
   (4) b.

410

1. The visible portion of the spectrum.
2. Electrons and protons.
3. A continuous outflow of energetic charged particles (electrons and protons) from the sun.
4. 27 days.
5. It may disappear as the area of the sun rotates away from the perspective on earth.

411

1. (a) X-ray.
   (b) Ultraviolet.
   (c) Radio-wave radiation.
2. X-ray radiation causes ionization of upper-atmospheric molecules. This process creates a layer of electrons within earth’s atmosphere.
3. (a) Gamma ray.
   (b) Visible.
   (c) Infrared radiation.

412

1. 250 to 1,000 kilometers per second or 600,000 to 2,000,000 miles per hour.
2. The magnetosphere.
3. A complex, teardrop-shaped cavity around earth caused by the interaction of the solar wind and earth’s magnetic fields.
4. A coronal hole.
5. They tend to be tied to solar features that last longer than the sun’s 27–day rotation and are therefore recurrant.

413

1. A portion of the sun’s radio-wave radiation that penetrates all layers of earth’s atmosphere.
2. Electrically charged particles emitted by the sun during an extreme solar burst and create high risk for personnel engaged in high-altitude flight operations.
3. Ionization and heating.
4. Thermosphere.
5. Ionosphere.

414

1. Earth’s magnetic field.
2. Auroral borealis and auroral australis (northern and southern lights), which are essentially atoms or molecules that emit light (visible radiation).
3. A shell-like region where earth’s magnetic field is the predominant magnetic force.
4. Solar wind.
5. Two—an inner and an outer radiation belt.
6. A dynamic and delicate visual manifestation of solar-induced geomagnetic storms.
7. Within 30 minutes.
8. An extraordinary variation in earth’s magnetic field.

9. During geomagnetic storms, the number and energy of electrons and ions increase. When a satellite or other spacecraft travels through this energized environment, the charged particles from the geomagnetic storm cause different parts of the satellite or spacecraft to take on different electrical charges which leads to electrical arcing and potential damage to components.
10. Energetic particles penetrate the outer covering of a satellite and deposit their charge in its internal parts. If sufficient charge accumulates in any one component, it may attempt to neutralize by discharging to other components, potentially causing damage to the satellite's electronic systems.
11. Lethal dosages of radiation from solar proton events.
12. Nightside sector.

415

1. To sense the arrival of uncharged atomic particles called neutrons at earth's surface.
2. The strength and variations of earth's magnetic field.
3. Absolute TEC by analyzing the signals from GPS satellites. It can also measure variations in GPS signal strength caused by variations in ion density along its path, a phenomenon called ionospheric scintillation.
4. (1) c.
   (2) b.
   (3) a.
   (4) f.
   (5) d.
   (6) e.

Complete the unit review exercises before going to the next unit.

Unit Review Exercises

Note to Student: Consider all choices carefully, select the *best* answer to each question, and *circle* the corresponding letter. When you have completed all unit review exercises, transfer your answers to the Field Scoring Answer Sheet.

6. (404) How much energy does the sun manufacture per second?
   a. 3.85×10^{22} watts.
   b. 3.85×10^{24} watts.
   c. 3.85×10^{26} watts.
   d. 3.85×10^{28} watts.

7. (404) The basic energy source for the sun is
   a. thermal radiation.
   b. the fusion of helium.
   c. electromagnetic radiation.
   d. the fusion of hydrogen into helium.

8. (405) Which layer of the sun contains one-half of the solar mass?
   a. Core.
   b. Corona.
   c. Chromosphere.
   d. Convection zone.

9. (405) In which of the sun's layers do large temperature gradients form because atoms absorb energy?
   a. Core.
   b. Corona.
   c. Chromosphere.
   d. Convection zone.

10. (405) Which layer of the sun is visible from earth when we look at the sun with our eyes?
   a. Corona.
   b. Photosphere.
   c. Chromosphere.
   d. Convection zone.

11. (405) The continual, outward flow of energetic charged particles from the sun is called the solar
   a. flux.
   b. flare.
   c. wind.
   d. radiation.

12. (406) The name given to the darkest area at the center of a sunspot is
   a. plage.
   b. umbra.
   c. penumbra.
   d. plasma flow.

13. (406) Generally, solar bursts are most common during
    a. daylight.
    b. nighttime.
    c. solar minimum.
    d. solar maximum.

14. (406) What is the *prime* cause of solar activity?
    a. Solar flares.
    b. Coronal holes.
    c. Sunspots.
    d. Plages.

15. (406) Which solar features are ribbon-like, suspended above the chromosphere by the magnetic field, and comparable to clouds on earth?
    a. Flares.
    b. Plages.
    c. Sun spots.
    d. Filaments.

16. (407) When is the greatest potential for large solar flares to occur?
    a. During a solar minimum.
    b. During a solar maximum.
    c. 2 to 3 years following a solar minimum.
    d. 2 to 3 years following a solar maximum.

17. (407) The overall polarity of the sun's northern and southern hemispheres reverse every
    a. 4 years.
    b. 7 years.
    c. 11 years.
    d. 22 years.

18. (408) The unit of measurement used to identify the strength of a magnetic field is the
    a. lux.
    b. gauss.
    c. angstrom.
    d. megahertz.

19. (408) Clouds of gases suspended above the chromosphere which appear as dark, ribbon-like features on the solar disk are called
    a. plages.
    b. sunspots.
    c. filaments.
    d. prominences.

20. (408) Which solar feature is formed by the condensation of material from the hot corona?
    a. Filament.
    b. Loop prominence.
    c. Limb prominence.
    d. Eruptive limb prominence.

21. (409) How many discrete (fixed) frequencies can the radio telescope simultaneously sample for radio emissions from the chromosphere and corona?
    a. 6.
    b. 7.
    c. 8.
    d. 9.

22. (409) The solar radio spectrograph (SRS) monitors solar emissions over a megahertz (MHz) frequency range of
    a. 25 to 180 MHz.
    b. 50 to 100 MHz.
    c. 245 to 410 MHz.
    d. 610 to 1,415 MHz.

23. (410) On what part of the electromagnetic spectrum does the most intense energy fall?
    a. X-ray.
    b. Visible.
    c. Gamma.
    d. Infrared.

24. (411) The type of radiation that causes ionization of molecules in the upper atmosphere is
    a. X-ray.
    b. infrared.
    c. ultraviolet.
    d. radio wave.

25. (411) Which type of radiation causes ionization of upper atmospheric atoms and molecules and results in the heating of the upper atmosphere?
    a. X-ray.
    b. Infrared.
    c. Ultraviolet.
    d. Radio wave.

26. (411) Which type of radiation has the *least* application in the space environment?
    a. X-ray.
    b. Infrared.
    c. Ultraviolet.
    d. Radio wave.

27. (412) What is the term used to identify the area between the sun and the planets?
    a. Space.
    b. Outer space.
    c. Interplanetary space.
    d. Interplanetary medium.

28. (412) The tails of comets that always point away from the sun show the influence of the
    a. Van Allen radiation belts.
    b. earth’s magnetic field.
    c. magnetosphere.
    d. solar wind.

29. (412) What is the interface called that separates interplanetary space from the magnetosphere?
    a. Magnetopause.
    b. Magnetic field.
    c. Geomagnetic storm.
    d. Interplanetary magnetic field.

30. (413) Which atmospheric layer serves as the primary reservoir of atoms/molecules that may be heated and/or ionized by the sun's ultraviolet radiation?
    a. Mesosphere.
    b. Stratosphere.
    c. Troposphere.
    d. Thermosphere.

31. (413) Where are the floating electrons created that make up the ionosphere?
    a. Mesosphere and thermosphere.
    b. Mesosphere and magnetosphere.
    c. Thermosphere and radiation belts.
    d. Thermosphere and magnetosphere.

32. (413) Which atmospheric layer contains sharp horizontal and vertical electron density gradients?
    a. Ionosphere.
    b. Mesosphere.
    c. Thermosphere.
    d. Magnetosphere.

33. (414) What phenomena is a dynamic and delicate visual manifestation of solar-induced geomagnetic storms?
    a. Aurora.
    b. Proton event.
    c. Solar shower.
    d. Geomagnetic storm.

34. (414) The term used to describe the event in which earth is showered with energetic solar particles released from a solar flare site is
    a. aurora.
    b. proton event.
    c. solar shower.
    d. geomagnetic storm.

35. (414) The mechanism by which charged solar particle streams disrupt the magnetosphere and adversely affect radar, communications, and space operations is
    a. an aurora.
    b. a meteor shower.
    c. a geomagnetic storm.
    d. a proton energy event.

36. (415) Which solar-geophysical sensor detects cosmic radio noise at a frequency of 30 megahertz (MHz)?
    a. Riometer.
    b. Magnetometer.
    c. Neutron monitor.
    d. Ionospheric sounder.

37. (415) Which solar-geophysical sensor acts like a radar and transmits radio energy vertically over a range of 2 to 30 megahertz (MHz), or between any two frequencies within this range?
   a. Riometer.
   b. Magnetometer.
   c. Neutron monitor.
   d. Ionospheric sounder.

38. (415) Which solar-geophysical sensor measures the absolute total electron content (TEC) by analyzing the signals from global positioning system (GPS) satellites?
   a. Polarimeter.
   b. Neutron monitor.
   c. Ionospheric sounder.
   d. Transionospheric sensor.

Please read the unit menu for unit 3 and continue ➔

Student Notes

Unit 3. Space Environmental Impacts, Operations, and Support

NOW THAT YOU UNDERSTAND what dynamics and physical processes are involved in causing space environmental effects, you probably have at least two questions, if not more. One probably is "How does space environmental effects impact my customers?" and two, "Where or who do I rely on to provide me with operational support on the space environment?" This unit answers both of these questions and provides you with the ease of mind to integrate information about the space environment into your daily support for your customers.

This unit provides you with the knowledge about how effects that occur in the space and near-earth environment affect daily military operations and what support and products are out there for you to use to support your customers' mission. The effects that changes in the space environment have on military operations are ever increasing. As the military relies more on sophisticated weapons systems and electronic equipment, especially in the command, control, communications, and intelligence (C3I) arena, the more potential for damage from space environmental effects.

3–1. Space Environmental Impacts on Department of Defense operations

The following are the two areas that are impacted within the Department of Defense (DOD) operations of the space environment (fig. 3–1):

- Radio-wave *signals*
- Systems

Space environmental effects can bend (reflect), distort, and/or slow down radio-wave *signals*, such as communication and navigation signals. Space environmental effects can also interact directly with hardware in space and/or on the ground, such as satellites and communications hardware.

416. Impacts on radio-

No matter what your customer's mission is currently, radio communications probably play a daily role in the successful completion of that mission.

Space environmental effects on radio-wave signals are a function of the signal frequency. Figure 3–2 depicts various types of radio-wave signal frequencies. The electrons in the ionosphere can bend (reflect), distort, and/or slow down a radio-wave signal to various degrees. Generally, the overall effect becomes less as the radio signal frequency increases.

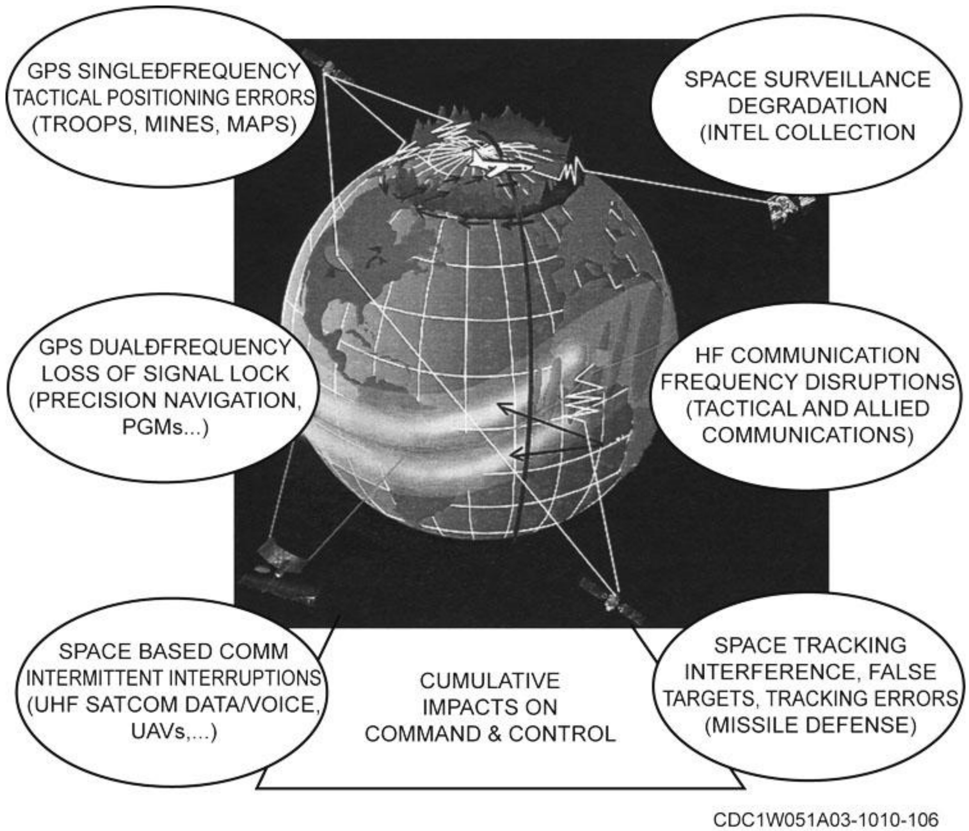

Figure 3–1. Impacts on DOD operations.

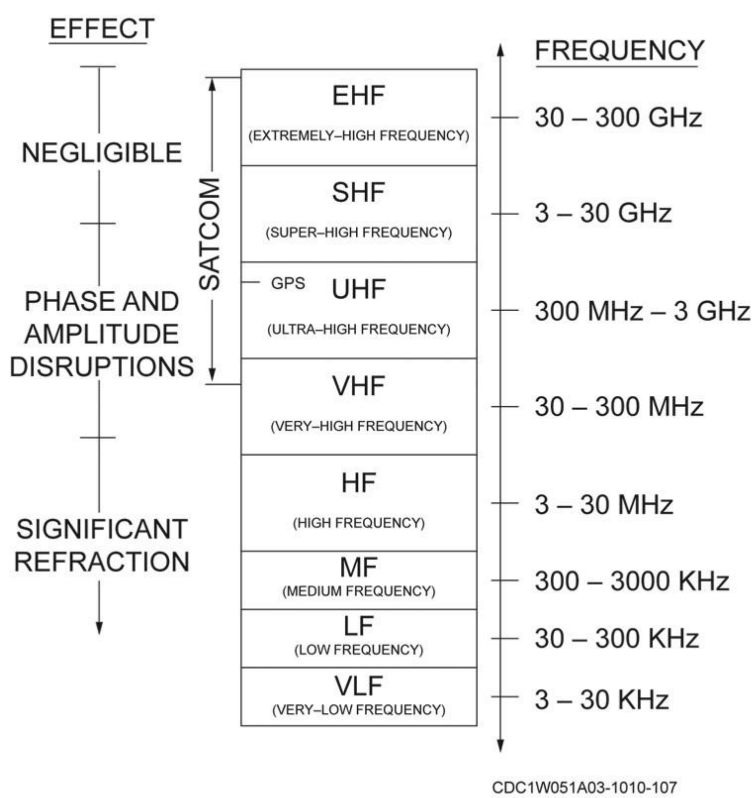

Figure 3–2. Radio-wave signal types and the general effects caused by the ionosphere.

This effect on radio-wave signals shows why the space environment affects the DOD in the areas of ground, sea, air, and space operations.

High-frequency communications

Space weather can negatively impact and ultimately expose many vulnerabilities to HF radio signals. High frequency communications are subject to the following space environment concerns.

Impact

HF communication signals (not including line-of-sight HF) are controlled and disrupted (fig. 3–3).

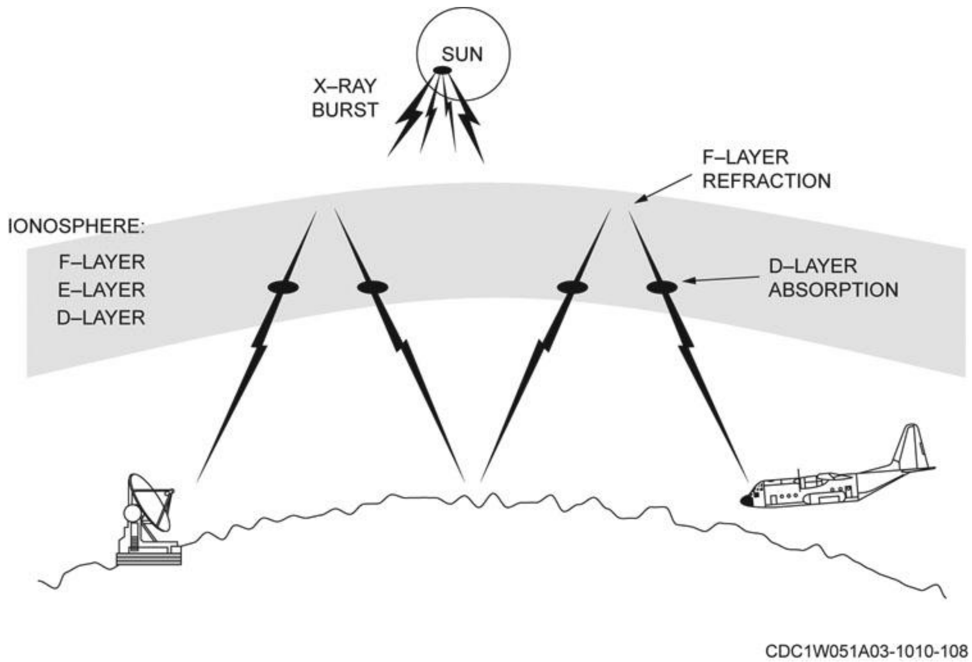

Figure 3–3. Refraction of high frequency signals in the ionosphere.

Cause

Electrons in the ionosphere refract HF radio-wave signals. The electron density profile determines the extent that signals are refracted also changes. As the electron density profile within the ionosphere changes in response to various space environmental effects processes, the manner in which various HF radio-wave signals are reflected also changes.

Scenario #1

During a daytime Air Mobility Command transoceanic flight, HF communications with the aircraft are prevented for 30 minutes due to a sudden burst of X-ray radiation by the sun. The X-ray radiation changes the electron density profile of the lower ionosphere (by way of ionization) such that HF radio-wave signals are absorbed rather than reflected.

Scenario #2

During nighttime HF communications between deployed ground forces and a tactical command center, large enhancements in the magnetosphere’s electric current systems (geomagnetic storming) create rapid changes in the electron density profile of the ionosphere, causing HF voice reception to be sporadic, ranging from “loud and clear” to “broken and unreadable.”

Satellite communications

Space weather can have a great impact on satellite signals. Satellite communications are subject to the following space environment concerns.

Impact

SATCOM signals at ultra-high frequencies (UHF) are intermittently interrupted.

Cause

As UHF radio signals move through the ionosphere on its way to or from a satellite, extremely large electron density gradients within the ionosphere distort the signal sufficiently such that the signal is unrecognizable to a receiver. The space environmental effects processes that cause these sharp gradients are most common at low and high latitudes, occur at night, and are migratory; hence, the signal disruptions are intermittent. Note that this does not affect UHF communications common between aircraft.

Scenario #1

During peacekeeping operations in Africa, data transmissions using UHF SATCOM between a command center and nearby naval forces are intermittently disrupted, causing the need to retransmit multiple messages.

Scenario #2

During late-night surveillance operations near low latitudes (such as South America, Southwest Asia, etc.), a remotely piloted aircraft (RPA) being commanded/controlled by way of UHF SATCOM sporadically fails to respond to commands.

Global positioning system (single-frequency) navigation

GPS technology has become prominent in day-to-day military operations. The following is an example of the impacts the space environment can have on these systems.

Impact

GPS single-frequency performance (positional accuracy) is degraded.

Cause

As a GPS signal moves through the ionosphere on its way down from a satellite, dense electrons "slow down" the signal. This slowing effect increases as the total number of electrons that the signal passes through increases. A GPS receiver typically uses four signals from four satellites to compute a position. Since the TEC or total number of electrons that each of the four GPS signals moves through is different, the receiver computes a position that is not exact. As the TEC changes in response to the changes in the space environmental processes, the positional errors change.

Scenario #1

During ground maneuvers in the Far East, Army ground forces using the single-frequency precision lightweight GPS receiver (PLGR) experience fluctuating errors. At one moment, the errors are 40 feet east of true (known) position. Thirty minutes later, the positional error has changed and appears to be 35 feet southwest of true position. These relatively large and changing errors are a result of large and spatially irregular changes in the number of electrons in the ionosphere.

Scenario #2

During first-in deployed operations, base civil engineering personnel using single-frequency GPS receivers have trouble in establishing a "good fix" to conduct surveying activities. Radio-wave jamming from a nearby mountain transmitter is suspected as a potential cause; however, large and irregular changes in the electron content of the ionosphere is the actual cause.

Global positioning system (dual-frequency) navigation

In addition to single frequency GPSs, dual frequency systems are also affected by the space environment.

Impact

GPS dual-frequency receivers intermittently lose lock of GPS signals, causing a potential decrease in system performance (positional accuracy is degraded).

Cause

As a GPS radio signal moves through the ionosphere on its way down from a GPS satellite, extremely large electron density gradients within the ionosphere distort the signal sufficiently such that the signal can be unrecognizable to a receiver. The space environmental effects processes that cause these sharp gradients are most common at low and high latitudes, occur at night, and are migratory (same cause as UHF SATCOM disruptions).

Scenario

The extent to which this effect will have an impact on operations is not well documented. A possible scenario may include precision-guided munitions (PGM) using dual-frequency GPS receivers and being launched several miles from the nighttime target. As the PGM enters a valley and approaches the target, the GPS receiver aboard the weapon loses lock of a GPS signal, cannot find four signals to lock onto, and reverts to the weapon's secondary and less precise navigation system, missing the desired "bulls-eye." Consequently, the positional accuracy and identification of the PGM (or any specific objected used) by the GPS receivers is degraded.

NOTE: The loss of lock phenomena described here also affects single-frequency GPS applications. However, the single-frequency effect described in the above section is the more significant space environmental impact for single-frequency applications.

Ground-based tracking of objects in orbit

Ground based space surveillance systems currently track thousands of space objects orbiting the earth. The following is an example of the impacts the space environment has on these systems.

Impact

Ground-based space tracking system performance (positional accuracy and object identification) is degraded.

Cause

As the radar's super-high frequency (SHF) signal moves through the ionosphere on its way to and from an object being tracked, the electrons "slow down" the signal. The location of the object is calculated based in part on the speed in which the radar signal is returned. The greater the total number of electrons through which the signal passes, the greater the effect. Furthermore, the irregular nature of the ionosphere, especially during periods of enhanced magnetospheric electric currents (geomagnetic storming), can cause abnormal radar signal backscatter, cluttering, and "false objects."

Scenario

As a result of enhanced electric currents within the magnetosphere, the electron density profile within the ionosphere changes significantly and becomes especially irregular. The irregular density profile causes radars at high latitudes great difficulty in identifying new objects (projectiles), and at the same time, causes positional errors on objects that have been previously identified (satellites and space junk). Efforts between two ground radar stations to collaborate on target identification are hampered because of the irregular nature of the ionosphere.

Intelligence collection

The ability to collect intelligence (INTEL) information can be affected by space weather conditions. The previous systems discussed in this unit are all used to gather information for collecting INTEL.

Impact

The ability to collect INTEL is affected.

Cause/scenario

Space environmental effects ability to affect radio-wave signals as described in previous sections can affect INTEL applications. Specific information is sensitive or classified.

Cumulative impacts on signals

The impacts described above are often caused by the same (or closely related) space environmental anomalies. Consequently, these impacts may be experienced simultaneously, creating a cumulative space “fog of warfare.”

417. Impacts on system hardware

The second category of impacts is those caused by systems directly meeting space environmental effects, such as particles, including meteors, bombarding a satellite, atoms/molecules causing increased drag (friction) on space objects, or the sun’s electromagnetic radiation blanketing a ground- or space-based radio-wave transmitter or receiver.

Satellite operations and health

The space environment can impact the physical attributes of satellite systems. The following is an example of the consequences space weather can have on these systems.

Impact

Damage to on-board satellite electronic components, false readings in satellite sensors, and anomalous (unexpected) behavior in satellite subsystems occur.

Cause

Electrically charged particles collide with satellites and trigger various impacts. Meteors don’t have a charge before they collide with an object; however, their impact creates a charge that can cause damage to electrical equipment.

Scenario #1

Following a burst of energetic protons by the sun, the satellite orbiting in the magnetosphere is bombarded by the protons. Visible light is emitted during the “collisions,” and the satellite’s star sensor falsely interprets the “light flashes” as a star. With these “false stars” not recognized by the satellite’s star catalog, the satellite loses altitude control and cannot perform its primary mission until stabilized.

Scenario #2

In response to rapid changes in the solar wind, the magnetospheric electric-current system intensifies (geomagnetic storming), and energetic electrons bombard a satellite. The electrons penetrate the satellite’s surface and deposit their electronic charge within the satellite’s circuitry. Subsequently, the charge build-up results in a power-supply module to short circuit.

Satellite or space object drag

Space objects are subject to a change in trajectory or space drag. The following discusses the impact of satellite or space object drag, its causes, and examples of how this occurs.

Impact

The orbit (altitude) of a satellite or other space object changes unexpectedly.

Cause

In response to heating of the thermosphere by the sun’s ultraviolet radiation or by enhanced electric currents in the magnetosphere, atoms and molecules from lower altitudes expand upward to higher altitudes. Satellites and pieces of space junk orbiting at this higher altitude are subsequently immersed in, and collide with many more atoms/molecules than normal. The friction from the collision with the atoms and molecules causes the satellite to lose altitude.

Scenario #1

USSPACECOM is tracking the location of various satellites, including those operated by potential adversaries, and is also tracking space junk to warn against possible collisions with other satellites. Those objects and satellites orbiting below 800 km experience a huge increase in drag over a one-week period after several days of geomagnetic storming and enhanced ultraviolet radiation, causing ground controllers to temporarily lose precise positional data on these objects.

Scenario #2

In preparation for a missile launch to place a new satellite in orbit, calculations are made for rocket fuel consumption and booster-satellite separation timing. Hours before a scheduled launch, thermospheric heating rapidly increases and requires a change to the drag calculations.

Satellite communications

The following discusses the impact of space weather on satellite communications for ground-based systems.

Impact

Ground-based SATCOM stations experience direct radio frequency interference.

Cause

The sun emits radio-wave radiation at the same frequencies that SATCOM ground stations operate on, including UHF, SHF, and EHF. If the sun is in the "field of view" of a SATCOM receiver, then the sun's radio-wave emissions, especially bursts, cause interference.

Scenario

A theater operations center has been formed and has established dedicated intertheater SATCOM using SHF and EHF. Occasionally, communication operators report intermittent signal spikes. With no reports of radio-wave bursts from the sun, the equipment is inspected and replaced as part of established troubleshooting procedures.

Ground-based tracking of objects in orbit

The following discusses the impact space weather has on ground based satellite systems tracking space objects.

Impact

Ground-based space radar stations experience direct radio frequency interference.

Cause/scenario

The same cause and scenario applies as with satellite communications, though frequencies may differ.

High-altitude flight

Space weather effects extend beyond system degradation, and can even impact humans flying at high altitudes. The following discusses the potential hazard the space environment presents to aircrews.

Impact

There are radiation hazards to aircrews when flying aircraft at high-altitude.

Cause/scenario

The most energetic of electrically charged particles emitted by the sun during extreme bursts can penetrate into the mid- to upper-stratosphere and increase what is known as the "particle radiation dosages" that aircrew members may experience. The most likely location that these particles might enter the stratosphere is at high latitudes, since that is where earth's magnetic field lines funnel electrically charged particles.

418. Operational impacts

In our previous lesson, we identified the solar and geophysical events that can adversely affect operational DOD radar, communications, and space systems. Now let's look at some of the major types of system impacts that may occur in an operational environment.

Solar effects and impacts

As we've learned, there are several types of enhanced solar emissions, each with its characteristics and impacts (fig. 3–4).

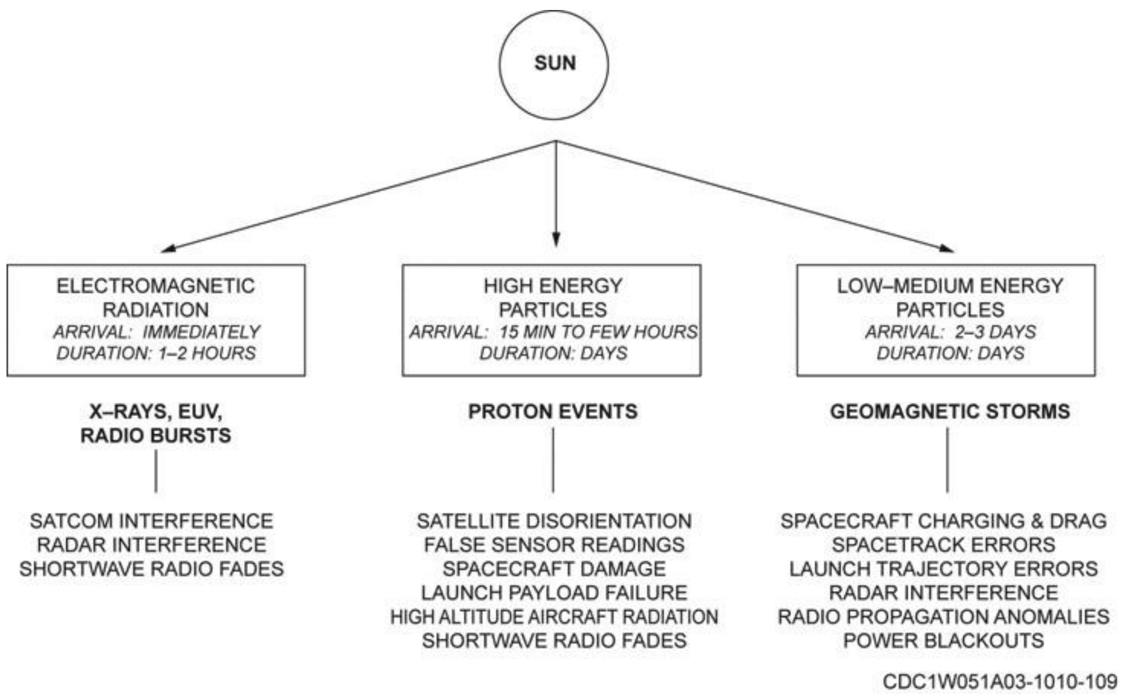

Figure 3–4. Solar emissions and impacts.

Electromagnetic radiation

Solar flare-enhanced X-rays, EUV, and radio waves reach earth at the speed of light (3×10^8 meters per second, or in about 8 minutes) and can cause environmental and DOD system impacts anywhere over earth's sunlit hemisphere. Fortunately, these effects tend to last only a bit longer than the flare that produced them, or about a few tens of minutes to an hour or two. Sample system impacts include SATCOM and radar interference (specifically, enhanced background noise) and absorption of HF (3–30 MHz) radio signals.

High energy particles

These particles (primarily protons, but occasionally cosmic rays) can reach earth within 15 minutes to a few hours after the occurrence of a strong solar flare—if they arrive at all. Not all flares produce these high-energy particles, plus earth is a rather small target 93 million miles from the sun, so predicting solar proton and cosmic ray events is a forecast challenge. The major impact of these protons is felt over the polar caps, where protons have ready access to low altitudes through funnel-like cusps in earth's magnetosphere. The impact of a proton event can last for a few hours to several days after the flare ends. Sample impacts include satellite disorientation, collision damage on satellites and spacecraft, false sensor readings, and absorption of HF radio signals.

Low to medium energy particles

Particle streams (composed of both protons and electrons) may arrive at earth about 2–4 days after a flare. As previously mentioned, such particle streams can also occur at anytime due to other, nonflare solar activity. These particles cause geomagnetic and ionospheric storms that can last for a few hours to several days. Typical problems include spacecraft electrical charging, drag on low orbiting satellites, radar interference, space track errors, and radio-wave propagation anomalies. These impacts are most frequently experienced in the night-side sector of earth.

Short-wave fades

Short-wave fades (SWF) are the absorption of HF radio waves in the D-layer of the ionosphere, resulting in the radio signals not reaching their intended destination or even causing them to fade. When this happens, the signals are not reaching the F-layer where they would then normally be refracted back towards earth.

SWFs affect HF propagation. Despite the increasing popularity of SATCOM, HF radio communication (which uses ionospheric refraction or bending to communicate beyond the horizon) is still used extensively by the military. The refraction occurs mostly in the highest portion of the ionosphere (or F-layer), where the number of free electrons is greatest. Frequencies below a maximum (max) usable frequency (MUF) are bent back toward earth, while those above the MUF do not encounter sufficient bending and pass through the ionosphere into space.

Each time a radio wave passes through the lowest portion of the ionosphere (or D-layer), it will cause ionized atmospheric particles to oscillate. Even under normal, undisturbed conditions, many of these ionized particles will collide with the still relatively dense neutral air molecules in the D-layer, causing radio-wave energy to be damped (i.e., converted to heat). The lower the frequency, the greater the degree of signal absorption. Hence, there exists a lowest usable frequency (LUF), below which the signal doesn’t get through the D-layer to even reach the F-layer.

Short-wave fades event

The HF propagation window is the range of frequencies between the LUF and MUF. HF operators choose propagation frequencies within this window so their signals will pass through the absorbing D-layer and subsequently refract from the F-layer (fig. 3–5). The LUF and MUF curves show a normal, daily variation. During early afternoon, incoming photo ionizing solar radiation is at a maximum, so the D- and F-layers are strong and the LUF and MUF are elevated. During the night, the removal of ionizing sunlight causes all ionospheric layers to weaken (some layers disappear altogether), and the LUF and MUF become depressed.

X-ray radiation emitted during a solar flare can significantly enhance D-layer ionization and absorption (thereby elevating the LUF) over the entire sunlit hemisphere of earth, for tens of minutes to an hour or two. This enhanced

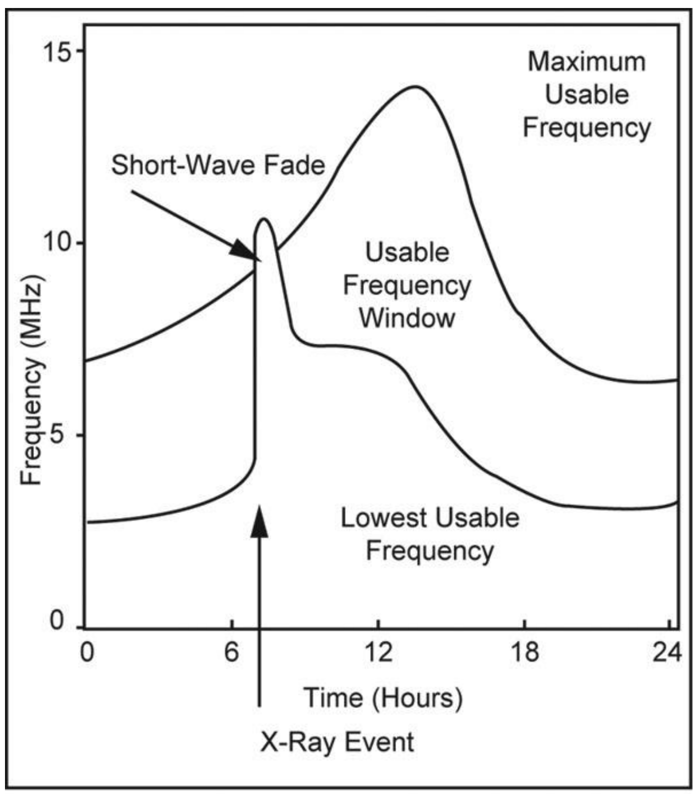

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Figure 3–5. Useable frequencies during an SWF.

absorption is known as an SWF and may at times be strong enough to close the HF propagation window completely (a short-wave blackout).

Radio burst effects

A radio burst is a burst of energy from a solar flare on the sun that reaches earth's upper atmosphere. A radio energy burst from a solar flare can produce direct radio frequency interference (RFI) on a SATCOM link, or a missile detection or space track radar if the sun is in the field of view of the receiver. When the burst is at the right frequency and intense enough, RFI is seriously degraded. Knowledge of such solar radio bursts allows an operator to isolate the RFI cause and avoid time-consuming investigation of possible equipment malfunction or intentional jamming. There is a similar geometry-related affect, called solar conjunction, which accounts for why geosynchronous communication satellites will experience interference or blackouts (e.g., on TV signals) during brief periods on either side of the spring and autumn equinoxes. This problem doesn't require a solar flare to be in progress, but its significance is definitely greatest during solar max when the sun is a strong background radio emitter.

Now, let's move on to some delayed, charged particle-induced system impacts. These impacts tend to occur hours to several days after the solar activity that caused them and persist for up to several days. Since the particles that cause the impacts usually come from the magnetosphere's tail and are mostly felt in the nighttime sector they are not limited to that time or geographic sector.

Absorption events

Similar to high frequency SWFs over the sunlit hemisphere (caused by flare-enhanced X-rays), we also find HF absorption events at high latitudes (above 55° north or south latitude). This is due to the enhanced ionization of atmospheric atoms and molecules caused by particle bombardment from space. These high latitude absorption (polar cap absorption (PCA) and auroral zone absorption (AZA)) events can last for hours to several days and usually occur simultaneously with other radio transmission problems like non-great circle propagation and multipath fading or distortion.

Polar cap absorption events

The enhanced ionization is caused by energetic solar flare protons that gain direct access to low altitudes by entering through the funnel-like cusps in the magnetosphere above earth's polar caps.

Auroral zone absorption events

The enhanced ionization is caused by particles (primarily electrons) from the magnetosphere's tail, which are accelerated toward earth during a geomagnetic storm and are guided by magnetic field lines toward auroral zone latitudes. These are the same ionizing particles that cause the aurora or northern/southern lights.

Scintillation

The intense ionospheric irregularities found in the auroral zones are also one cause of ionospheric scintillation, at least at high geomagnetic latitudes. Scintillation is similar to the human eye observing the apparent twinkling effect when viewing a star or the heat shimmer over a hot road. Scintillation of radio-wave signals is the rapid, random variation in signal amplitude, phase, and/or polarization caused by small-scale irregularities in the electron density along a signal's path. The result is signal fading and data dropouts on satellite command uplinks, data downlinks, or on communications signals.

Scintillation tends to be a highly localized effect. Normally, the impact is felt only if the signal path penetrates an ionospheric region where these small-scale electron density irregularities occur (fig. 3–6). Low latitude, nighttime links with geosynchronous communications satellites are particularly vulnerable to intermittent signal loss due to scintillation. During the Persian Gulf War, allied forces relied heavily on SATCOM links, and scintillation posed an unanticipated, but very real operational problem.

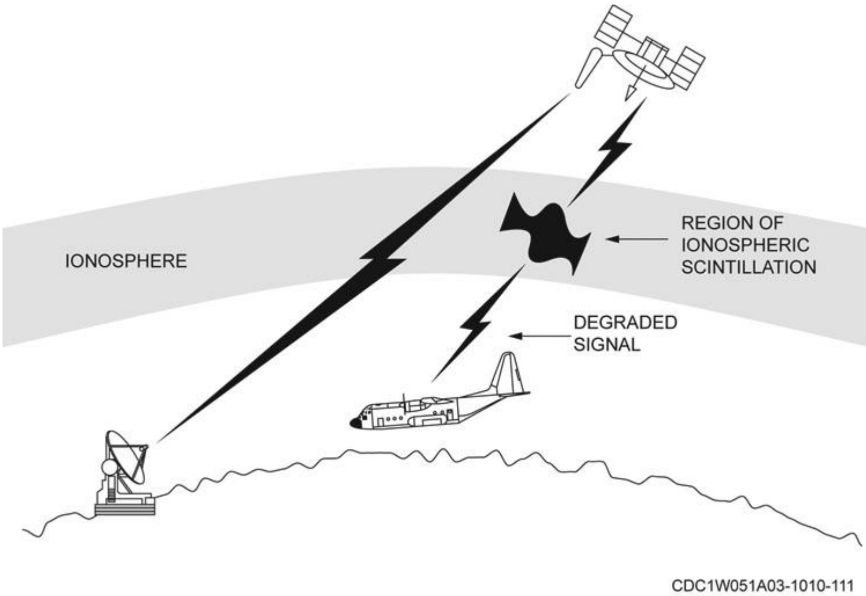

Figure 3–6. Ionospheric scintillation effects on satellite communications.

Global positioning system

GPS satellites, which are located at semisynchronous altitude, are also vulnerable to scintillation. Phase changes and signal strength enhancements and fades due to scintillation can cause a GPS receiver to lose signal lock with a particular satellite. The reduction in the number of simultaneously usable GPS satellites may result in a potentially less accurate position fix. Scintillation occurrence is positively correlated with solar activity and the GPS constellation has received widespread use only recently (during a quiet portion of the 11–year solar cycle).

Total electron content

The TEC along the path of a GPS signal can introduce a positioning error. Just as the presence of free electrons in the ionosphere caused HF radio waves to be bent (or refracted), the higher frequencies used by GPS satellites will suffer some bending (although to a much lesser extent than with HF radio waves). The signal bending increases the signal path length. In addition, passage through an ionized medium causes radio waves to be slowed (or retarded) somewhat from the speed of light. Both the longer path length and slower speed can introduce up to 300 nanoseconds (equivalent to about 100 meters) of error into a GPS location fix—unless some compensation is made for the effect.

Scintillation conditions

Communication/Navigation Outage Forecast System (C/NOFS) is a satellite developed by the Air Force Research Laboratory Space Vehicles Directorate to investigate and forecast scintillations in the Earth's ionosphere. However, no actual sensor currently exists to detect real-time scintillations. The satellite allows the prediction of the effects of ionospheric activity on signals from communication and navigation satellites, outages of which could potentially cause problems in battlefield situations.

Statistically, scintillation tends to be most severe at low latitudes (within plus or minus 20 degrees of the geomagnetic equator) due to ionospheric anomalies in that region. It is also strongest from local sunset until just after midnight and during periods of high solar activity. At high geomagnetic latitudes (the auroral and polar regions), scintillation is strong, especially at night, and its influence increases with higher levels of geomagnetic activity. Knowledge of those time periods and portions of the ionosphere where conditions are conducive to scintillation permits operators to reschedule activities and/or to switch to less susceptible radio frequencies or satellite links.

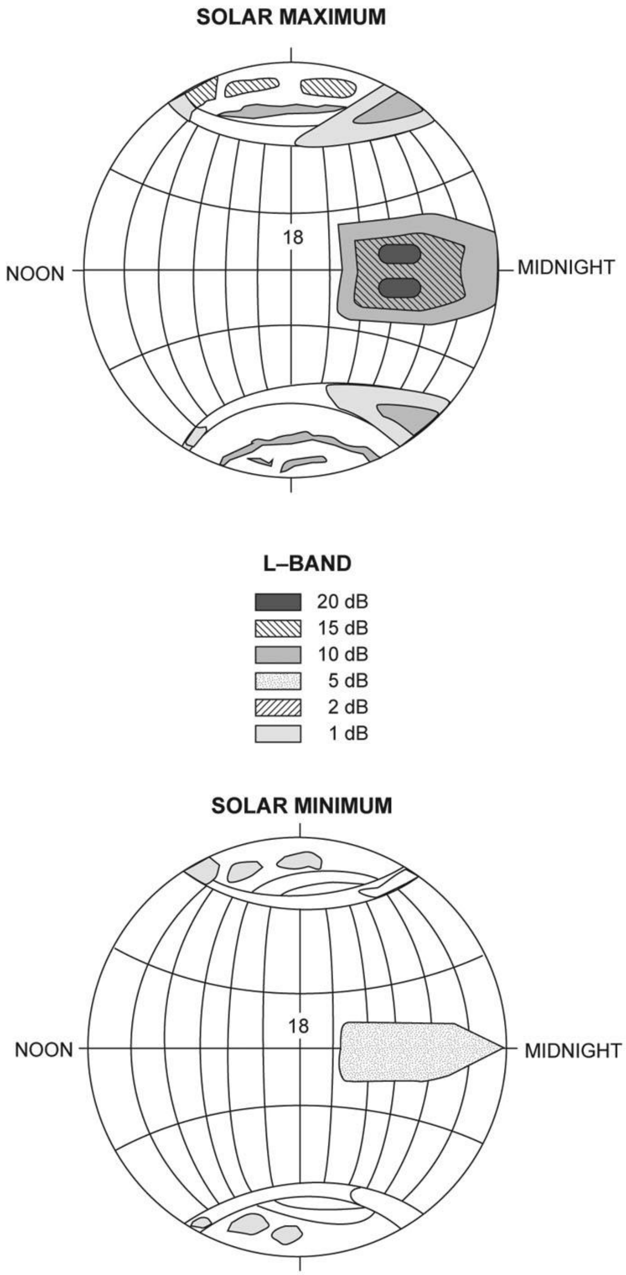

Figure 3–7. Scintillation occurrence.

Radar aurora

As mentioned earlier, a geomagnetic and ionospheric storm will cause both enhanced ionization and rapid variations (over time and space) in the degree of ionization throughout the auroral oval. Visually this is observed as the aurora or northern/southern lights. This enhanced, irregular ionization can also produce abnormal radar signal backscatter on poleward looking radars, a phenomenon known as radar aurora. Impacts can include increased clutter and target masking, inaccurate target locations, and even false target or missile launch detections. (While improved software screening programs have greatly reduced the frequency of false aircraft or missile launch detections, they've not been eliminated totally.)

The presence of free electrons in the ionosphere causes UHF and SHF radio waves from missile detection and space track radars to be bent (or refracted), as well as slowed (or retarded) somewhat from the speed of light. These effects will produce unacceptable errors in target bearing and range (fig. 3–8). The bearing (or direction) error is caused by signal bending while the range (or distance) error is caused by a longer path length for the refracted signal and a slower signal speed. For range errors, the effect of longer path length dominates for UHF signals, while slower signal speed dominates for SHF signals.

Radar operators routinely try to compensate for these errors by applying correction factors that are based on the expected ionospheric TEC along the radar beam's path. These predicted TEC values are based on time of day, season, and the overall level of solar activity. Unfortunately, individual solar and geophysical events will cause unanticipated, short-term variations from the predicted TEC values and correction factors. These variations (which can be either higher or lower than anticipated values) will lead to inaccurate position determinations or difficulty in acquiring targets. Real-time warnings when significant TEC variations are occurring help operators minimize the impacts of their radar's degraded accuracy.

These bearing and range errors caused by refraction and signal retardation also affect space-based systems. For example, a space sensor trying to lock-on to a ground radio emitter may experience a geolocation error.

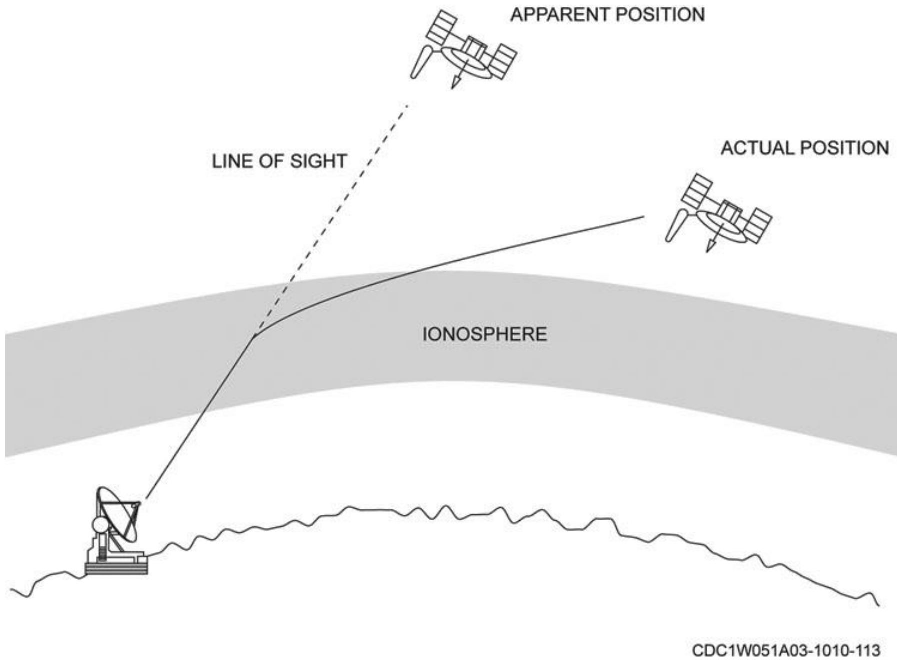

Figure 3–8. Surveillance radar errors.

Atmospheric drag

Another source for space object positioning errors is either more or less atmospheric drag than expected on low orbiting objects (generally at less than about 1,000 km altitude). Energy deposited in earth's upper atmosphere by EUV, X-ray, and charged particle bombardment heats the atmosphere, causing it to expand outward. Low earth-orbiting satellites and other space objects then experience denser air and more drag than expected. This drag decreases the object's altitude and increases its orbital speed. The result is the satellite will be some distance below and ahead of its expected position when a ground radar or optical telescope attempts to locate it (fig. 3–9).

The consequences of satellite drag include:

- Inaccurate satellite locations hinder rapid acquisition of SATCOM links for commanding or data transmission.
- Costly orbit maintenance maneuvers become necessary.
- De-orbit predictions become unreliable. (A classic case of the latter was *Skylab*. Geomagnetic activity was so severe, for such an extended period, that *Skylab* burned-up in orbit before a planned space shuttle rescue mission was ready to launch.)

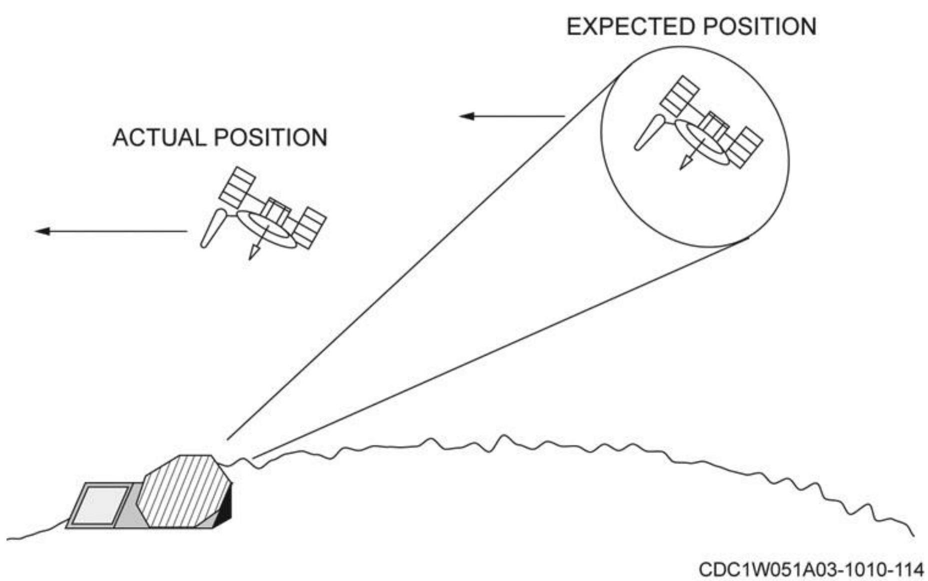

Figure 3–9. Atmospheric drag effects.

Contributions to drag

The two space environmental parameters used by current models to predict the orbits of space objects are the solar F10 index and the geomagnetic planetary amplitude (Ap) index.

Solar F10 index

Although the F10 index is a measure of solar radio output at 10.7 centimeters (2800 MHz), it is a very good indicator of the amount of EUV and X-ray energy emitted by the sun and deposited in earth's upper atmosphere. The solar flux (F10) graph shows a clear, 27-day periodicity caused by the sun's 27-day period of rotation and the fact that hot, active regions are not uniformly distributed on the sun's surface.

Geomagnetic planetary amplitude index

The geomagnetic planetary Ap index is a measure of the energy deposited in our upper atmosphere by charged particle bombardment. This index shows strong spikes corresponding to individual geomagnetic storms.

Storm impact on orbit changes

We've seen two impacts of geomagnetic storms on space track radars. The first was bearing and range errors induced by inadequate compensation for TEC changes, which caused apparent location errors. The second was atmospheric drag, which caused real position errors. Both of these effects can occur simultaneously. Figure 3–10 shows the relative impact of geomagnetic storms. In March 1989, during a severe magnetic storm, more than 1,300 space objects were temporarily misplaced; it took almost a week to reacquire all the objects and update their orbital elements. This incident led to a revision in operating procedures. Normally, drag models do not include detailed forecasts of the F10 and Ap indices. However, when severe conditions are forecast, more comprehensive model runs are made, even though they're also more time consuming.

LEVEL	ap OR Ap INDEX	POTENTIAL FOR IMPACTS
Quiet	0 to 7	Low
Unsettled	8 to 15	Low
Active	16 to 29	Moderate
Minor Storm	30 to 49	Moderate
Major Storm	50 to 99	High
Severe Storm	Greater than 100	Very High

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Figure 3–10. Geomagnetic storm impact on orbit changes.

Launch errors

Excessively high or low geomagnetic conditions can produce atmospheric density variations along a proposed launch trajectory that may be outside a launch vehicle's capacity to compensate.

In addition, the atmospheric density profile with altitude determines how early the protective shielding around a payload can be jettisoned. Jettison too early and you expose the payload to excessive frictional heating; jettison too late and booster fuel is wasted.

Geomagnetic storms and proton events can cause another problem for space launches and payload deployment. Specifically, charged particle bombardment can produce direct collisional damage and/or deposit an electrical charge on or inside a spacecraft. The electrostatic charge deposited can be discharged by on-board electrical activity such as vehicle commanding. In the past, payloads have been damaged by attempted deployment during geomagnetic storms or proton events. This leads us to our final class of impacts: space radiation hazards.

Radiation hazards

Despite all engineering efforts, satellites are still quite susceptible to the charged particle environment; in fact, with the newer microelectronics and lower voltages, it may be easier to cause electrical upsets than on the older, simpler vehicles. Furthermore, with the perceived lessening of the man-made nuclear threat, there has been a trend to build new satellites with less nuclear radiation hardening. This previously used nuclear hardening also protected the satellites from space environmental radiation hazards.

Both low and high earth-orbiting spacecraft and satellites are subject to a number of environmental radiation hazards, such as direct collisional damage and/or electrical upsets, caused by charged particles. These charged particles may be:

- Trapped in the Van Allen radiation belts.
- In directed motion during a geomagnetic storm.
- Protons/cosmic rays of direct solar or galactic origin.

Van Allen radiation belts

The Van Allen radiation belts are two concentric, donut-shaped regions of stable trapped charged particles that exist because the geomagnetic field near earth is strong and field lines are closed (fig. 3–11). The inner belt has a maximum proton density near 5,000 km above earth's surface (and contains mostly high-energy protons produced by cosmic ray collisions with earth's upper atmosphere). The outer belt has a maximum proton density near 16,000 to 20,000 km (and contains low to medium energy electrons and protons whose source is the influx of particles from the magnetotail during geomagnetic storms).

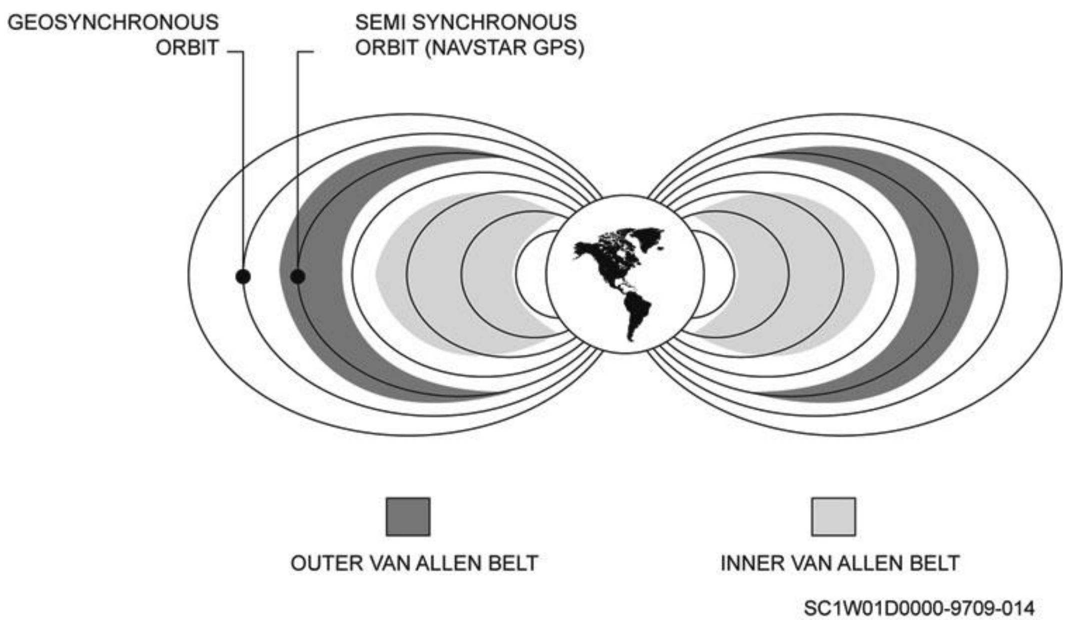

Figure 3–11. Van Allen radiation belts.

Geosynchronous orbit (35,782 km or 22,235 statute miles altitude) is commonly used for communication satellites. Unfortunately, it lies near the outer boundary of the outer belt and suffers whenever that boundary moves inward or outward. Semisynchronous orbit (which is used for GPS satellites) lies right in the middle of the outer belt (in a region called the ring current) and suffers from a variable, high-density particle environment.

Both orbits are particularly vulnerable to the directed motion of charged particles that occurs during geomagnetic storms, and can lead to both physical and electrical damage. It's not hard to imagine, that particle densities observed by satellite sensors can increase by a factor of 10 to 1,000 over a time period as short as a few tens of minutes. You may also recall from a previous lesson that geometric storms can lead to a satellite experiencing increased drag. As a result, both geosynchronous and semisynchronous orbits can lead to physical, electrical damage, as well as the drag to cause the loss of precise position data.

Geomagnetic storms

As mentioned earlier, it is often a surprise to most people that charged particles emitted by the sun cause problems primarily on the night side of earth! The reason is the arrival of solar particles causes a shock wave to ripple through the magnetosphere, magnetic field lines out in the magnetosphere's tail recombine, and previously stored particles are shot towards earth's night side hemisphere. Some of these particles stay near the plane of the equator and feed the ring current in the outer Van Allen belt, while others follow magnetic field lines up (and down) towards the auroral latitudes.

As for those particles that stay near the plane of the equator—the electrons and protons—have an opposite charge that tend to move in opposite directions when they reach the ring current (the electrons move toward the post-midnight sector, and the protons move toward the evening sector). Furthermore, the protons and electrons have about the same energy, but the electrons (since they are 1,800 times less massive) move 40 times faster.

Finally, the electrons are about 10–100 times more numerous than the protons. The result of all these factors is that electrons are much more effective at causing collisional damage and electrical charging than the protons. This fact explains why the preponderance of satellite problems occur in the midnight to dawn (0000–0600L) sector, while the evening (1800–0000L) sector is the second most preferred location for problems. This explanation is well supported by the large number of satellite anomalies observed in the midnight to dawn sector.

Now consider those charged particles that moved up (and down) magnetic field lines toward the auroral latitudes. These particles will penetrate to very low altitudes (as low as 35 km), and can cause collisional damage and electrical charging on high-inclination, low-altitude satellites or space shuttle missions.

One of the most common anomalies caused by the radiation hazards just covered is spacecraft or satellite electrical charging.

Spacecraft charging

Charging can be produced on the spacecraft by the following:

- An object's motion through a medium containing charged particles (called "wake charging"), which is a significant problem for large objects like the space shuttle.
- Directed particle bombardment, as occurs during geomagnetic storms, proton events, and meteor showers.
- Solar illumination, which causes electrons to escape from an object's surface.

The impact of each phenomenon is strongly influenced by variations in an object's shape and the materials used in its construction.

Charging impacts

An electrical charge can be deposited either on the surface or deep within an object. Solar illumination and wake charging are surface charging phenomena. For directed particle bombardment, the higher the energy of the particles, the deeper the charge can be placed. In the case of meteor showers, the high-speed impact of the meteor with a spacecraft is similar to the speed of a .22 caliber bullet.

This creates a sudden electrical discharge, which can fry electrical components on spacecraft. Normally electrical charging will not (in itself) cause an electrical upset or damage. It will deposit an electrostatic charge, which will stay on the vehicle (for perhaps many hours) until some triggering mechanism causes a discharge or arcing. Such mechanisms include the following:

- A change in particle environment.
- A change in solar illumination (like moving from eclipse to sunlit).
- On-board vehicle activity or commanding.

Discharging impacts

Generally, an electrostatic discharge can produce spurious circuit switching; degradation or failure of electronic components, thermal coatings, and solar cells; or false sensor readings. In extreme cases, a satellite's life span can be significantly reduced, necessitating an unplanned launch of a replacement satellite.

Warnings and precautions

Warnings of environmental conditions conducive to spacecraft charging allow operators to reschedule vehicle commanding, reduce on-board activity, delay satellite launches and deployments, or reorient a spacecraft to protect it from particle bombardment.

Should an anomaly occur, an environmental post-analysis can help operators determine whether the environment contributed to it and the satellite function can be safely reactivated or reset, or whether engineers need to be called out to investigate the incident. An accurate assessment can reduce downtime by several days. Charging occurs primarily when solar and geomagnetic activities are high, and with geosynchronous or polar-orbiting satellites.

Single event upsets

Single event upsets (SEU) are random, unpredictable events which can occur at any time during the 11–year solar cycle. SEUs are most common near solar minimum, when the interplanetary magnetic field emanating from the sun is weak and unable to provide earth much shielding from cosmic rays originating outside the solar system.

Very high-energy protons or ions (either from solar flares or the inner Van Allen belt) or cosmic rays (either from the largest solar flares or from galactic sources outside our solar system) are capable of penetrating completely through a satellite. As they pass through, they will ionize particles deep inside the satellite. As a result, an SEU can be caused by a single proton or cosmic ray which can (by itself) deposit enough charge to cause an electrical upset (circuit switch, spurious command, or memory change or loss) or serious physical damage to on-board computers or other components.

Disorientation

Disorientation occurs primarily when solar activity is high and impacts geosynchronous or polar orbiting satellites. Essentially, high-energy protons and cosmic rays cause problems with a satellite's orientation when they collide with one of its star sensors. The bright spot produced on the sensor may be falsely interpreted as a star. When computer software fails to find this false star in its star catalogue or incorrectly identifies it, the satellite can lose attitude lock with respect to earth.

Upon disorientation, directional communications antenna, sensors, and solar cell panels fail to see their intended targets. The result may be loss of communication with the satellite; loss of satellite power; and, in extreme cases, loss of the satellite due to drained batteries.

Examples of impacts

To make things worse, all the solar and geophysical system impacts previously mentioned do not occur one at a time. The table below lists a sampling of actual system impacts experienced during a major solar flare and geomagnetic storm in March 1989. Notice that DOD systems are not the only ones affected. For example, system impacts from geomagnetic storms can include induced electrical currents in power lines, which can cause transformer failures and power outages, and magnetic field variations, which can lead to compass errors and interfere with geological surveys.

Examples of System Impacts Caused by the March 1989 Solar Flare and Geomagnetic Storm
Worldwide HF radio blackouts and SATCOM interference.
AF satellite control network interference.
Long Range Navigation (LORAN) system problems.
Missile warning radar interference at six radar sites.
Lost weather satellite communications and imagery.
Memory upsets on various communications satellites.
Permanent loss of half the command circuitry on a Japanese communications satellite.
7 commercial satellites required 177 manual operator interventions to maintain orientation.
9-hour power outage in Canada left 6 million people without power and caused a power grid collapse which almost spread into the northeastern US.
USSPACECOM lost track of over 1,300 space objects.
Compass alignment errors.

Self-Test Questions

After you complete these questions, you may check your answers at the end of the unit.

416. Impacts on radio-wave signals

1. What determines the space environmental effects on radio-wave signals?

2. Name one space environmental effect on high-frequency communications.

3. How can space environmental effects impact satellite communications?

4. What causes space environmental effects to impact satellite communications?

5. How can space environmental effects impact GPS (single frequency) navigation signals?

6. What causes space environmental effects to impact single frequency GPSs?

7. How can space environmental effects impact GPS (dual frequency) navigation signals?

8. What causes space environmental effects to impact dual frequency GPSs?

9. How is a GPS guided PGM affected by a large electron density gradient within the ionosphere?

417. Impacts on system hardware

1. Explain how an orbiting satellite is directly impacted by space environmental affects.

2. How can space environmental effects cause satellites to lose altitude?

3. What type of communication system experiences direct radio frequency interference?

418. Operational impacts

1. At what speed do solar flare-enhanced X-rays, EUV, and radio waves reach earth?

2. What are two examples of high-energy particles that result from the occurrence of a solar flare?

3. Why is the prediction of solar proton and cosmic ray activity that affects earth so difficult?

4. Over what regions of earth are the major impacts of proton activity felt?

5. How long can ionospheric storms that are caused by electron and proton particle streams last?

6. What is a short-wave fade?

7. What is the cause of a short-wave fade?

8. What is a radio energy burst?

9. What is the cause of an absorption event?

10. Describe ionospheric scintillation.

11. How can scintillation affect a GPS satellite?

12. What effect can the TEC along the path of a GPS signal have?

13. What sensors detect scintillation?

14. Where in the atmosphere, statistically, is scintillation most severe?

15. What is radar aurora?

16. What effect can free electrons in the ionosphere have on missile detection and space track radars?

17. State the consequences of satellite drag.

18. List the two space environmental parameters used by current models to predict the orbits of space objects.

19. Name the two observed impacts of geomagnetic storms on space track radars.

20. What is a result of the protective shielding around a payload (satellite) being jettisoned too early?

21. What impact do the Van Allen radiation belts have on geosynchronous and semisynchronous orbits?

22. What can produce spacecraft charging?

23. What are some impacts of spacecraft electrostatic discharging?

24. What is a single event upset?

25. What causes satellite disorientation?

26. What occurs during satellite disorientation?

3–2. Space Environmental Operations and Support

Solar anomalies that occur in space weather have an adverse impact on DOD operations. The threat of space weather affecting national security is so serious that each space, defense, and missile wing has 24–hour per day support to ensure mission success. Additionally, Air Force Weather Agency Space Weather Operation Center holds an enormous responsibility to ensure increased readiness against space weather and its impacts. While you may find the level of support and products overwhelming, suffice it to say that the threat of space weather affecting national security is real. Let's begin by taking a look at the space environmental units and the dedicated support they receive.

419. Air Force Space Command weather and space environmental units

Air Force-wide, five major space agencies, each with differing responsibilities, are charged with missions ranging from strategic defense to space exploration. Dedicated support is required to guarantee mission success. Without the dedicated support these agencies receive, national security will undoubtedly suffer.

21st Operations Support Squadron Weather Flight

The Weather Flight within the 21st Operations Support Squadron (OSS), located at Peterson AFB, Colorado, provides operational and staff support to the 21st Space Wing, Cheyenne Mountain AFS, North American Aerospace Defense Command (NORAD), and United States Northern Command (US NORTHCOM). The flight is responsible for coordinating weather support for the Air Force's most diverse wing, with 16 units operating 12 unique weapons systems, in 24 separate locations, based in five countries.

The Mission Weather Operations Element provides resource protection for Peterson AFB and Cheyenne Mountain AFS, aircrew briefings for four tenant units assigned to Peterson AFB, flying C–21, C–130, and UV–18 aircraft, as well as numerous transient aircraft flying in and out of the second busiest DV airfield in the DOD. The NORAD-NORTHCOM Weather Operations Element operates 24-hours, 7-days-a-week, and provides both terrestrial weather and space environmental support to the NORAD-NORTHCOM Command Center which includes monitoring the numerous environmental phenomena that could affect space operations.

30th Weather Squadron

30 Weather Squadron (WS), Vandenberg AFB, California, provides operational weather support to include observations, forecasts, and advisories and warnings, to HQ 14th Air Force, 30th Space Wing, and tenant units. The squadron provides staff support to the 30th Space Wing and provides weather services for all DOD and civilian space and ballistic missile launches and aircraft operations on the Western Range 24 hours per day.

45th Weather Squadron

45 WS, Patrick AFB, Florida, provides weather observations, forecasts, advisories and warnings, and staff support to the 45th Space Wing, NASA, and tenant units. They provide weather services for all DOD and civilian space and ballistic missile launch operations on the Eastern Range, Cape Canaveral Air Station, space shuttle operations at Kennedy Space Center and overseas abort landing sites, cross-country space shuttle orbiter ferry flights, and Patrick AFB flight operations 24 hours per day.

90th Operations Support Squadron Weather Flight

90 OSS/OSW, F. E. Warren AFB, Wyoming, provides weather services to the 90th Missile Wing (Minuteman III and Peacekeeper missiles) with weather warnings, watches, advisories, and forecast support. Tailored forecasts and briefings are provided for missile movements, maintenance activities, and for the 41st Rescue Flight (UH–1) helicopter operations. The weather flight provides support to the 153rd Airlift Wing Reserve (C–130 aircraft) and to the Army Aviation Support Facility (AASF) of the Wyoming Army National Guard (C–12 and UH–1 aircraft) located at the Cheyenne Municipal Airport. Staff weather support is also provided to HQ 20th Air Force.

341st Operations Support Squadron Weather Flight

341 OSS/OSW, Malmstrom AFB, Montana, provides weather services to the 341st Missile Wing (Minuteman III missiles) with weather warnings, watches, advisories, and forecast support. Tailored forecasts and briefings are provided for missile movements, maintenance activities, and for the 40th Helicopter Squadron (UH–1) helicopter operations. Support is provided on an as-requested basis to other government agencies such as the US Forest Service and the National Weather Service.

420. 2d Weather Squadron Space Weather Operations Center

The 2d Weather Squadron Space Weather Operations Center provides space environmental forecasts, warnings, and anomaly assessments to enhance the capability of DOD forces. They operate the worldwide Solar Electro-optical Network (SEON) and a product development center, 24 hours per day, and are responsible for collection, analysis, and dissemination of space environmental information required by high-priority space operations and systems for NORAD, NORTHCOM, AFSPC, other DOD agencies, and the intelligence community. SEON is the only network of its kind in the world that provides real-time, 24–hour observation and notification of solar radio and optical events.

The 2d Weather Squadron Space Weather Operations Center is the focal point for weather and space environmental operations supporting AFSPC mission areas. This operations center develops and implements operations policy, standards, and procedures. They also evaluate unit technical forecasting performance and advise the commander of capabilities.

421. Obtaining space environmental products and services

So, where do you go for assistance, and what kinds of products and services are available to help you anticipate, cope with, or even take advantage of problems like we’ve just looked at? Government and military space environmental resources are available to support your mission, including space environmental climatology, forecasts, and analyses.

Space environmental data and services

In the US, space environmental support is provided by two agencies. Non-DOD federal customers (e.g., NASA and FAA) and civilian customers (e.g., power companies, researchers, and ham radio operators) receive support from the Department of Commerce; specifically the National Oceanic and Atmospheric Administration's (NOAA) Space Weather Prediction Center (SWPC) in Boulder, Colorado.

Military customers receive support from the 2d Weather Squadron Space Weather Operations Center. The branch is the DOD's sole space environmental forecast and warning facility.

The two forecast centers work in close cooperation; in fact, USAF personnel are assigned to the SWPC center in Boulder. The centers operate 24-hour-day, 7-days-week; share all space environmental data and observations each collects; coordinate on the primary forecast parameters and several products; and act as a partial backup for each other.

Data collection

Both the 2d Weather Squadron Space Weather Operations Center and SWPC collect space environmental data from worldwide networks of solar, ionospheric, and geophysical sensors. While these networks are global, the number of data sensors (roughly 30 space-based and 70 ground-based) pales in comparison to the sheer volume of space that needs to be monitored.

The SWPC receives energetic particle and other geophysical data from the GOES spacecraft. 2d Weather Squadron Space Weather Operations Center receives similar data from low-altitude, high-inclination DMSP spacecraft and other geosynchronous military satellites. Both centers receive ground-based magnetometer data collected by the US Geological Service and ionospheric data collected by a mix of civilian, contract, and military sensors. Solar optical and radio observatories provide extensive information on solar features and activity.

All this observational data is quickly crossfed between the two centers and is then carefully analyzed or processed through sophisticated computer models and used to produce alerts, analyses, forecasts, and environmental parameter specifications. The civilian and military forecasters confer throughout the day while preparing their forecasts. As a result, there is full agreement on most forecast parameters; plus some routine, general products are even issued jointly. Most products, however, are issued by one center or the other, so they can be tailored to the specific needs of the intended customers.

Services

Services provided by the 2d Weather Squadron Space Weather Operation Center include rapid warnings when a solar or geophysical event is observed as well as short- or long-range forecasts of space environmental conditions, either in general terms or very specific numerical data or indices. These products can be either standardized or tailored to the particular needs of an individual customer, and either of an ongoing or one-time nature. The branch also performs post-analysis assessments on specific radar, communications, or satellite anomalies, to help operators determine whether the environment contributed to a problem they experienced or whether the cause lies elsewhere.

Of particular interest is the USAF-operated network of five solar optical and radio observatories, which permit near continuous coverage of the sun. These observatories are unique because they provide real-time coverage of solar features and activity. Significant solar events are reported to the forecast centers within two minutes of observation, which allows the forecast centers in turn to issue alerts of potential system impacts to customers within an additional five minutes.

Publication

The publication, Air Force Space Command Pamphlet (AFSPCPAM) 15–2, *Space Environmental Impacts on DOD Operations*, describes the basic types of solar and geophysical activity that can influence the near-earth environment; their impacts on DOD radar, communications, and space systems; and the types of customer products and services available. The pamphlet also includes information on how space environmental data are collected and a comprehensive glossary of solar and geophysical terms.

422. Routine products and advisories/warnings

Products produced by AFWA are available through a variety of means such as the Joint Air Force and Army Weather Information Network (JAAWIN).

Joint Air Force and Army weather information network

The JAAWIN is an Air Force Weather Web site maintained by AFWA. The Web site allows weather personnel to access a large variety of computer modeled and centrally produced weather data, including space bulletins and graphic products. The list of space products available on JAAWIN is particularly extensive and allows users to obtain solar and space anomaly information for any location in the world. In the sections that follow, you'll learn about some of the more commonly used products.

High frequency radio propagation reports

Ionospheric conditions that impact HF radio propagation are continually updated on JAAWIN. The product is presented in graphic format with an easily understood legend.

Description

The graphic format depicts HF communication propagation which describes conditions on a global scale, both observed and forecasted for the next six hours. Figure 3–12 depicts an example of this product. On this particular day, a narrow swath of marginal ionospheric activity was forecasted to affect the high latitudes of the Northern Hemisphere.

Application

Ensure that you brief aircrews, tactical forces, mission planners, and HF airways station operators on expected HF conditions.

Short-wave fade advisory

WOXX50 KGWC (fig. 3–13) is an example of a short-wave fade advisory.

Description

This real-time advisory provides notice that certain HF communication frequencies may become unusable during *daylight* conditions due to a sudden burst in the sun's X-ray radiation that modifies the ionosphere. The advisory specifies the frequencies affected and for what amount of time the conditions will exist. The product is issued within minutes of the burst.

Application

Inform aircrews, tactical forces, and HF airways station operators of degraded conditions.

Polar cap absorption event warning report

WOXX50 KGWC (fig. 3–14) is one example of a polar cap absorption event warning report we encounter.

Description

This real-time warning provides notice that HF communications north of about 50°N latitude (or south of 50°S) may be seriously degraded or impossible to use (black-out) due to a burst of protons from the sun that modify the ionosphere. The condition may last for several hours (or days). A final bulletin is issued when significantly degraded conditions no longer exist. This effect occurs at high latitudes because earth's magnetic field deflects/funnels the protons into this region.

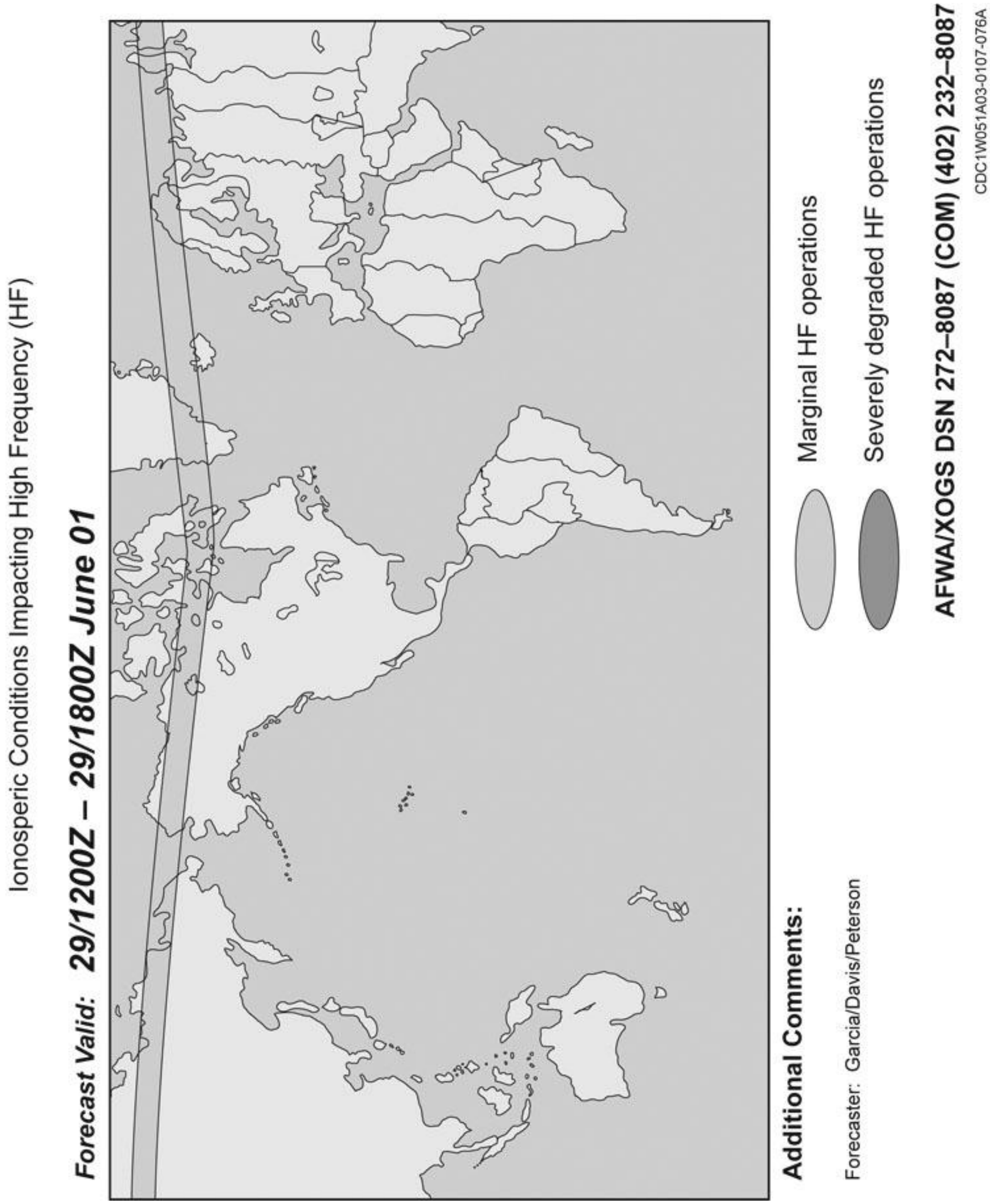

Figure 3–12. HF conditions impact product.

Application

Inform aircrews, tactical forces, mission planners, and HF airways station operators of degraded conditions.

Geomagnetic event warning report

WOXX54 KGWC (fig. 3–15) is an example of a geomagnetic event warning report we work with.

WOXX50 KGWC 200642
SUBJECT: AFWA EVENT WARNING REPORT ISSUED AT 0642Z 20 JAN 2005
PART A. SHORT WAVE FADE EVENT:
A SOLAR X-RAY FLARE OCCURRED AT 0642Z 20 JAN 2005 AND IS CAUSING DISRUPTIONS IN HF PROPAGATION. ANOTHER MESSAGE WILL BE ISSUED WITH MORE INFORMATION WHEN X-RAY LEVELS PEAK.
PART B.
THIS EVENT WILL AFFECT HIGH FREQUENCY RADIO COMMUNICATIONS AND INTERCEPT CAPABILITY IN DAYLIT AREAS OF THE GLOBE. SUCH AN EVENT LASTS UP TO TWO HOURS.
PART C. REMARKS:
ISSUED BY THE AIR FORCE WEATHER AGENCY, OFFUTT AFB, NE. IF YOU HAVE QUESTIONS OR REQUIRE FURTHER INFORMATION, CALL THE DUTY FORECASTER AT DSN 272-8087, COMMERCIAL 402-232-8087. INFORMATION CAN ALSO BE OBTAINED AT https://weather.AFWA.af.mil UNDER THE SPACE WEATHER LINK.
FORECASTERS: Otero/ Bauman

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Figure 3–13. Short-wave fade advisory.

FOXX50 KGWC 150701
SUBJECT: AFWA EVENT WARNING REPORT ISSUED AT 0701Z 15 JAN 2005
PART A. POLAR CAP ABSORPTION EVENT FORECAST:
A MAJOR SOLAR EVENT OCCURRED NEAR 0602Z 15 JAN 2005 AND IS EXPECTED TO CAUSE A POLAR CAP ABSORPTION EVENT. THE PCA IS FORECAST TO BEGIN NEAR 1500Z 15 JAN 2005 AND LAST UNTIL 0000Z 18 JAN 2005. MAXIMUM DAYLIGHT ABSORPTION IS EXPECTED TO BE ABOUT 5 DBS, WHILE MAXIMUM NIGHTTIME ABSORTPION WILL BE ABOUT 1 DBS. NO FURTHER ADVISORIES WILL BE ISSUED UNTIL THE ONSET OF EVENT IS OBSERVED, THE FORECAST IS AMENDED, OR THE FORECAST IS CANCELED.
PART B.
HF PATHS OPERATING POLEWARD OF ABOUT 55 DEGREES LATITUDE MAY EXPERIENCE SIGNAL ABSORPTION, WITH GREATEST ABSORPTION OCCURRING IN THE DAYLIGHT HOURS. LF/VLF SYSTEMS OPERATING IN OR TROUGH THE POLAR CAP MAY EXPERIENCE PHASE ADVANCES.
PART C. REMARKS:
ISSUED BY THE AIR FORCE WEATHER AGENCY, OFFUTT AFB, NE.
IF YOU HAVE QUESTIONS OR REQUIRE FURTHER INFORMATION, CALL THE DUTY FORECASTER AT DSN 272-8087, COMMERCIAL 402-232-8087.
INFORMATION CAN ALSO BE OBTAINED AT https://weather.AFWA.af.mil UNDER THE SPACE WEATHER LINK.
FORECASTERS: Ybarra/ Otero

CDC1W051A03-1010-119

Figure 3–14. Polar cap absorption event.

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WOXX54 KGWC 261705
SUBJECT: AFWA EVENT WARNING REPORT ISSUED AT 1705Z 26 JAN 2005
PART A. GEOMAGNETIC EVENT FORECAST:
 THE GEOMAGNETIC FIELD IS AT QUIET LEVELS.
 THE 3-HOUR AP WAS 1 AND THE 24-HOUR AP WAS 2 AT 1705Z 26 JAN 2005.
 A GEOMAGNETIC DISTURBANCE OF MAJOR STORM LEVELS (BASED ON THE 24-HOUR
 AP) IS EXPECTED TO BEGIN DURING THE NEXT 24 HOURS.
 NO FURTHER ADVISORIES WILL BE ISSUED UNTIL EVENT ONSET OF EVENT IS
 OBSERVED, THE FORECAST IS AMENDED, OR THE FORECAST IS CANCELED.
PART B.
 POSSIBLE EFFECTS ARE SATELLITE DRAG ON LOW EARTH ORBIT SATELLITES,
 SATCOM SCINTILLATION, HF RADIO COMMUNICATIONS INTERFERENCE OR LAUNCH
 TRAJECTORY ERRORS.
PART C. REMARKS:
 ISSUED BY THE AIR FORCE WEATHER AGENCY, OFFUTT AFB, NE. IF YOU HAVE
 QUESTIONS OR REQUIRE FURTHER INFORMATION, CALL THE DUTY FORECASTER AT
 DSN 272-8087, COMMERCIAL 402-232-8087. INFORMATION CAN ALSO BE
 OBTAINED AT https://weather.AFWA.af.mil UNDER THE SPACE WEATHER LINK.
FORECASTERS: Harper/ Davis
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CDC1W051A03-1010-120

Figure 3–15. Geomagnetic event warning report.

Description

This real-time warning provides notice that a significant enhancement in the magnetosphere's electric-current network (geomagnetic storming) is either expected to occur or has already started. The storming can cause significant changes and irregularities in the ionosphere, particularly at middle and high latitudes.

Application

Inform aircrews, tactical forces, mission planners, and HF airways station operators of degraded HF communication conditions. Inform SATCOM ground operators at high-latitudes that UHF and SHF radio-wave signals may be intermittently disrupted. Inform operators of ground-based space tracking radars operating at high latitudes of potential radar clutter or unusual signal bending.

NOTE: The "Ap" referred to is an index that describes how much the magnetosphere's electric-current network is enhanced and disturbed. Larger Ap values mean larger disturbances that correspond to greater irregularity in the ionosphere (among other effects). A value of 50 is considered to be "major storming," and 100 is considered "severe storming." The 3-hr Ap refers to the current condition, and the 24-hr Ap refers to the average over the last 24 hours.

Solar radio burst advisory

NWXX50 KGWC (fig. 3–16) is an example of a solar radio burst advisory with which we deal.

NWXX50 KGWC 091713

A SIGNIFICANT RADIO BURST IS IN PROGRESS. THE FOLLOWING
SITES MAY EXPERIENCE INTERFERENCE:
ANTIGUA (DET 1, 45 RANS) , ASCENSION(DET 2, 45 RANS),
BUCKLEY(2 SPCS), EGLIN(20 SPSS), FYLINGDALE (OL-FY)
HOLLOMAN(4 SPCS), KAENA PT (DET 6, 750 SGP), KAPAUN (3 SPCS),
MILLSTONE (MIT/LIN LABS) , OFFUTT (1000 SOG) , ONIZUKA (750 SGP) ,
OTIS (6 SWS)
99999

OM

SC1W01D000-9909-070

Figure 3–16. Radio burst advisory.

Description

This real-time advisory provides notice that a burst of radio-wave radiation has been emitted by the sun that could produce direct radio-wave interference at frequencies ranging from about 200 MHz–16 GHz (specific frequency is included). Product is issued within minutes of the burst.

Application

Notify SATCOM ground operators (communications squadron or equivalent) and space-tracking operators of potential interference.

Energetic particle event warning report

WOXX53 KGWC (fig. 3–17) is an example of an energetic particle event warning report.

Description

This real-time warning provides notice that extremely energetic charged particles may begin to enter or have arrived at the near-earth environment.

Application

While this product is primarily used for satellite operations applications, high-altitude aircraft (mid-stratosphere) traversing the polar latitudes may be exposed to enhanced radiation levels. This phenomenon also poses a risk to shuttle astronauts performing “space-walks.”

WOXX53 KGWC 150041
SUBJECT: 2WS EVENT WARNING REPORT ISSUED AT 0041Z 15 JAN 2005
PART A. ENERGETIC PARTICLE EVENT ALERT:
A MAJOR SOLAR EVENT OCCURRED NEAR 0041Z 15 JAN 2005. PRELIMINARY DATA INDICATE THE EVENT MAY CAUSE A NEAR-EARTH ENHANCEMENT IN HIGH ENERGY PARTICLE FLUX.
PART B.
AN ADVISORY WILL BE ISSUED WITHIN 30 MINUTES OF THE SOLAR FLARE MAXIMUM TO CONFIRM OR CANCEL THIS ALERT.
PART C. REMARKS:
ISSUED BY THE AIR FORCE WEATHER AGENCY, OFFUTT AFB, NE.
IF YOU HAVE QUESTIONS OR REQUIRE FURTHER INFORMATION, CALL THE DUTY FORECASTER AT DSN 272-8087, COMMERCIAL 402-232-8087.
INFORMATION CAN ALSO BE OBTAINED AT https://weather.AFWA.af.mil UNDER THE SPACE WEATHER LINK.
FORECASTERS: Deaton/ Stewart

SC1W01D000-9909-073

Figure 3–17. Energetic particle event warning report.

Self-Test Questions

After you complete these questions, you may check your answers at the end of the unit.

419. Air Force Space Command weather and space environmental units

1. Identify the AFSPC unit that provides operational and staff support to Cheyenne Mountain.

2. Name the AFSPC unit that provides weather services for all DOD and civilian space and ballistic missile launches at the Western Range.

3. Which AFSPC unit provides weather services for all DOD and civilian space and ballistic missile launches at the Eastern Range?

420. 2d Weather Squadron Space Weather Operations Center

1. List two responsibilities of the 2d Weather Squadron Space Weather Operations Center.

2. Who is the focal point for weather and space environmental operations supporting AFSPC mission areas?

421. Obtaining space environmental products and services

1. What two agencies provide space environmental support in the United States?

2. From what agency do military customers receive space environmental support?

3. What space vehicle provides energetic and geophysical data to SWPC?

4. What happens to space environmental observational data after the 2d Weather Squadron Space Weather Operations Center or SWPC collect it?

5. Explain the services provided by 2d Weather Squadron Space Weather Operations Center Space Weather Operations Center.

6. How many solar optical and radio observatories does the USAF operate?

422. Routine products and advisories/warnings

1. Explain what an HF propagation product describes.

2. What does a short-wave fade advisory describe?

3. What does a polar cap absorption event warning report describe?

4. What is the application for the WOXX50 KGWC bulletin?

5. Which bulletin describes that a significant enhancement in the magnetosphere's electric-current network (geomagnetic storming) has already started?

6. What is an application for the WOXX54 KGWC bulletin?

7. Which bulletin would you use to inform you that a burst of radio-wave radiation has been emitted by the sun and could produce radio-wave interference in a frequency range of 200 MHz–16 GHz?

8. What is the primary application for an energetic particle event warning report?

Answers to Self-Test Questions

416

1. Signal frequency.
2. Controllability problems or disruption problems.
3. By intermittently interrupting SATCOM signals.
4. As UHF radio signals move through the ionosphere on their way to or from a satellite, extremely large electron density gradients within the ionosphere distort the signal sufficiently such that the signal is unrecognizable to a receiver.
5. The performance (positional accuracy) of GPS single-frequency navigation systems is degraded.
6. As a GPS signal moves through the ionosphere on its way down from a GPS satellite, the electrons slow down the signal. This slowing effect increases as the total number of electrons the signal passes through increases. Typically, four GPS signals from four satellites are used to compute a position. Since the total number of electrons each GPS signal moves through is different, the receiver computes a position that is not exact.
7. GPS dual-frequency receivers intermittently lose lock of GPS signals causing loss of positional accuracy.
8. Extremely large density gradients in the ionosphere distort the signal sufficiently such that the signal is unrecognizable to a receiver.
9. Positional accuracy and identification of specific objects are degraded.

417

1. Damage to on-board electronic components, false readings in satellite sensors, and anomalous behavior in satellite subsystems.
2. Heating of the thermosphere by the sun's ultraviolet radiation or by enhanced electric currents in the magnetosphere expands atoms and molecules from lower altitudes upward into the orbit altitudes of satellites. These atoms and molecules increase frictional drag thus slowing their velocity and causing the satellites or space objects to lose altitude.
3. Satellite communications.

418

1. Speed of light (3×10^8 meters per second, or in about 8 minutes).
2. Protons and cosmic rays.
3. Not all solar flares produce high energy particles, the distance between earth and the sun is 93 million miles, and earth is a small target.
4. Over the polar caps.
5. From a few hours to several days.
6. The absorption of HF radio waves by the ionosphere which results in radio signals not reaching their intended destination or fading.
7. HF radio signals being absorbed in the D-layer of the ionosphere and not reaching the F-layer where they can be refracted back toward earth.
8. A burst of energy from a solar flare on the sun that reaches earth's upper atmosphere.
9. Enhanced ionization of atmospheric atoms and molecules caused by particle bombardment from space.

10. The rapid, random variation in signal amplitude, phase, and/or polarization caused by small-scale irregularities in the electron density along a signal's path. Scintillation is similar to the human eye observing the apparent twinkling effect when viewing a star or the heat shimmer over a hot road.
11. It can cause a GPS receiver to lose signal lock with a particular satellite.
12. It can introduce a positioning error.
13. Currently, C/NOFS allows the forecasting of scintillations, but no actual sensors currently exist to detect real-time scintillation.
14. At low latitudes.
15. Abnormal radar signal backscatter on poleward looking radars.
16. They cause them to be bent or refracted, as well as slowed somewhat from the speed of light.
17. Inaccurate satellite locations hinder rapid acquisition of SATCOM links for commanding or data transmission; costly orbit maintenance maneuvers become necessary; de-orbit predictions become unreliable.
18. F10 solar index and the geomagnetic Ap index.
19. Bearing and range errors and atmospheric drag.
20. The payload is exposed to excessive frictional heating.
21. They affect orbiting spacecraft by exposing them to charged particles that can cause drag and electrical damage.
22. A spacecraft's motion through a medium containing charged particles, directed particle bombardment, and solar illumination.
23. Spurious circuit switching; degradation or failure of electronic components, thermal coatings, and solar cells; or false sensor readings.
24. An SEU is a random, unpredictable event and can occur any time during the 11–year solar cycle. Essentially, an SEU is caused by a single proton or cosmic ray depositing enough charge to cause an electrical upset in a circuit switch, spurious command or memory change or loss. This SEU can also cause serious physical damage to onboard computers or other components.
25. Disorientation occurs primarily when solar activity is high and with geosynchronous or polar orbiting satellites. Essentially, high-energy protons and cosmic rays cause problems with a satellite's orientation when they collide with one of its star sensors. The bright spot produced on the sensor may be falsely interpreted as a star. When computer software fails to find this false star in its star catalogue or incorrectly identifies it, the satellite can lose attitude lock with respect to earth.
26. Directional communications antenna, sensors, and solar cell panels fail to see their intended targets. The result may be loss of communication with the satellite; loss of satellite power; and, in extreme cases, loss of the satellite due to drained batteries.

419

1. 21st OSS Weather Flight.
2. 30th Weather Squadron.
3. 45th Weather Squadron.

420

1. Two of any of the following: provides space environmental forecasts, warnings, and anomaly assessments to enhance the capability of DOD forces; operate the worldwide Solar Electro-optical Network (SEON) and a product development center, 24 hours per day, and are responsible for collection, analysis, and dissemination of space environmental information required by high-priority space operations and systems for NORAD, NORTHCOM, AFSPC, other DOD agencies, and the intelligence community. SEON is the only network of its kind in the world that provides real-time, 24–hour observation and notification of solar radio and optical events.
2. 2d Weather Squadron Space Weather Operations Center.

421

1. NOAA's Space Weather Prediction Center (SWPC) in Boulder, Colorado and the 2d Weather Squadron Space Weather Operations Center.

2. 2d Weather Squadron Space Weather Operations Center.
3. GOES.
4. The data is quickly cross-fed between the two centers then analyzed and processed and used to produce alerts, analyses, forecasts, and environmental parameter specifications.
5. Rapid warnings when a solar or geophysical event is observed as well as short-range and long-range forecasts of space environmental conditions. The branch also performs post-analysis assessments on specific radar, communications, or satellite anomalies, to help operators determine whether the environment contributed to a problem they experienced or whether the cause lies elsewhere.
6. Five.

422

1. HF communication propagation conditions on a global scale, both observed and forecasted for the next six hours.
2. The HF frequencies that may become unusable during daylight conditions due to a sudden burst in the sun's X-ray radiation that modifies the ionosphere.
3. That HF communications north of about 50°N latitude and south of 50°S latitude may be seriously degraded or impossible due to a burst of protons from the sun that modify the ionosphere.
4. Informing aircrews, tactical forces, and HF airways station operators of degraded conditions.
5. WOXX54 KGWC, geomagnetic event warning report.
6. Informing aircrews, tactical forces, mission planners, and HF airways operators of degraded HF communications conditions.
7. NWXX50 KGWC, solar radio burst advisory.
8. Satellite operations.

Unit Review Exercises

Note to Student: Consider all choices carefully, select the *best* answer to each question, and *circle* the corresponding letter. When you have completed all unit review exercises, transfer your answers to the Field Scoring Answer Sheet.

39. (416) What is the impact of electron density gradients within the ionosphere on single frequency or dual frequency global positioning system (GPS) navigation?
    a. Positional readouts are delayed by 30 minutes or more.
    b. Positions are not able to be calculated.
    c. Positional accuracy is degraded.
    d. Positional accuracy is improved.

40. (417) When a satellite orbiting the magnetosphere is bombarded by energetic protons from the sun, the satellite's star sensor
    a. falsely interprets light flashes caused by collisions as stars and the satellite experiences decreased drag.
    b. experiences "white out" by light flashes caused by collisions and the satellite loses attitude control.
    c. falsely interprets light flashes caused by collisions as stars and the satellite loses attitude control.
    d. experiences "white out" by light flashes caused by collisions and the satellite experiences decreased drag.

41. (417) What impact will atoms and molecules from lower altitudes, expanding upward into the orbit altitudes of satellites, have on the spacecraft?
    a. On-board sensors will malfunction.
    b. The satellite will become disoriented.
    c. On-board electrical systems will short-circuit.
    d. Frictional drag will increase, possibly causing a loss of altitude.

42. (417) What is the impact of electrically charged particles from the sun that penetrate into the mid to upper stratosphere?
    a. Satellite communication (SATCOM) signal interference.
    b. Radiation hazard to aircrews of high altitude flight.
    c. Excessive frictional drag on high altitude aircraft.
    d. High-frequency (HF) radio-wave interference.

43. (418) How long after a solar flare does it usually take for low to medium energy particles to arrive at earth?
    a. 12 to 36 hours
    b. 2 to 4 days.
    c. 5 to 7 days.
    d. 8 to 10 days.

44. (418) What term is used to describe rapid, random variation in signal amplitude, phase, and/or polarization caused by small-scale irregularities in the electron density along a signal's path?
    a. Radio burst.
    b. Scintillation.
    c. Short-wave fade.
    d. Auroral zone absorption event.

45. (418) During a 24-hour day, when do the majority of satellite problems occur due to geomagnetic storms?
    a. Midday to sunset.
    b. Sunrise to midday.
    c. Midnight to dawn.
    d. Sunset to midnight.

46. (419) Which Air Force Space Command (AFSPC) weather and environmental unit provides weather services for all Department of Defense (DOD) and civilian space and ballistic missile launch operations on the Western Range?
    a. 30th Weather Squadron.
    b. 45th Weather Squadron.
    c. 90th Operations Support Squadron Weather Flight.
    d. 2d Weather Squadron Space Weather Operations Center.

47. (420) Which organization operates the worldwide Solar Electro-optical Network (SEON)?
    a. 30th Weather Squadron.
    b. 45th Weather Squadron.
    c. 90th Operations Support Squadron Weather Flight.
    d. 2d Weather Squadron Space Weather Operations Center.

48. (421) Which agency collects data and issues space environmental forecasts for non-Department of Defense (DOD) agencies?
    a. Federal Aviation Administration (FAA).
    b. 21st Operations Support Squadron Weather Flight.
    c. National Aeronautics and Space Administration (NASA).
    d. National Oceanic and Atmospheric Administration (NOAA).

49. (421) The Space Weather Prediction Center receives energetic particle and other geophysical data from the
    a. Geosynchronous operational environmental satellite (GOES) spacecraft.
    b. Defense meteorological Satellite Program (DMSP) spacecraft.
    c. National Aeronautics and Space Administration (NASA).
    d. United States Geological Service.

50. (422) Which bulletin, produced by Air Force Weather Agency (AFWA) Space Weather Operations Center, provides notice that certain high-frequency (HF) communications frequencies may become unusable during daylight conditions due to a sudden burst in the sun's X-ray radiation?
a. FXXN12 KGWC.
b. WOXX50 KGWC.
c. FOXX50 KGWC.
d. WOXX54 KGWC.

Student Notes

Glossary

Terms

3–D plasma—A sensor system that is part of the WIND solar-sensing satellite. The device is designed to measure interplanetary ions and electrons, including energy contained in the solar wind.

absorption limited frequency—This is the lowest frequency for reliable radio communications by the ionosphere. It is significant only on daylight sectors of circuits.

absorption—The loss of energy from a radio wave. Absorption occurs mostly in the D region.

active region—A region on the sun that is active. Usually an active region incorporates sunspots, plages, and filaments. Active regions contain strong magnetic fields. Flares occur within active regions.

active—When referring to the sun, the term means "changing." Solar activity is the changing appearance of the sun.

albedo—The percentage of reflected incident energy.

Ap index—The planetary index for measuring the strength of a disturbance in earth's magnetic field. Defined over a period from a set of standard stations around the world. The Ap index is a 24-hour "planetary amplitude" index representing the degree of geomagnetic activity on a worldwide scale.

atom—The smallest particle of an element that can exist either alone or in combination.

attachment—The collision of an electron with a neutral molecule or an atom that causes the formation of a negative ion. Later the negative charges disappear due to recombination between positive and negative ions. Attachment depends on the density of the oxygen atoms, the greater this density, the faster the ionization disappears.

aurora—Auroras are intermittent radio, infrared, visible, or ultraviolet emission from earth's upper atmosphere. Earth's geomagnetic field guides charged particles from space toward the higher latitudes, where they collide with atmospheric gases and cause them to become excited or ionized. When they deexcite or recombine, energy is emitted. Auroras occur simultaneously at high northern and southern latitudes, and are sometimes called the "northern or southern lights."

auroral oval—A roughly elliptical band around either geomagnetic pole in which auroras occur at a particular time. The dimensions of the oval and the intensity of the aurora in it, depend on the level of geomagnetic activity and local time. Auroral activity is generally most intense, has the greatest latitudinal width, and extends farthest equatorward, during periods of high geomagnetic activity and/or near the local midnight meridian.

backscatter—The scattering of radiant energy into the hemisphere of space bounded by a plane normal to the direction of the incident radiation and lying on the same side as the incident rays.

chromosphere—"Color sphere" or layer of the sun's atmosphere between the photosphere and the corona. Appears as a red ring around the solar limb during a solar eclipse. Plage regions are visible in the chromosphere, usually overlying sunspot groups. It's the inner layer of the solar "atmosphere," which contains comparatively transparent gases. It extends outward from the photosphere for approximately 21,000 km until it gradually merges with the outer layer of the solar "atmosphere." The temperatures in the chromosphere rise from 43,000° K at the top of the photosphere to 1,000,000° K at the top of the chromosphere.

coordinated universal time—Time referred to the zero meridian of longitude (through Greenwich, UK). 0000 UTC is local midnight at Greenwich. For example, 10 AM EST = 7 AM WST = 9 AM CST = 0000 UTC.

core—The region of very high density and temperature located at the center of the sun.

coronagraph—An instrument for photographing the corona and prominences of the sun at times other than at solar eclipse.

coronal hole—A low density region of open magnetic field lines in the corona with a relatively low temperature. Since the field lines are open, charged particles are not trapped. Holes are thus a primary source of high-speed particle streams superimposed on the normal solar wind. These streams can cause geomagnetic storms if they reach earth.

coronal mass ejection—An ejection of material from the sun into interplanetary space. If the material is directed toward earth then the event is associated with a disturbance to earth's magnetic field or ionosphere.

corona—The outer atmosphere of the sun with low density and high temperature. Visible as an extended bright region about the sun during solar eclipse.

cosmic rays—Very high energy particles that permeate interstellar space. Most cosmic rays originate from outside the solar system, and are called galactic cosmic rays. Their observed flux at earth increases during periods of low solar activity due to the weak shielding effect provided by a weak solar wind. (So the frequency of DOD system impacts caused by galactic cosmic rays increases during periods of low solar activity.) Solar cosmic rays are produced by rare, very energetic solar flares.

critical frequency—The greatest frequency that can be reflected vertically from an ionospheric layer.

daylight fadeout—When flares occur, increased absorption of a radio wave in the D layer may make part of the HF spectrum unusable. At times the whole HF spectrum is affected, but normally the lower frequencies are affected most. Only those circuits with daylight sectors can be affected.

deviative absorption—Absorption of a radio wave near the point of reflection.

differential solar rotation—Refers to the fact that the rotation of the sun varies with latitude on the sun—being generally faster the closer to the equator.

disk—When referring to the sun, it is the visible hemisphere.

D-layer—The lowest region of the ionosphere where most HF absorption occurs. Only present during daylight hours.

E-layer—A solar controlled ionospheric region around 80–150 km. Present during daylight hours.

E-layer screening—A radio signal directed to the F layer is deflected and attenuated by the E layer. E layer screening occurs when the E layer maximum useable frequency is greater than the operating frequency. The signal cannot reach the F layer and propagation is by multiple E layer hops. These modes are very heavily attenuated, especially when more than two hops occur, and effective communication is not possible.

electromagnetic radiation—EMR has both electric and magnetic properties. For example: microwaves, light, infrared, ultraviolet, X-rays, gamma, radio, and television. EMR travels at 300 million m/s.

electromagnetic spectrum—The array of EMR, extending from the shortest gamma rays, through X-rays, ultraviolet waves, visible light, and infrared waves, to radio waves.

electron—A light atomic particle with a fixed negative electric charge.

electron density—The number of electrons in a unit volume, for example, 1 cm^3.

elevation angle—Angle between the horizontal and the direction of concern.

energetic particle acceleration, composition, and transport—An instrument that is part of the WIND solar-sensing satellite. The EPACT instrument is designed to measure elemental and isotopic abundances for the minor ions that make up the solar wind.

equatorial anomaly—A depression in F layer frequencies at the geomagnetic equator relative to frequencies at low latitudes. A daytime phenomenon.

equinox—Time when the sun crosses the geographic equator. Days and nights are of equal lengths. It occurs in March and September.

extreme ultraviolet radiation—EMR at the high frequency end of the ultraviolet spectrum.

F10 index—The 10.7 cm (2800 MHz) solar radio flux observed daily at local noon. The 10.7 cm radio flux tends to vary hand-in-hand with the enhanced ultraviolet radiation from solar active regions, and thus the overall level of solar activity.

FEW—Used to describe thunderstorm coverage along a route of light; indicates 3–15 percent thunderstorm coverage along the route of flight.

filament—A mass of relatively high density, low temperature gas suspended in the mid- to upper-solar atmosphere by magnetic fields. It is seen as a ribbon-like absorption feature, in single wavelength observations, against the solar disk.

flare—A sudden, short-lived release of electromagnetic and particle radiation from a small region in the sun's lower atmosphere. This explosion on the sun usually releases large amounts of energy and particles, and usually occurs within an active region. Flares are more likely at solar maximum.

F-layer—Located above altitudes of about 160 km. During the day, it often divides into two regions where the lower region is called the F1 layer and the upper region is called the F2 layer. The increase in ionization during the day is responsible for this phenomenon. However, at nighttime, when ionization decreases, individual F1 and F2 layers become indistinguishable and are referred to simply as the F layer.

foe—The critical frequency of the E layer. The maximum frequency that can be reflected from this layer.

foF2—The critical frequency of the F2 layer. It is the maximum frequency that can be supported by the F2 layer when a wave is vertically incident upon the layer.

gamma—Unit of charge of earth's magnetic field. 1 gamma = 1 nanoTesla = 10 gauss. Also, short wavelength located between X-ray and cosmic ray wavelength.

gauss—A unit of magnetic induction or flux density equal to one dyne per unit.

geomagnetic activity—Natural variations in the geomagnetic field classified into quiet, unsettled, active, and storm conditions.

geomagnetic field—The magnetic field observed near earth.

geomagnetic storm—A widespread disturbance in earth's geomagnetic field, which results when an enhanced stream of solar particles strikes the magnetosphere. Geomagnetic storms are caused by particle emissions from solar flares and disappearing filaments (or equivalently eruptive prominences), or by enhancements and discontinuities in the solar wind associated with solar sector boundaries in the interplanetary magnetic field or high speed streams from solar coronal holes.

geosynchronous orbit—The orbit of any equatorial satellite with an orbital velocity equal to the rotational velocity of earth, and thus a period of 23 hours, 56 minutes. Geosynchronous altitude is near 35,782 kilometers, 22,235 statute miles, or 19,321 nautical miles above earth's surface. To also be geostationary, the satellite must satisfy the additional restriction that its orbital inclination be exactly zero degrees. The net effect is that a geostationary satellite is virtually motionless with respect to an observer on the ground.

ground wave—The radio wave that propagates close to earth's surface. Severe signal losses due to ground resistance limit the range of ground waves to about 100 km over land and 300 km over sea for the lowest HF frequencies. The ground waves for the higher HF frequencies cover much shorter distances.

H-alpha—The strongest spectral line in the solar spectrum. The wavelength is 656.3 NM. Energy of this wavelength is formed in the chromosphere and is responsive to solar flares. It is the spectral line used for worldwide surveillance of solar flares.

high frequency—The 3–30 MHz radio wave band; normally used for long-distance communication by refraction in the ionosphere's uppermost (or F) layer.

high-speed stream—A high-speed, energetic stream of charged particles superimposed on the normal (or background) solar wind. The primary source for HSSs are coronal holes in the upper solar atmosphere, where magnetic field lines are open and do not impede the outward flow of charged particles.

interplanetary magnetic field—A magnetic field that originates on the sun's surface and extends into interplanetary space. The IMF typically has four to six sectors where the magnetic field is directed either away from or toward the sun. A sector boundary in the IMF is normally narrow, being convected past earth in minutes or hours, compared to days to a week or so required for passage of the sector itself. The IMF strongly influences the motion of charged particles in the solar wind.

ion—An atom or molecule with one or more electrons removed (positive ion) or added (negative ion).

ionization—The process of removal or attachment of an electron to an atom or molecule to form a positive or negative ion respectively.

ionize—To cause an atom or molecule to lose an electron and thus be converted into a positive ion and a free electron.

ionosonde—Swept frequency HF pulsed radar used to monitor the ionosphere. Pulses are transmitted vertically upwards and the ionosonde records the time delay of the returning echoes. Ionosondes normally sweep in frequency from about 1–20 MHz.

ionosphere—The portion of earth's upper atmosphere where ions and electrons are present in quantities sufficient to affect the propagation of radio waves. Normally, the ionosphere extends down to about 50 km altitude, but at certain times and locations it can reach as low as about 35 km.

ionospheric storm—A disturbance in the ionosphere that may follow the onset of a geomagnetic storm.

ISOLD—A term used to describe isolated thunderstorm coverage along a route of flight; indicates 1–2 percent thunderstorm coverage along the route of flight.

K index—A three-hourly index of geomagnetic activity relative to an assumed quiet day curve for the recording site. K index values range from 0 (very quiet) up to 9 (extremely disturbed).

Kp index—Several K-indices can be averaged and processed through an algorithm that derives the Kp index. It indicates the approximate latitude where the edge of the aurora will be located based on the strength of geomagnetic activity.

limb—The edge of the solar disk.

loss—In the ionosphere it refers to the removal of free electrons from the ionosphere.

lowest usable frequency—The lowest frequency that allows reliable long range HF radio communication between two points on earth's surface by ionospheric refraction. It depends on the ionosphere's lowest (or D) layer absorption, transmitted power, receiver sensitivity, and other equipment parameters.

magnetosphere—The outer magnetic field surrounding earth in which the geomagnetic field dominates and prevents, or at least impedes, the direct entry of solar wind particles.

magnetotail—The portion of the magnetosphere in the antisunward direction, where geomagnetic field lines are drawn out to great distances by the flow of the solar wind passing earth.

maximum usable frequency—The highest frequency that allows reliable long range HF radio communication between two points on earth's surface by ionospheric refraction. It depends on the electron density in the ionosphere's strongest, uppermost (or F) layer at the point of refraction and the angle of incidence with which a radio wave enters the ionosphere. The median HF is the highest frequency usable at a particular hour for at least 50 percent of the days of the month. Frequencies higher than the MUF do not suffer sufficient refraction to be bent back toward earth and are transionospheric.

M-class flare—Solar flares that have a particular range of energy output of X-ray radiation. An M-class event will usually produce a short-wave fadout in the daylight hemisphere of earth. An M1 event is 10 percent less intense than X1 events, but 10 times more intense than C1 events.

megahertz—A measure of frequency equal to a million cycles per second.

MESONET—A small network of weather sensors or data collection devices. MESONETs are most often used in rural, agricultural areas and monitored by the National Weather Service, universities, and weather scientists to obtain weather data when weather reports would not otherwise exist. MESONETs are excellent tools for identifying the development of severe weather.

meteor—A body that enters earth's atmosphere and becomes incandescent by friction. A "shooting star."

mission execution forecast—A generic term used to describe a forecasted weather product. The MEF can be considered a terminal aerodrome forecast, flight weather briefing, mission briefing, and so forth, and may combine one or more products into the MEF.

mode—The path followed by a radio wave between transmitter and receiver. The so-called first propagation mode is the mode with the fewest number of hops for a circuit.

molecule—Smallest part of an element or compound that exhibits the properties of the specific element or compound. A molecule is normally considered a group of atoms.

photon—Light behaves as a wave in some circumstances and as a particle with energy in others. A particle of light is called a photon.

photosphere—The surface of the sun that we see. It lies beneath the corona and the chromosphere. Sunspots are seen here.

plage—A region in the sun's lower atmosphere where material is concentrated by intense magnetic fields. Plage areas are denser, hotter, and brighter than surrounding areas. Bright areas in the chromosphere overlying sunspots and the source of EUV radiation. Nearly all flares occur near plage.

plasma—A gas in which there are approximately equal numbers of positive ions and negative particles. There may also be many neutral particles, as is the case for the ionosphere.

plasma frequency—The maximum frequency of internal oscillation of a plasma. The plasma frequency is proportional to the square root of the electron density.

plasmapause—The outer boundary of the plasmasphere. The plasmasphere resides in the magnetosphere and consists of ions and electrons—it may be considered an extension of the ionosphere.

polar cap absorption—The ionization of the D region over the polar latitudes by high energy solar protons causes radio blackouts for trans-polar circuits that can last for several days. PCAs are usually preceded by a major solar flare on the visible hemisphere of the sun. The time between the flare event and the onset of the PCA ranges from a few minutes to several hours. Some energetic solar flares emit protons that can gain direct access to the polar caps via funnel-like cusps in the magnetosphere. These protons can penetrate to low altitudes before colliding with atmospheric gases and producing an increase in ionization that, in turn, causes enhanced absorption of HF radio waves crossing the polar caps.

polar cusps—Funnel-like features in the magnetosphere over each geomagnetic pole. High energy solar particles can be deflected by earth's geomagnetic field and guided in through the polar cusps, allowing the particles direct access to low altitudes over the polar caps.

polarimeter—An instrument for determining the degree of polarization of light.

polarization—In an ionized medium in the presence of a magnetic field, a radio wave is split into two circularly polarized components, each propagating independently. In the ionosphere a radio wave is split by earth's magnetic field into ordinary (o) and extraordinary (x) waves. The partitioning of the wave energy between the two depends on the angle the wave makes with the magnetic field. At low frequencies, the x-wave is heavily attenuated relative to the o-wave.

prominence—A mass of relatively high density, low temperature gas suspended in the mid to upper solar atmosphere by magnetic fields. It is seen as a bright, ribbon-like emission feature, in single wavelength observations, against the dark of space beyond the visible solar limb.

proton—A positively charged subatomic particle (equivalent to a hydrogen atom nucleus) with a mass 1,836 times that of an electron.

proton flare—A flare that liberates significant amounts of high energy protons. If this stream intercepts earth the protons cause a PCA.

radar aurora—Radar signal returns reflected off ionization produced by particle precipitation in the auroral oval. Radar aurora is distinctly different from auroral emissions at radio, or radar, wavelengths.

radio burst—A short-lived enhancement of solar radio emission over background levels, normally associated with an active region or flare.

radio emission—The sun emits radio waves. The intensity of the radio emission from the sun often increases during solar flares (radio bursts) and above large sunspot groups (radio noise storms).

recombination—The process of joining together of ions and free electrons to form neutral atoms or molecules.

recurrent disturbance—A disturbance (usually geomagnetic) which repeats at an interval of 27 days, the approximate rotation rate of some features on the sun.

reflection—Although a radio wave is actually refracted in the ionosphere, it is often permissible to substitute a simple triangular ray path for the real ray path, as if the ray were reflected from a mirror. Thus radio waves are often referred to as being reflected from the ionosphere.

refraction—The bending of a wave when it crosses a boundary between media due to a change in velocity of the wave. Until it reaches the ionosphere, a radio wave propagates in a straight line. Once in the ionosphere, it is refracted back toward the ground. The amount of refraction depends on the electron density of the ionosphere and the operating frequency.

regional area forecast program—A compilation of forecast tools that describes seasonal weather scenarios likely for specific regions. Weather units consult the RAFP to determine what type of weather they should forecast based on the synoptic weather situation.

ring current—An electric current that flows above the geomagnetic equator and is located in the outer Van Allen radiation belt. The ring current is produced by the drift (eastward for electrons and westward for protons) of trapped charged particles. The ring current is greatly enhanced during geomagnetic storms by the injection of particles from the magnetotail.

riometer—The riometer is a relative ionospheric opacity meter consisting of a vertically directed antenna that detects cosmic radio noise at a typical frequency of 30 MHz. The riometer responds to increases in ionization caused by either protons or electrons deposited in the ionosphere. The presence of these charged particles makes the ionosphere more opaque to cosmic radio noise so that the riometer registers a corresponding loss of signal (absorption), measured in decibels.

scintillation—A rapid, random variation in the amplitude, phase, and/or polarization of a radio signal passing through the ionosphere. Scintillation is caused by abrupt variations in electron density anywhere along the signal path.

seasonal anomaly—See winter anomaly.

short-wave fade—An abrupt decrease in the strength of HF radio signals observed over transmission paths in the sunlit hemisphere. An SWF is due to increased signal absorption in the lower ionosphere (D-layer) caused by increased ionization produced by X-ray radiation accompanying many solar flares.

signal-to-noise ratio—The ratio of the magnitude of a signal to that of noise.

single event upset—An electrical upset caused by a cosmic ray or high energy proton passing through a satellite. Each single particle has sufficient energy to deposit enough charge deep in the satellite to cause an electrical upset—hence the name single event upset.

sky wave—The radio wave that propagates through the ionosphere. It is often called the ionospheric wave to distinguish it from the direct (line-of-sight) wave and the ground wave.

smoothed sunspot number—An average of monthly sunspot numbers centered on the month of concern. There are various formulas; however, the aim is to smooth discrete data points.

SMS—A package of sensors that are part of the WIND solar wind-sensing satellite. The sensor package measures solar ion charging, solar mass, and suprathermal ions.

solar activity—Any change in the sun's appearance or behavior. The sun's activity is described as being very low, low, moderate, high, or very high.

solar control—The term used to indicate that the behavior of an ionospheric region is dominated by the sun.

solar cycle—Solar activity changes over a period of, on average, 11 years. At solar maximum, the solar activity is high and so too the EUV radiation output that affects the ionosphere. At solar minimum, the opposite is true.

solar maximum (or solar minimum)—The activity peak (or minimum) in the 11-year solar or sunspot cycle.

solar sector boundaries—Boundaries within the IMF that separate regions of opposite magnetic polarity (either toward or away from the sun). A sector boundary in the IMF is normally narrow, being convected past earth in minutes or hours, compared to days to a week or so required for passage of the sector itself.

solar wind—The outflow of solar material from the hot, unstable corona. The solar wind blows into interplanetary space with a speed of about 400 km/s (this can vary dramatically), carrying with it the magnetic fields that originate in the sun.

solar wind experiment—An instrument that is part of the WIND solar wind-sensing satellite. The SWE instrument provides measurements of the solar wind protons and alpha particles.

solstice—The times when the sun reaches its greatest declination away from the equator. The times of longest day and shortest night, and vice versa. Occurs in June and December.

sporadic E—A thin ionized layer in the E layer that occurs irregularly.

spread F—Irregularities in the F layer of the ionosphere that scatter radio signals causing degradation in communications.

storm—Severe departure from normal conditions in either the ionosphere or earth's magnetic field.

sudden ionospheric disturbance—See daylight fadeout.

sunspot—Sunspots are relatively dark regions on the solar surface. Seen in white light, they appear dark because they are cooler than the surrounding gases. Sunspots are characterized by strong magnetic fields and are closely related to the overall level of solar activity. Sunspots occur in groups and they underlie plage areas.

sunspot cycle—A mostly periodic variation in the number of observed sunspots. The cycle exhibits an average period of 11 years, but past cycles have been as short as 8, or as long as 15 years. Generally, there is a 4-year rise to a solar maximum, followed by a gradual 7-year decline to a solar minimum. The overall level of solar activity, and resultant DOD system impacts, tend to follow the same 11-year cycle.

sunspot number—An index of solar activity related to the number of sunspots and sunspot groups present on the sun.

total electron content—The number of electrons along a wave path measured in electrons/square cm. The TEC is used in determining delay and directional changes of a wave in the ionosphere.

transient gamma ray spectrometer—An instrument that is part of the WIND solar-sensing satellite. The instrument detects gamma-ray burst events and surveys cosmic gamma-ray bursts.

troposphere—The lowest layer of earth's atmosphere extending up to about 13 km in altitude.

ultraviolet radiation—Radiation of immediately shorter wavelengths than visible light, between 5 and 400 NM. EUV and X-rays have shorter wavelengths again.

Van Allen radiation belts—Regions near earth consisting of stably trapped charged particles that are produced by the presence of strong, closed geomagnetic field lines. The source and distribution of the trapped particles led to a division of this region into two belts: the inner and outer Van Allen belts.

waves—A sensor system that is part of the WIND solar-sensing satellite. It is constructed of three electric antenna systems. The device is designed to measure properties of solar waves and plasma over a wide range of frequencies.

WIND—A solar wind-sensing satellite launched by NASA on 1 November 1994. WIND provides nearly continuous monitoring of solar wind conditions in the near-earth environment.

winter anomaly—At midlatitudes the F2 frequency is lower in summer than in winter, in spite of the larger solar zenith angle during summer.

X-class flare—Flares that have a particular range of energy output of X-ray radiation. X-class flares are very energetic events that definitely produce a short-wave fadeout in the daylight hemisphere of earth.

X-rays—Electromagnetic waves of wavelength 0.001 to 1 NM. Emitted during solar flare activity and ionize the D region causing increased absorption of HF radio waves.

zenith angle—The angle between the overhead point for an observer and an object such as the sun. The solar zenith angle is zero if the sun is directly overhead and 90 degrees when the sun is on the horizon.

Abbreviations and Acronyms

Acronym	Meaning
A	angstrom
AASF	Army Aviation Support Facility
ACE	advanced composition explorer
AFB	Air Force base
AFCAT	Air Force catalog
AFCCC	Air Force Combat Climatology Center
AFI	Air Force instruction
AFMAN	Air Force Manual
AFRES	Air Force Reserve
AFSFC	Air Force Space Forecast Center
AFSPC	Air Force Space Command
AFSPCPAM	Air Force Space Command Pamphlet
AFW	Air Force Weather
AFWA	Air Force Weather Agency
AIREPS	air reports
ALF	absorption limited frequency
AMIS	Automated Meteorological Information System
AOR	area of responsibility
Ap	planetary amplitude
APR	active prominence region
ATC	Air Traffic Control
AW	airlift wing
AWDS	Automatic Weather Distribution System
AWN	Automated Weather Network
AZA	auroral zone absorption
C^3I	command, control, communications, and intelligence
cm	centimeter
cm^3	cubic centimeter
CME	coronal mass ejection
C/NOFS	Communication/Navigation Outage Forecast System
db	decibels
DLT	desired lead time
DMSP	Defense Meteorological Satellite Program
DOD	Department of Defense
DSN	Defense Switched Network
EHF	extremely high frequency
EMR	electromagnetic radiation
EPACT	energetic particle acceleration, composition, and transport

ESA	European Space Agency
EUF	extreme ultraviolet frequency
EUV	extreme ultraviolet
FAA	Federal Aviation Administration
FREQS	frequencies
FWA	forecast weather advisory
GHz	gigahertz
g	gram
GLE	ground level event
GOES	geosynchronous operational environmental satellite
GPS	global positioning system
Hα	hydrogen alpha
HF	high frequency
HSS	high speed stream
IMF	interplanetary magnetic field
INTEL	intelligence
ISOLD	isolated
JAAWIN	Joint Air Force and Army Weather Information Network
JTWC	Joint Typhoon Warning Center
K	degrees Kelvin
kg	kilogram
km	kilometer
km/s	kilometer per second
LAFP	local area forecast program
LLWS	low-level wind shear
LORAN	long-range aid to navigation
LUF	lowest useable frequency
m	meter
m^2	square meter
m^3	cubic meter
m/s	meters/second
m/s^2	meters/second/second
max	maximum
MEF	mission execution forecast
MESONET	Mesoscale Weather Network
METSAT	meteorological satellite
METWATCH	meteorological watch
MeV	million electron volts
MHz	megahertz
MISSIONWATCH	mission watch

MUF	maximum useable frequency
NASA	National Aeronautics and Space Administration
NM	nautical mile
NOAA	National Oceanic and Atmospheric Administration
NORAD	North American Air Defense Command
OSS	Operational Support Squadron
OWA	observed weather advisory
OWS	Operational Weather Squadron
PCA	polar cap absorption
PGM	precision guided munitions
PIREP	pilot report
PLGR	precision lightweight GPS receiver
RAFP	regional area forecast program
Re	Earth radii
RFI	radio frequency interference
RIMS	radio interference monitoring set
RPA	remotely piloted aircraft
RSTN	Radio Solar Telescope Network
SATCOM	satellite communication
SDO	Solar Dynamics Observatory
SEON	Solar Electro-optical Network
SEU	single event upset
SFU	solar flux unit
SHF	super-high frequency
SIGMET	significant meteorology reports
SOHO	solar and heliospheric observatory
SOON	solar observing optical network
SRS	solar radio spectrograph
SSB	solar sector boundary
SVMG	Solar Vector Magnetograph
SWF	Short-wave fades
SWPC	Space Weather Prediction Center
SXI	Solar X-ray Imager
TAF	terminal aerodrome forecast
TEC	total electron count
TISS	transionospheric sensing system
UHF	ultra-high frequency
USAF	United States Air Force
US	United States
US NORTHCOM	United States Northern Command

USSPACECOM	United States Space Command
UV	ultraviolet
VI	vertical incidence
W	Watts
WF	Weather Flight
W/m^2	Watts/square meter
WS	Weather squadron

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