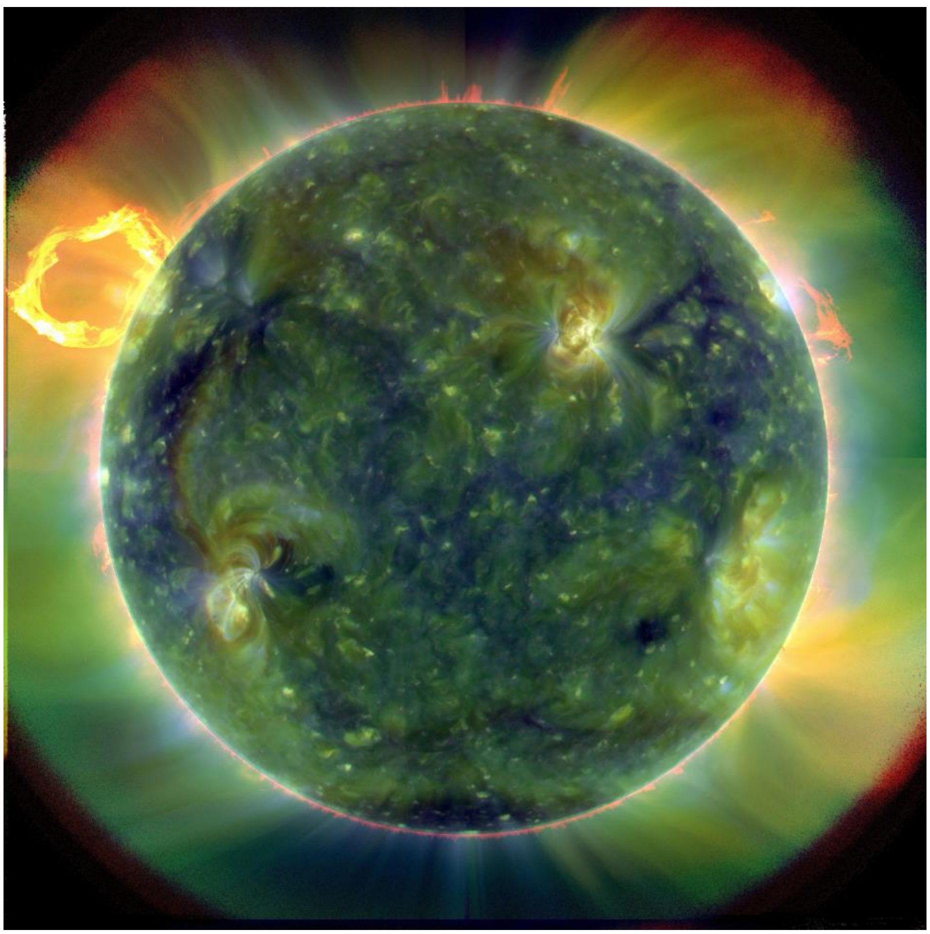
Research with Space Weather Monitor Data

Classroom Activities and Guide for Teachers

Developed by Deborah Scherrer
Stanford Solar Center



Stanford Solar Center, Stanford University
http://sid.stanford.edu

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Introduction

The Space Weather Monitor Program


The Earth from space. Image courtesy NASA.

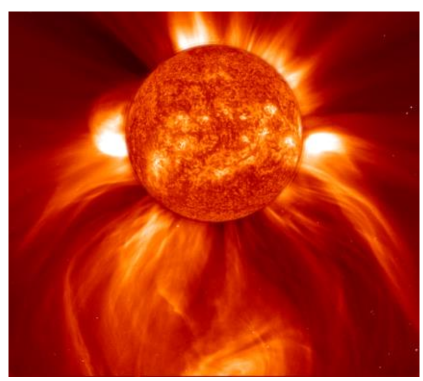
Stanford's Solar Center, in conjunction with the Electrical Engineering Department's Very Low Frequency group and local educators, have developed inexpensive space weather monitors that students can install and use at their local high schools and universities. The monitors detect changes to the Earth's ionosphere caused by solar flares and other disturbances. Students "buy in" to the project by building their own antenna, a simple structure costing little and taking a few hours to assemble. Data collection and analysis is handled by a local PC, which need not be fast or elaborate. Stanford provides a centralized data repository and blog site where students can exchange and discuss data.

Two versions of the monitor exist - one low-cost designed for placement in high schools, nicknamed SID (Sudden Ionospheric Disturbance), and a more sensitive, research-quality monitor called AWESOME, for university use. This document describes using data from the SID monitor. You need not have access to a SID monitor to use the data. More information on the SID monitor program is available at:

http://sid.stanford.edu

What is a Space Weather Monitor?

A space weather monitor measures the effects on Earth of the Sun and solar flares by tracking changes in very low frequency (VLF) transmissions as they bounce off Earth's ionosphere. The VLF radio waves are transmitted from submarine communication centers and can be picked up all over the Earth. The space weather monitors are essentially VLF radio receivers. Students track changes to the strength of the radio signals as they bounce off the ionosphere between the transmitter and their receiver.


Composite image of the Sun in extreme ultraviolet light. Photo courtesy of Steele Hill & the SOHO consortium.

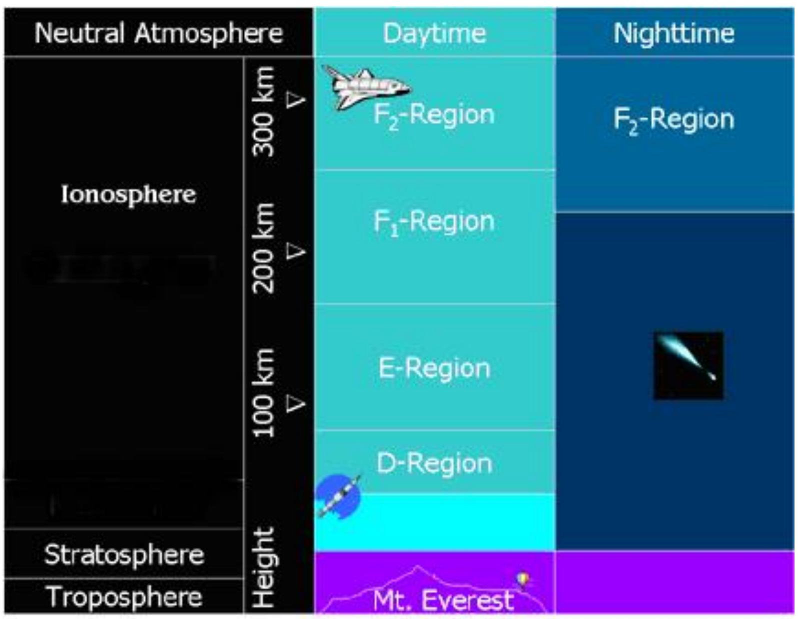
How Does the Sun affect the Earth?

The Sun affects the Earth through two mechanisms. The first is *energy*. The Sun spews out a constant stream of X-ray and extreme ultraviolet (EUV) radiation. In addition, whenever the Sun erupts with a flare, it produces sudden large amounts of X-rays and

EUV energy. These X-ray and EUV waves travel at the speed of light, taking only 8 minutes to reach us here at Earth.

The second manner in which the Sun affects Earth is through the impact of *matter* from the Sun. Plasma, or matter in a state where electrons wander freely among the nuclei of the atoms, can also be ejected from the Sun during a solar disturbance. This "bundle of matter" is called a Coronal Mass Ejection (CME). CMEs flow from the Sun at a speed of over 2 two million kilometers per hour. It takes about 72 hours for a CME to reach us from the Sun.

Both energy and matter emissions from the Sun affect the Earth. Our space weather monitors track the **energy** form of solar activity. This energy from the Sun and cosmic rays constantly affect the Earth's ionosphere, starting some 60 km above us. When solar energy or cosmic rays strike the ionosphere, electrons are stripped from their nuclei. This process is called ionizing, hence the name ionosphere.



The Earth's Ionosphere

The ionosphere has several layers created at different altitudes and made up of different densities of ionization. Each layer has its own properties, and the existence and number of layers change daily under the influence of the Sun. During the day, the ionosphere is heavily ionized by the Sun. During the night hours the cosmic rays dominate because there is no ionization caused by the Sun (which has set below the horizon). Thus there is a daily cycle associated with the ionizations.

In addition to the daily fluctuations, activity on the Sun can cause dramatic sudden changes to the ionosphere. When energy from a solar flare or other disturbance reaches the Earth, the ionosphere becomes suddenly more ionized, thus changing the density and location of layers. Hence the term "Sudden Ionospheric Disturbance" (SID) to describe the changes we are monitoring.

It is the free electrons in the ionosphere that have a strong influence on the propagation of radio signals. Radio frequencies of very long wavelength (very low frequency or "VLF") "bounce" or reflect off these free electrons in the ionosphere thus, conveniently for us, allowing radio communication over the horizon and around our curved Earth. The strength of the received radio signal changes according to how much ionization has occurred and from which level of the ionosphere the VLF wave has "bounced."

Access to Data

SID monitors are being placed around the world as part of the International Heliophysical Year 2007-2009. Data collected from these sites is stored in a centralized data server, hosted at Stanford, and accessible to all:

http://sid.stanford.edu/database-browser/

To do the described activities and research projects, students may use their own SID data, use data from the central server, or use sample data provided here. Hence students need not have their own monitor to receive and analyze data.

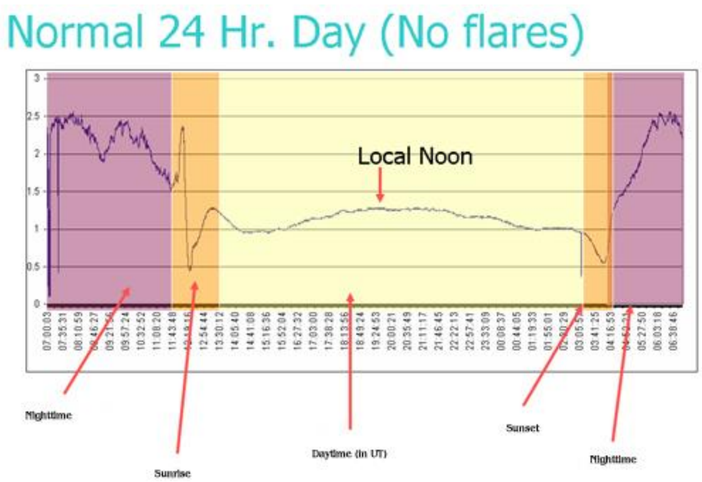
Students at Deer Valley High School calibrate their SID monitors

SID Monitor

Sunrise, Sunset Activity

Teacher Instructions

Activity: Although the SID monitors are designed to detect Sudden Ionospheric Disturbances (SIDs, caused by solar flares), they also detect the normal influence of solar X-rays and UV light as well as cosmic rays at nighttime. There is a distinct shape to a 24-hour SID data graph, with unique "signatures" or shapes of the graph appearing at sunrise and sunset.



Sample day of SID data (colors added)

What follows is a SID data introductory exercise where students track the sunrise and sunset "signatures" in their SID data to determine when, in relation to their site, their monitor is sensing sunrises and sunsets.

Objective: For students to better understand SID data and how changes to the ionosphere affect it. It is a precursory activity to further use of SID data.

Grade Level: grades 5-14

Materials Required:

- At least 7 days worth of data from a SID monitor. Example data are provided if real data are not available. Data are also available on the web at http://sid.stanford.edu/database-browser/
- "What do you think?" student pre-assessment survey
- Student Data Analysis Form, with examples, worksheets, and information about the Earth's ionosphere
- Access to the internet, or the ability to determine local sunrise and sunset times for both the local site and the transmitter being tracked.

Time: 1-2 class periods for activity; 1 week beforehand to collect data if you have your own SID monitor

Prerequisite Skills: math averaging; graphing; measuring; a conceptual understanding of time zones, Universal Time (UT), and longitude; ability to convert local to UT time.

Background Requirements: Your students should understand that sunrise and sunset fall at different times every day, and why. They should understand that the amount of sunlit time at any given location on Earth changes during the seasons and with latitude.

Relationship to National Science Education Standards (USA only):

See http://books.nap.edu/readingroom/books/nses/html/

Unifying concepts & processes (systems, order & organization; evidence, models; change, constancy, & measurement); Science as Inquiry (abilities necessary to do scientific inquiry; understanding about scientific inquiry); Physical Science (properties & changes of properties in matter; motions & forces; transfer of energy; structure & properties of atoms & matter; interactions of energy & matter); Earth & Space Science (structure of the Earth system; energy in the Earth system; Earth in the solar system); Science & Technology (abilities of technological design; understanding about science & technology); Science in Personal & Social Perspectives (natural resources; natural & human-induced hazards; science & technology in local, national, & global challenges); History & Nature of Science (science as a human endeavor; nature of scientific knowledge); Mathematics (problem solving, reasoning, connections, computation and estimation, measurements, patterns and functions); Science Process Skills (Measuring, communicating, collecting data, inferring, interpreting data)

Procedure:

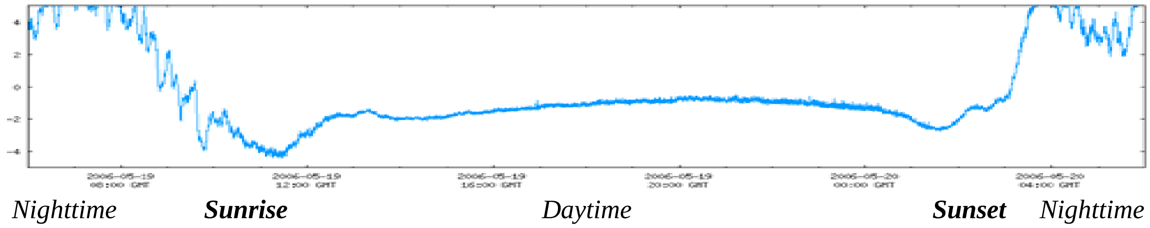
1. Ask students to complete the "What do you think?" pre-assessment survey (attached). Discuss and accept all conjectures, since this is an inquiry lesson.

2. Set up and run your SID monitor for at least 7 days. Check each day to see that you are getting the sunrise and sunset patterns. If not, (re)calibrate your monitor as per the instructions in the manual. It's ok to miss a day or two of data. If you don't have a SID monitor, students can use the sample data provided or they can access data collected on the web at http://sid.stanford.edu/database-browser/.

3. After data collection, students will need to graph and print or display their SID data. This is most easily done using Excel (instructions are in the SID manual) or by accessing data on the web (http://sid.stanford.edu/database-browser/). Or, students may use the sample graphs provided.

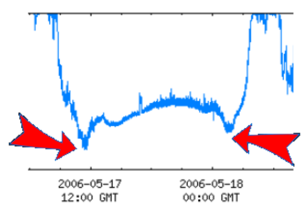
4. With your students, look at your data graphs and discuss. Do they see times when the signal strength is high, then periods when it is low? The gradual fall of the signal strength indicates ionization caused by the Sun, and thus the beginning of daytime. The gradual rise of signal strength occurs after the Sun goes down, and indicates nightfall. There are normally standard "signatures," or shapes of the data graph, at sunrise and at sunset. Can your students locate these?

Sample SID data graph



5. Pass out copies of the Data Analysis form to teams or to each of your students and discuss the following procedures they will use:

   - Find the shapes, or signatures, on the graphs that indicate sunrise and sunset. Because these signatures span a period of time, it is useful to pick one single point as your place for measuring. The minima, or lowest points that occur right around sunrise and sunset, are known as the terminators. These are usually distinct points and thus convenient measures to use.



Lowest point, for sunrise and sunset signatures

   - Ask students to read from their data graphs or files to determine the (UT) time of occurrence for each of the sunrise and sunset terminator values in your data. Write these down in the table given.

   - Find the actual time of sunrise and sunset at your site (or the site from which your data comes) for each day you took data. Do the same thing for the city in which the transmitter is located. You can use http://aa.usno.navy.mil/data/docs/RS_OneDay.html to get the sunrise and sunset times. Remember you will need to convert the local times given by the program into UT times. This site might help you: http://www.worldtimezone.com/

   - Graph the sunrise times for your local site, the transmitter site, and the times from your data (an example is given on the students' worksheet). On a separate graph, do the same with the sunset times.

   - Ask students to complete their Data Analysis forms and, as a group, discuss the results.

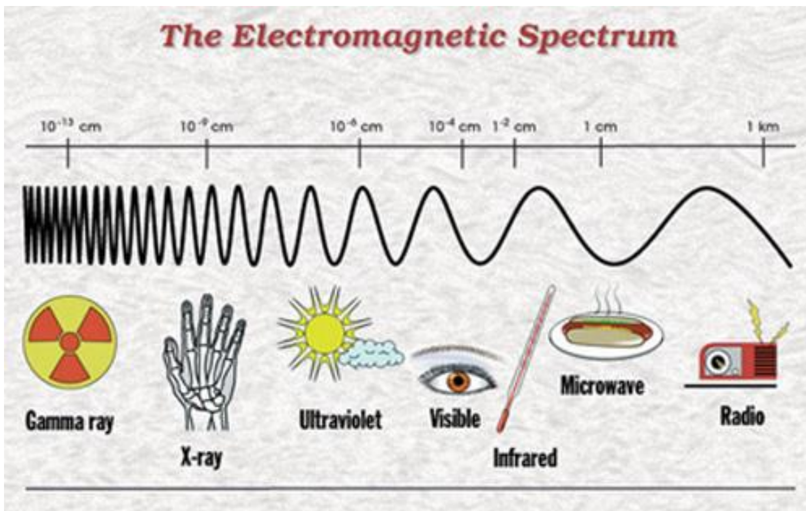
   - Discuss ideas for further research with your students. Some are given in the "Further Suggestions" section of this guide.

Name: ____________________________

What Do You Think?

Student Pre-activity Survey

You are going to be doing an activity that involves the transmission and receiving of radio signals. Radio waves, microwaves, x-rays, gamma rays, and visible colors are all really the same thing - electromagnetic energy. The differences are their wavelengths. Radio waves are long; those you are going to study have wavelengths measured in miles between peaks. Gamma ray wavelengths are extremely short, as little as trillionths of a meter.



Electromagnetic spectrum. Image credit: Herschel Space Observatory.

Radio waves and all other electromagnetic radiation travel by means of oscillating electromagnetic fields that can pass through the air and the vacuum of space. Hence they do not need wires or other forms of transport. Radio and other electromagnetic waves generally travel in straight lines although they can be reflected, refracted, or absorbed by other materials. Parts of the Earth's atmosphere have the ability to reflect, refract, and/or absorb different radio frequencies.

1. You will be using either your own monitor data, or the samples provided, or data from the web. Your data comes from a monitor located in which city, state, and country?

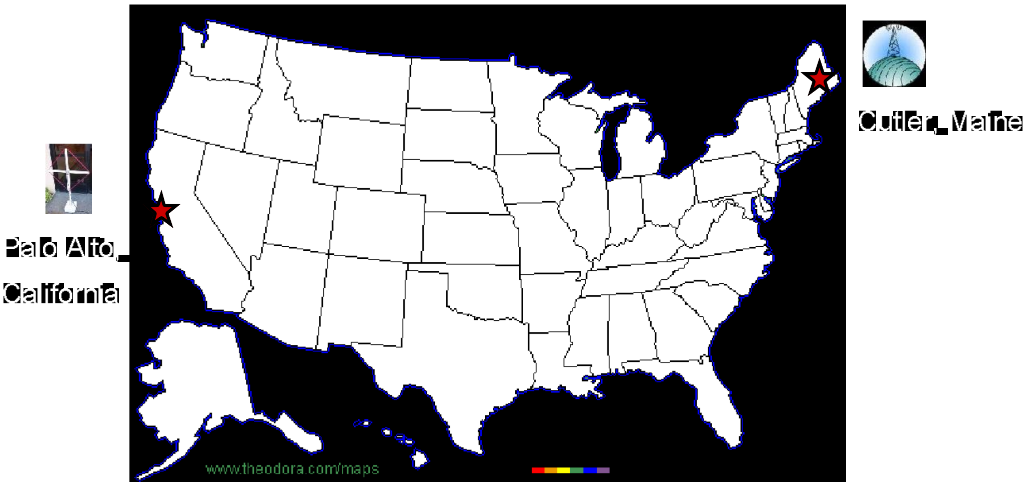
   ____

2. Your monitor picks up very low frequency radio waves from a transmitter. In which city, state, and country is the transmitter you are monitoring located?

____

3. Find both your monitor site and the transmitter site on a map or globe, or use Google Earth (http://earth.google.com/). Estimate how far apart these are in kilometers/miles, in longitude, and in latitude. (There is also a freeware computer program which will help you draw "great circle routes" between your sites: http://tonnesoftware.com/pizza.html).

Example map of transmitter and receiver



Map courtesy of www.theodora.com/maps, used with permission.

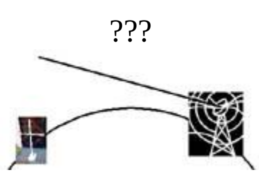
Receiver: Palo Alto, California 38°N -122°W
Transmitter: Cutler, Maine 44°N -67°W
About 4900 kilometers, 55° longitude, 6°latitude apart

Write down the latitude and longitude of your receiver:
____________________ ____________________

Write down the latitude and longitude of your transmitter:
____________________ ____________________

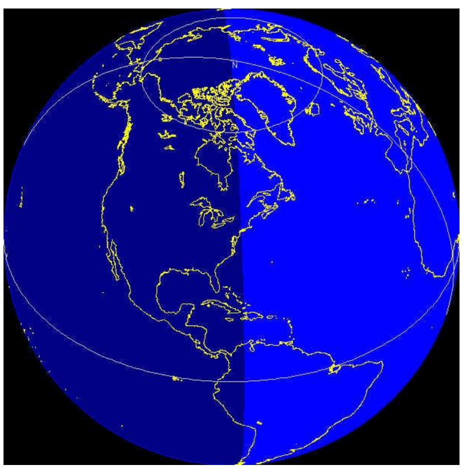
How far apart are they in kilometers/miles? : ____________________________

4. Your monitor measures the strength of a very low frequency (VLF) radio signal sent from a transmitter (that normally communicates with submarines). Radio waves travel only in straight lines. If your monitor is far from the transmitter, how do you think the radio waves get "around" the curved Earth to your site?

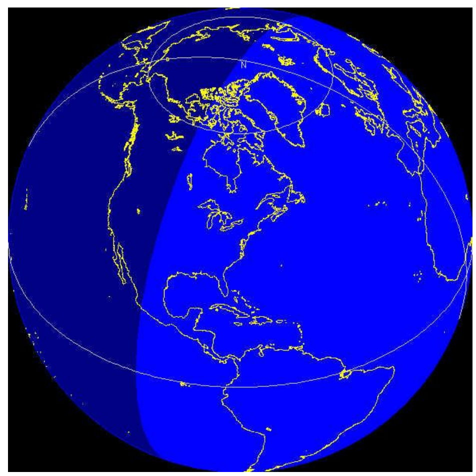


5. Would you expect the radio signal strength to be different during the day and the night? If so, what do you think could cause this?

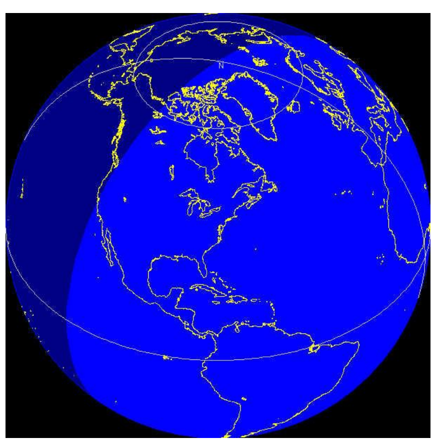
6. After you look at your data, you'll see that the monitor picks up indications of sunrise and sunset. If your monitor and the transmitter are at different longitudes, do you think your monitor will pick up the sunrise signature for sunrise time at your site, sunrise time at the transmitter site, or sunrise time elsewhere?



Sunrise at the transmitter in Cutler, Maine
Around 11:00 UT



Sunrise in central USA
Around 12:30 UT

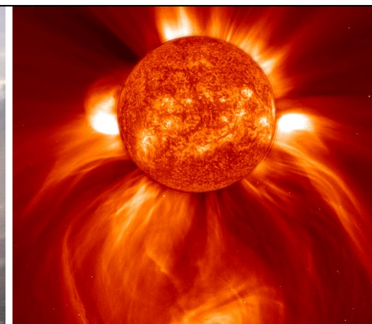
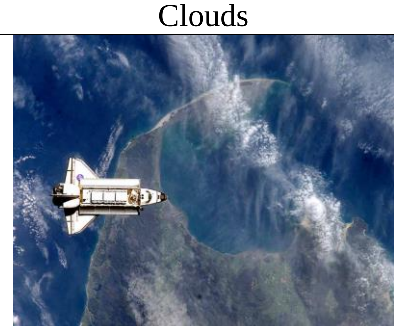


Sunrise at receiver in Palo Alto, California

Around 14:00 UT
Images by Piero Massimino, Osservatorio Astrofisico, Catania – Italy
http://ntserver.oact.inaf.it/cgiplan/terminator.htm

7. HOW FAR?

Cut out the pictures and place the objects in order of distance from the surface of the Earth.

 Ionosphere	 Top of Mt. Everest	 Aurora
 Hubble Space Telescope	 Supersonic Jet	 The Sun
 Comet	 Lightning	 Clouds
 The Moon	 Geosynchronous Satellite	 Space Shuttle

SID Monitor

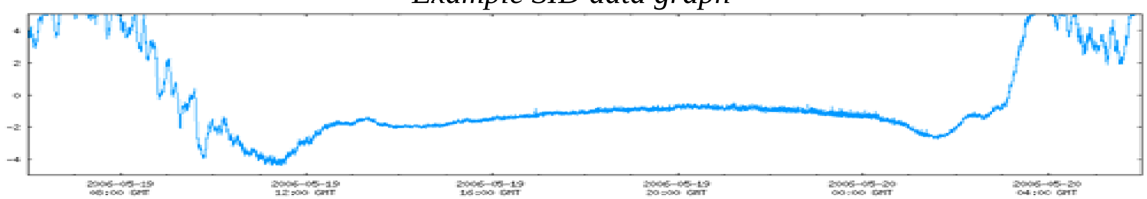
Student Data Analysis Form

- **Collect your SID data graphs.** You will obtain these from your own SID monitor, from the web, or your teacher will provide them.

- My monitor is located in __________________, time zone ________.
  The transmitter is located in __________________, time zone ______.

- **By reading your SID data graphs, identify daytime, nighttime, and the sunrise and sunset signatures.** Here's how:

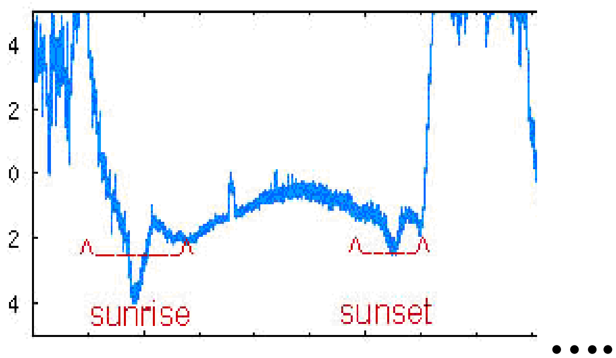
Example SID data graph



Nighttime ***Sunrise*** *Daytime* ***Sunset*** *Nighttime*

a) Is the signal strength
   ____ Higher at night?
   ____ Higher during the day?
   ____ Same at night as in daytime?

Example sunrise and sunset signatures



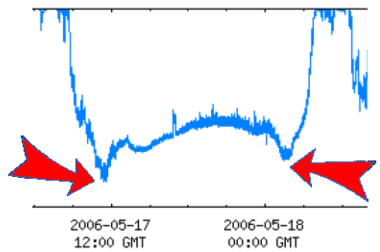
How many minutes? How many minutes?

b) By looking at your graphs, *estimate* the amount of time (i.e. number of minutes) between the start and stop of your sunrise signature:

   ____

c) *Estimate* the amount of time between the start and stop of your sunset signature: ____

- **On your worksheet, write down the times for your various sunrises and sunsets**. Because your signatures span a period of time, **pick some common place to measure them all. The lowest point of each signature is a reasonable choice.**



Sunrise for Day 1 shows up at 11:30 AM UT on 17 May 2006

	Data Sunrise (UT)	*Local Sunrise (UT)*	*Transmitter Sunrise (UT)*
Day 1	**11:30 AM** 17 May 06		
Day 2	**11:30 AM**		
Day 3	**11:25 AM**		

Sunset for Day 1 shows up at 1:45 AM UT on 18 May 2006

	Data Sunset (UT)	*Local Sunset (UT)*	*Transmitter Sunset (UT)*
Day 1	**1:45 AM** 18 May 06		
Day 2	**1:20 AM**		
Day 3	**1:40 AM**		

- **Look up your local sunrise and sunset times for the days for which you have data**. In this case, local means the place where your data's monitor resides. Newspapers often have them, or try http://aa.usno.navy.mil/data/docs/RS_OneDay.html.

  Then, **convert your local time to UT time** (you can find out how at http://www.timezoneconverter.com/cgi-bin/tzc.tzc). Here's an example for the monitor in Palo Alto, California, USA:

  My local time zone is PDT (Pacific Daylight Time)
  My local time is 7 hours after the current UT time.
  So I would add 7 hours to local time to obtain UT time.

  My local time zone is ________________________________.
  (Remember to account for daylight savings time, if necessary.)
  My local time is ______ hours ______________ the current UT time.
  before or *after?*
  So I would ______ this many hours __________ local time to obtain UT time.
  add or *subtract?* *to or from*?

Write the UT times for your local sunrises and sunsets into your data table. Here's an example:

	Data Sunrise (UT)	*Local Sunrise (UT)*	*Transmitter Sunrise (UT)*
Day 1	11:30 AM 17 May 06	12:58 AM UT 5:58 AM PDT	
Day 2	11:30 AM	12:57 AM UT	
Day 3	11:25 AM	12:56 AM UT	

↑↑↑↑↑↑

Use http://aa.usno.navy.mil/data/docs/RS_OneDay.html
http://www.timezoneconverter.com/cgi-bin/tzc.tzc

↓↓↓↓↓↓↓↓

	Data Sunset (UT)	*Local Sunset (UT)*	*Transmitter Sunset (UT)*
Day 1	1:45 AM 18 May 06	3:12 AM UT 8:12 PM PDT	
Day 2	1:20 AM	3:13 PM UT	
Day 3	1:40 AM	3:14 PM UT	

- **Find the sunrise and sunset times for the location of the transmitter**, as you did above for the receiver. Then **convert to UT and write that information into your data table**. Here's an example for the transmitter in Cutler, Maine, USA:

	Data Sunrise (UT)	*Local Sunrise (UT)*	*Transmitter Sunrise (UT)*
Day 1	11:30 AM 17 May 06	12:58 UT 5:58 AM PDT	**8:59 UT** 4:59 AM EDT
Day 2	11:30 AM	12:57 UT	**8:58 UT**
Day 3	11:25 AM	12:56 UT	**8:57 UT**

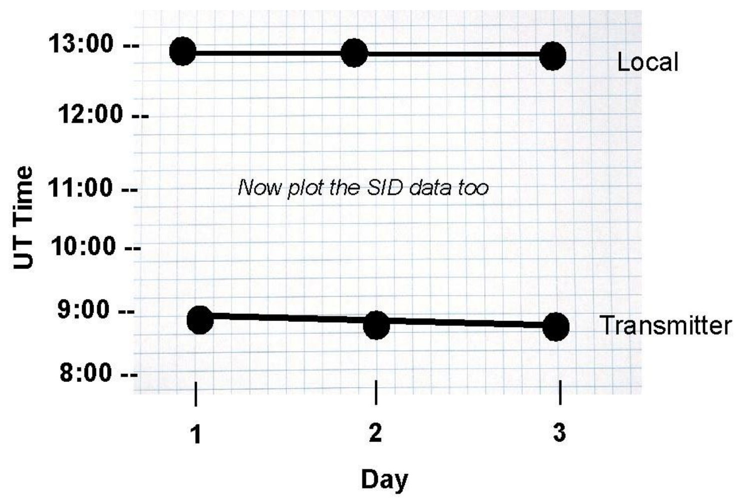
↑↑↑↑

http://aa.usno.navy.mil/data/docs/RS_OneDay.html
http://www.timezoneconverter.com/cgi-bin/tzc.tzc

↓↓↓↓

	Data Sunset (UT)	*Local Sunset (UT)*	*Transmitter Sunset (UT)*
Day 1	1:45 AM 18 May 06	3:12 UT (5/18) 8:12 PM PDT	**11:52 UT** 7:52 PM EDT
Day 2	1:20 AM	3:13 UT	**11:53 UT**
Day 3	1:40 AM	3:14 UT	**11:54 UT**

- **Graph your daily data for sunrises and sunsets** on the graph sheets provided. Below is a start for our example data:



Example Sunrise Graph (incomplete)

- **By reading your data tables and your graphs, answer the following questions:**

a) Are your data sunrise and sunset times

___ Same as your local sunrise/set times?
___ Same as the transmitter sunrise/set times?
___ Neither?

b) Compute the average difference in time between local sunrises/sets and your data sunrises/sets.

- The average difference between local **sunrise** and data sunrise is ___________________ (hours and minutes)
- The average difference between local **sunset** and data sunset is ___________________ (hours and minutes)

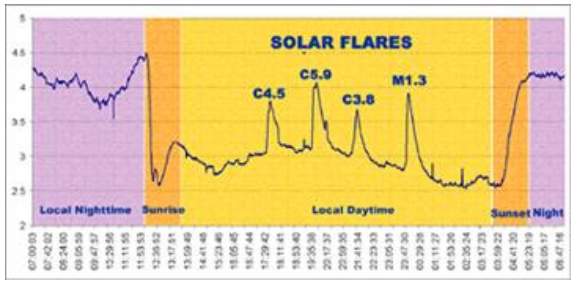
c) Do the differences between local sunrise/set times and data sunrise/set times remain roughly the same each day, or do they change? If they change, what do you think might be the causes(s)?

____
____
____

d) The transmitters are usually taken down for weekly maintenance. Is there a time in your data where it looks like you have no signal at all?

___ No
___ Yes, between the following UT times: _______ and _________

e) If your monitor picked up a solar flare, it would appear as a sudden spike (or occasionally a sudden drop) in signal strength. And only during the daytime (why?).



SID Data Graph (colors and labels added for clarity)

_____Do you think you found a flare?
If so, at what (UT) time? ______________________

If you'd like to go further, the second activity tells you how to track down a solar flare to its original location on the Sun.

f) Read the sheet on how the ionosphere changes during the daytime, nighttime, during a solar flare, and during a lightning storm. Can you identify any lightning storms in your data?

___ Yes, I found lightning storms at _______________, ____________
______________________, _________________

- **Discuss your results with your teacher and other students.**

- If you are interested in doing further research with SID monitor data, your teacher can provide you with the "Suggestions for Further Activities and Research Projects" sheet.

Name ___________________________

SID Monitor

Sunrise/Sunset Worksheet

My data comes from: ___________________________ Time zone: _________
(city, state, country)
The transmitter is located in: ________________________ Time zone: _________
(city, state, country)

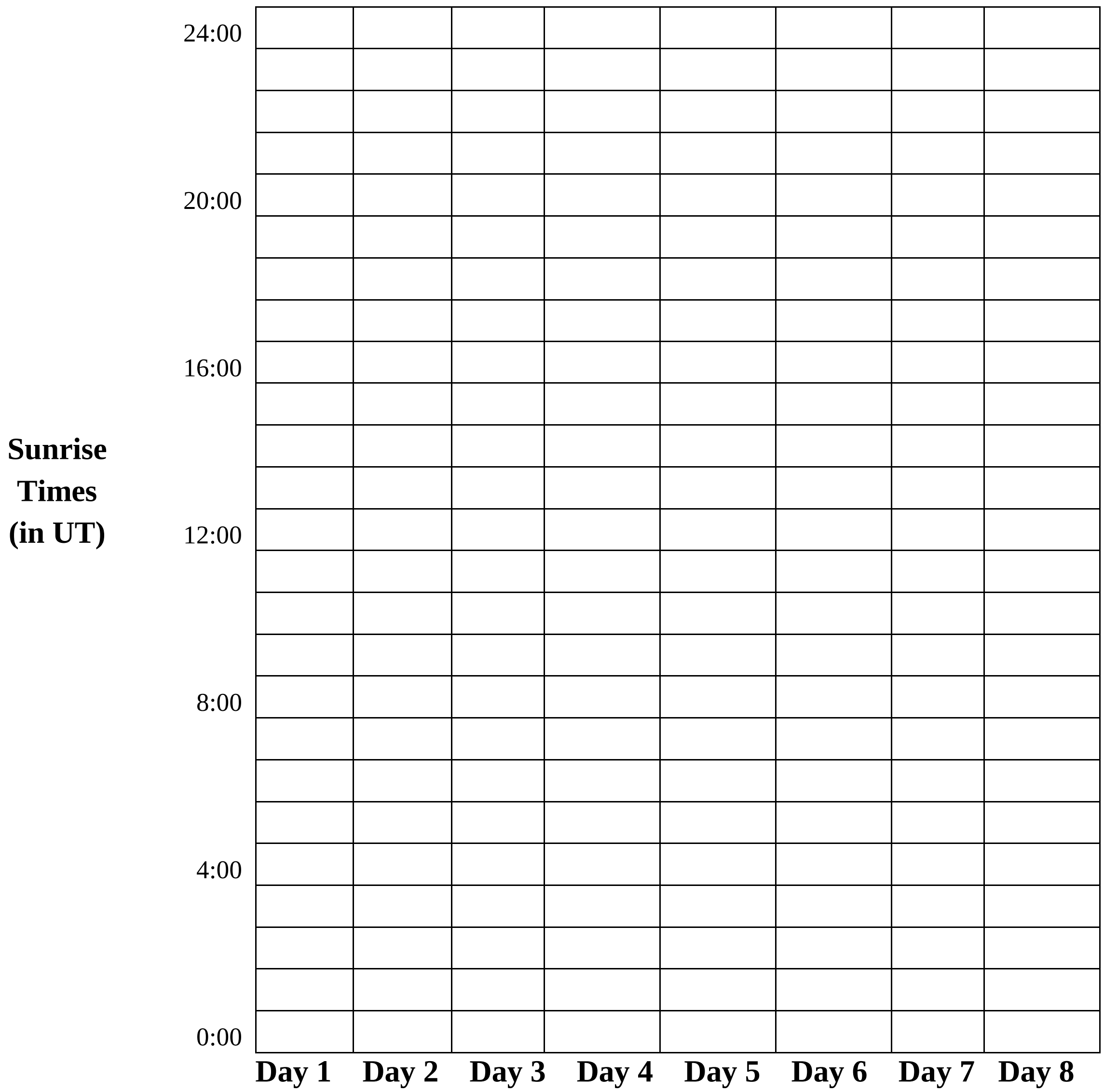
	Data Sunrise (UT)	*Local Sunrise (UT)*	*Transmitter Sunrise (UT)*
Day 1			
Day 2			
Day 3			
Day 4			
Day 5			
Day 6			
Day 7			
Day 8			

	Data Sunset (UT)	*Local Sunset (UT)*	*Transmitter Sunset (UT)*
Day 1			
Day 2			
Day 3			
Day 4			
Day 5			
Day 6			
Day 7			
Day 8			

To find sunrise and sunset times, see http://aa.usno.navy.mil/data/docs/RS_OneDay.html
To convert from local to UT time, see http://www.timezoneconverter.com/cgi-bin/tzc.tzc

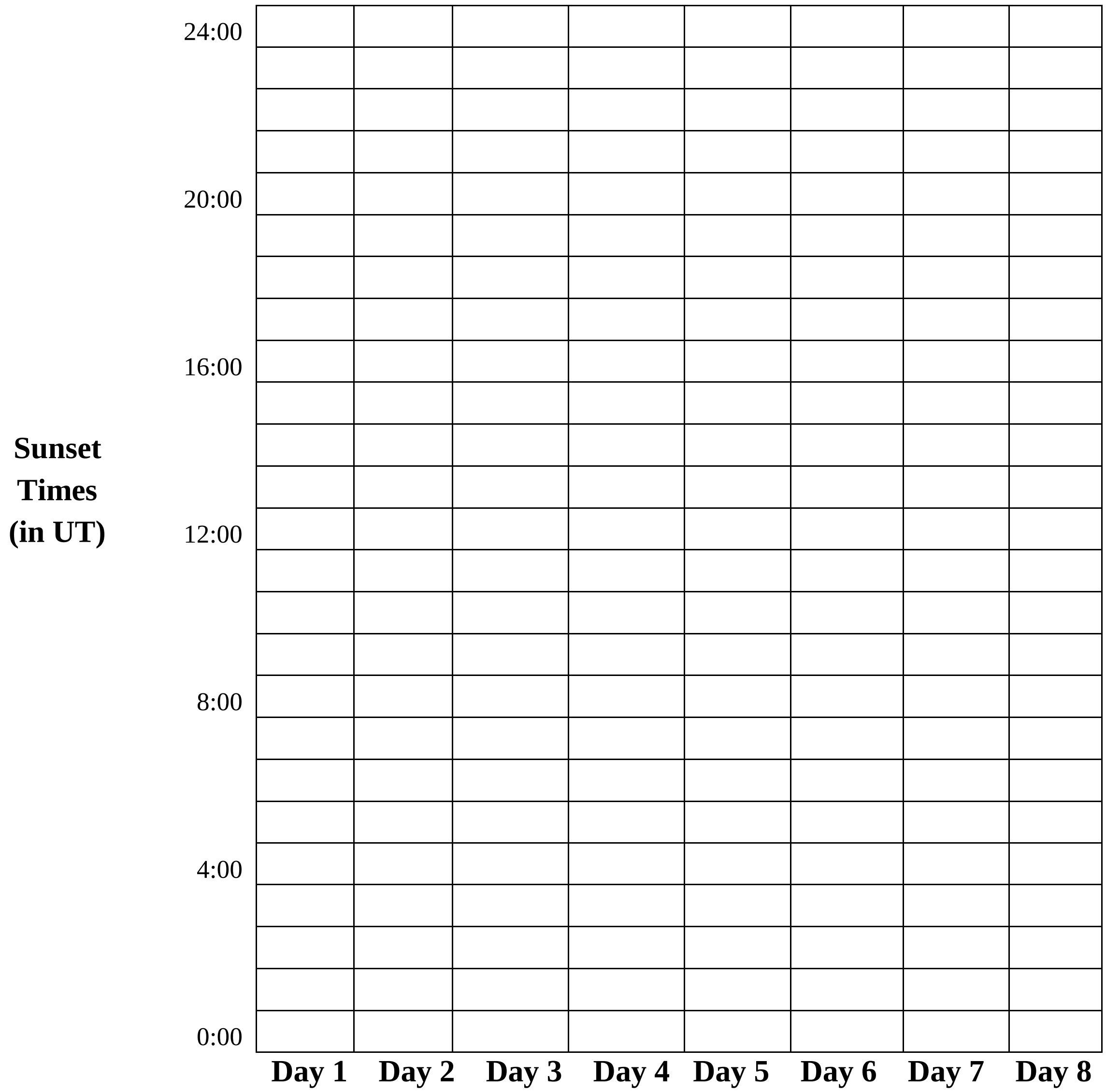
Name ___________________________

Sunrise Time Graph



Name: ___________________________

Sunset Time Graph



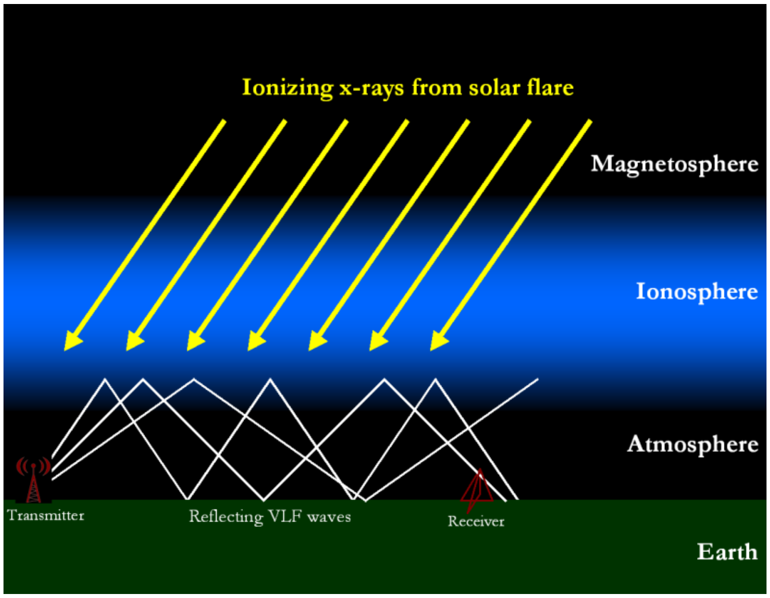
The Earth's Ionosphere

Information Sheet

The ionosphere is defined as the layer of the Earth's atmosphere that is ionized by solar and cosmic radiation. It lies 75-1000 km (46-621 miles) above the Earth. (The Earth's radius is 6370 km, so the thickness of the ionosphere is quite tiny compared with the size of Earth.) Because of the high energy from the Sun and from cosmic rays, the atoms in this area have been stripped of one or more of their electrons, or "ionized," and are therefore positively charged. The ionized electrons behave as free particles. The Sun's upper atmosphere, the corona, is very hot and produces a constant stream of plasma and UV and X-rays that flow out from the Sun and affect, or ionize, the Earth's ionosphere. Only half the Earth's ionosphere is being ionized by the Sun at any time (why?).

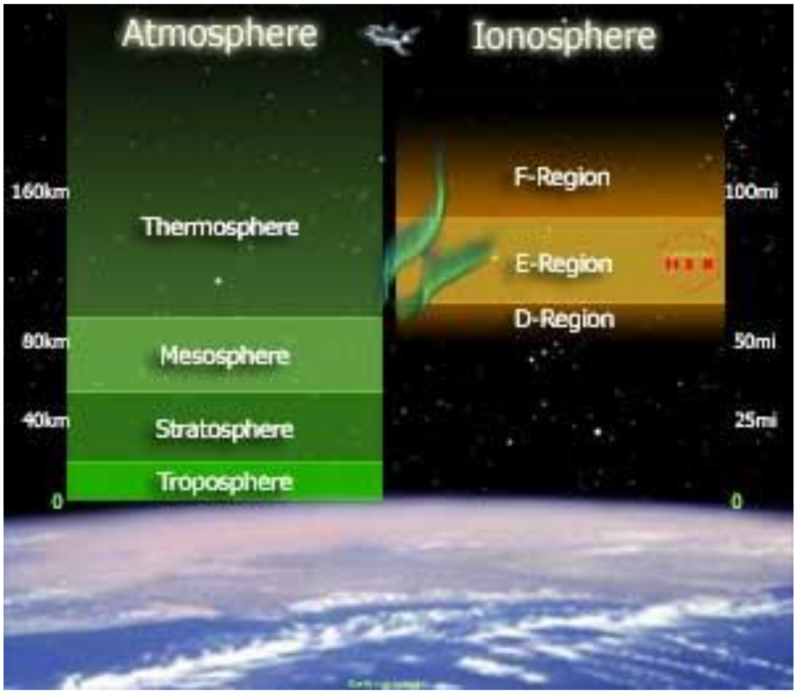
During the night, without interference from the Sun, cosmic rays ionize the ionosphere, though not nearly as strongly as the Sun. These high energy rays originate from sources throughout our own galaxy and the universe -- rotating neutron stars, supernovae, radio galaxies, quasars and black holes. Thus the ionosphere is much less charged at nighttime, which is why a lot of ionospheric effects are easier to spot at night – it takes a smaller change to notice them.

The ionosphere has major importance to us because, among other functions, it influences radio propagation to distant places on the Earth, and between satellites and Earth. For the very low frequency (VLF) waves that the space weather monitors track, the ionosphere and the ground produce a "waveguide" through which radio signals can bounce and make their way around the curved Earth:



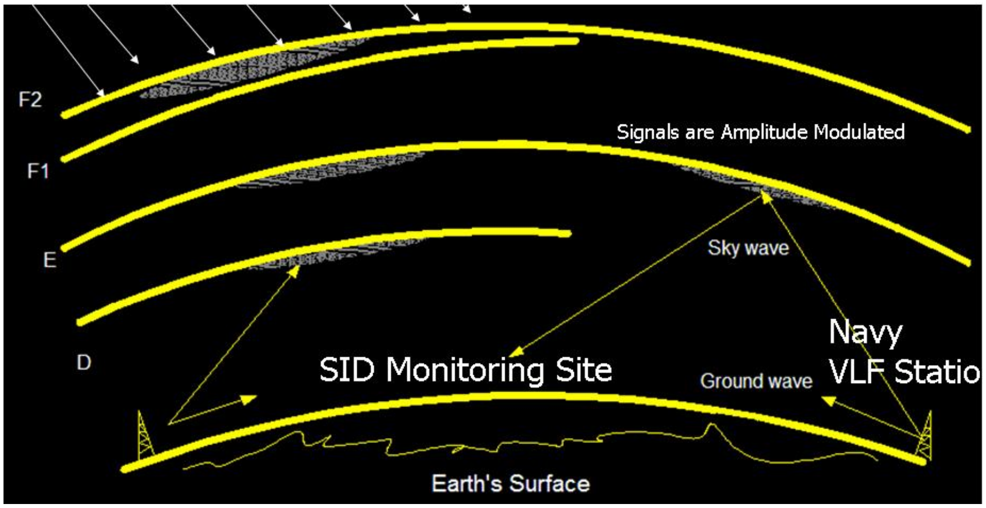
The Earth's ionosphere and ground form a "waveguide" through which VLF radio signals can propagate or "bounce" around the Earth.
Image courtesy Morris Cohen, Stanford University

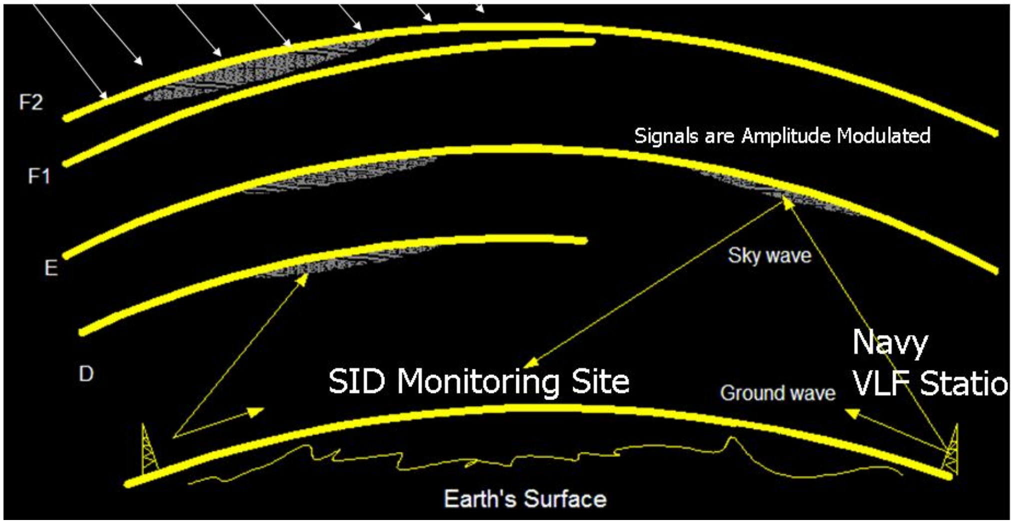
The ionosphere is composed of three main parts, named for obscure historical reasons: the **D, E, and F regions.** The electron density is highest in the upper, or F region. The F region exists during both daytime and nighttime. During the day it is ionized by solar radiation, during the night by cosmic rays. The D region disappears during the night compared to the daytime, and the E region becomes weakened.



The Earth's atmosphere and ionosphere

Nighttime: During the night (image below, right side), the ionosphere has only the F and E layers. A VLF wave from a transmitter reflects off the ions in the E layer and bounces back.



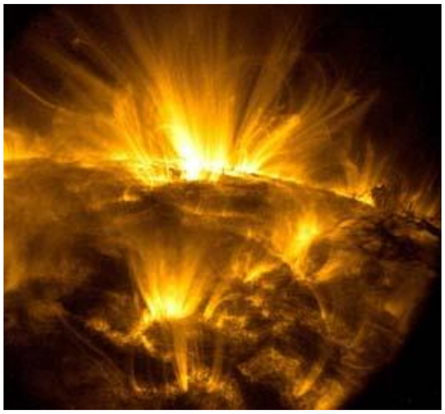


Daytime: During the daytime (image above, left side), the Sun's X-ray and UV light increase the ionization of the ionosphere, creating the D and enhancing the E layers, and splitting the F region into 2 layers. The D layer is normally not dense enough to reflect the radio waves. However, the E layer is, so the VLF signals go through the D layer, bounce off the E layer, and go back down through the D layer to the ground. The signals lose energy as they penetrate through the D layer and hence radios pick up weaker signals from the transmitter during the day. When a solar flare occurs, even the D layer becomes ionized, hence allowing signals to bounce of it.

Sunrise and Sunset Effects: The reflection height for VLF waves changes from about 70 km in the daytime to about 85 km at night (44-53 miles). During sunrise, sunlight strikes the ionosphere before the ground, and at sunset the light continues to strike the ionosphere after the Sun has set above the ground (why?). The amount of time it takes for the Sun to ionize the ionosphere once it strikes it is virtually instantaneous.

So at sunrise and sunset, the signal your SID monitor picks up is basically the effect of the VLF waves bouncing off the ionosphere along the entire path from transmitter to receiver. That is, the monitor picks up this process of change in conditions as sunlight sweeps over the path between transmitter and receiver. The length of the effect is dependent upon the longitudinal separation between the two sites (because the sunrise/sunset terminator takes longer to sweep over the path). Hence if you look at primarily north/south paths between transmitter and receiver, the data will show a well-defined "daytime" and a well-defined nighttime, with a pretty quick transition. For paths far apart in longitude, however, the sunrise/set effect lasts much longer and does not feature as rapid changes. Latitude contributes too, since the equatorial daytime is the same length, but the higher latitude daytimes are highly seasonal in length.

Solar Flare:



Solar flares imaged by the TRACE satellite. Photo courtesy NASA.

When a solar flare occurs, the flare's X-ray energy increases the ionization of all the layers, including the D. Thus D now becomes strong enough to reflect the radio waves at a lower altitude. So during a solar flare, the waves travel less distance (bouncing off D instead of E or F). The signal strength usually increases because the waves don't lose energy penetrating the D layer. However, the VLF wave strength during a flare can either increase or decrease. The signal strength could decrease because the lower the waves reflect, the more collisions, or interferences of waves, there will be because of the thicker atmosphere. These wave collisions can result in destructive interference, as seen in the diagram below:

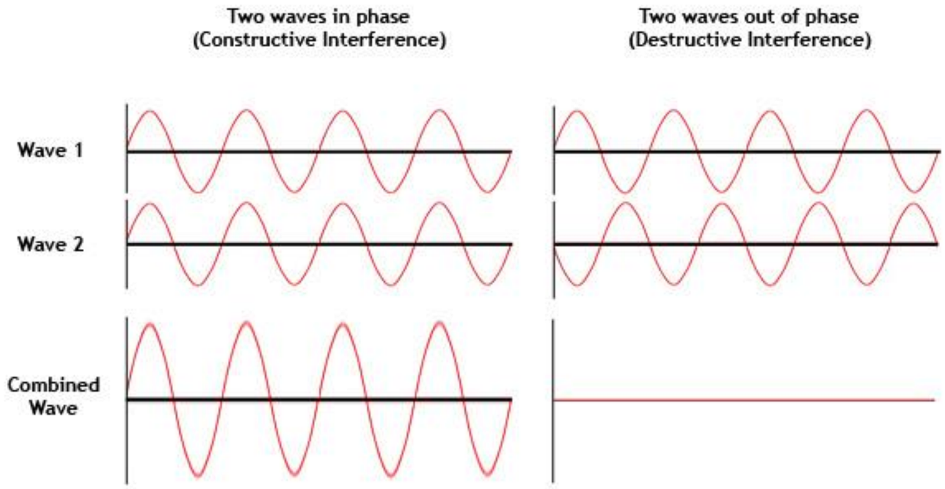


Image from New Worlds, http://newworlds.colorado.edu/starshade/

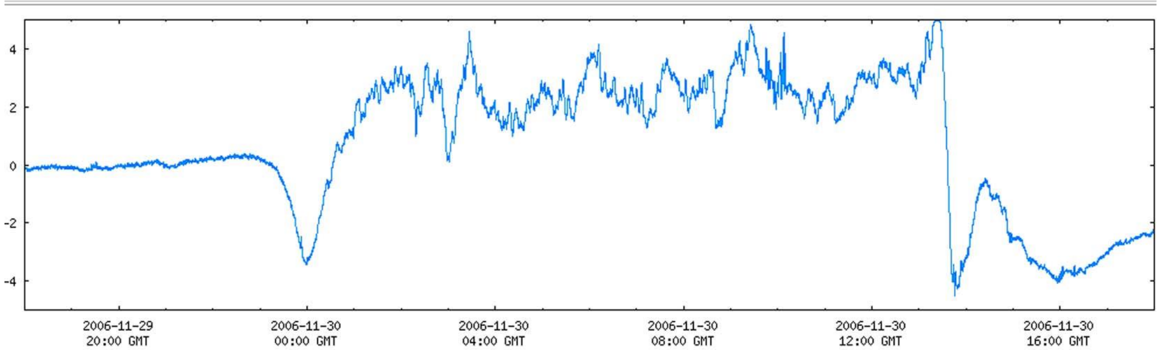
In fact, collisions near the reflection height are the primary damping mechanism of the VLF waves. However there are other factors so not all disturbances result in a decrease. As soon as the X-rays end, the sudden ionospheric disturbance (SID) ends as the electrons in the D-region rapidly recombine and signal strengths return to normal.

Lightning:
During the daytime, the Sun's ionization generally overpowers any effects of lightning. However, during the nighttime, lightning storms can ionize the ionosphere and thus change where the radio waves bounce.

Photo from the NOAA Photo Library

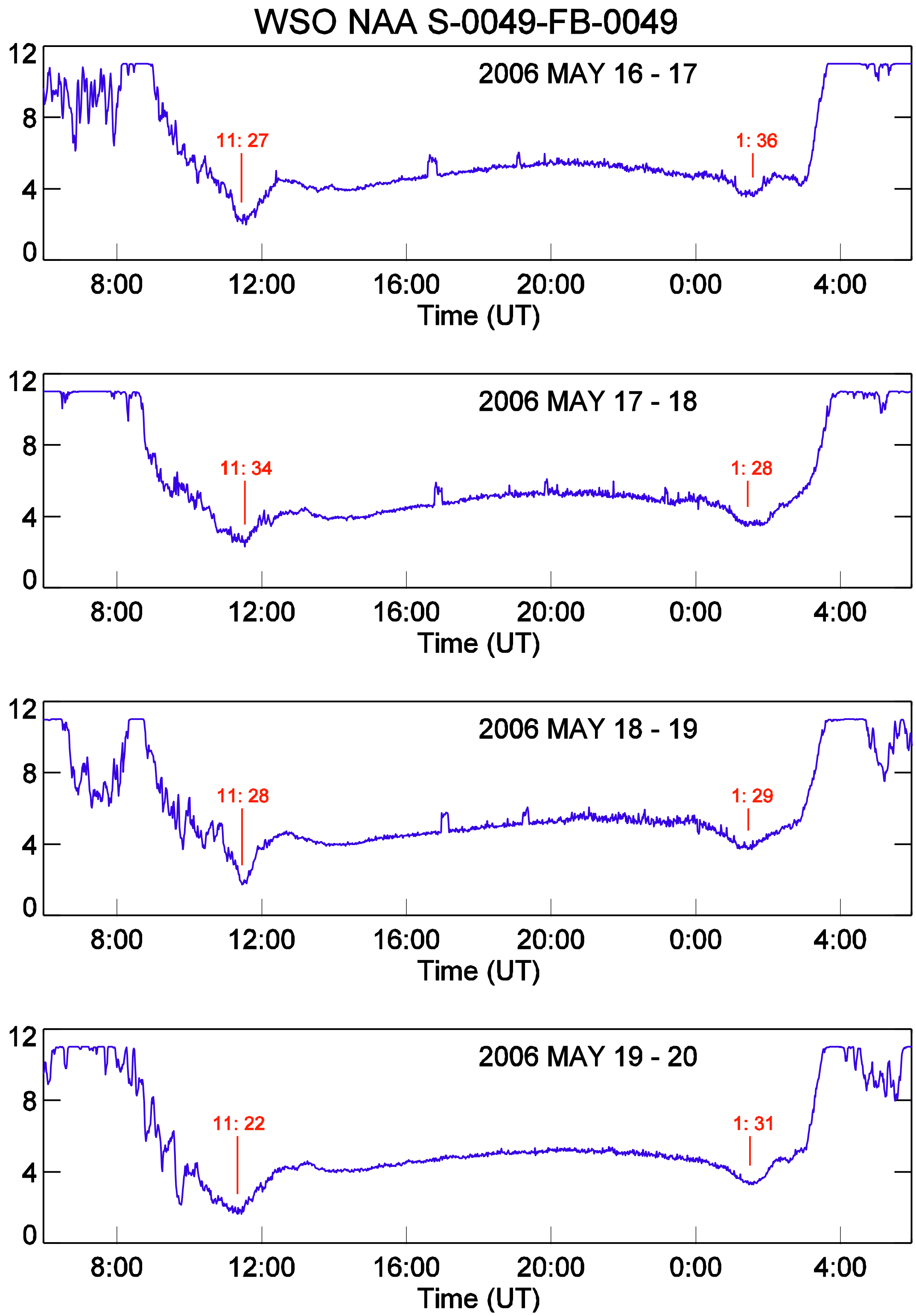
If you see a lot of "wiggles" in your data in the nighttime, the radio waves are probably responding to a lightning storm somewhere between your site and the transmitter. By checking the weather reports, and comparing your data with data from other locations, you can sometimes track down where these storms were!

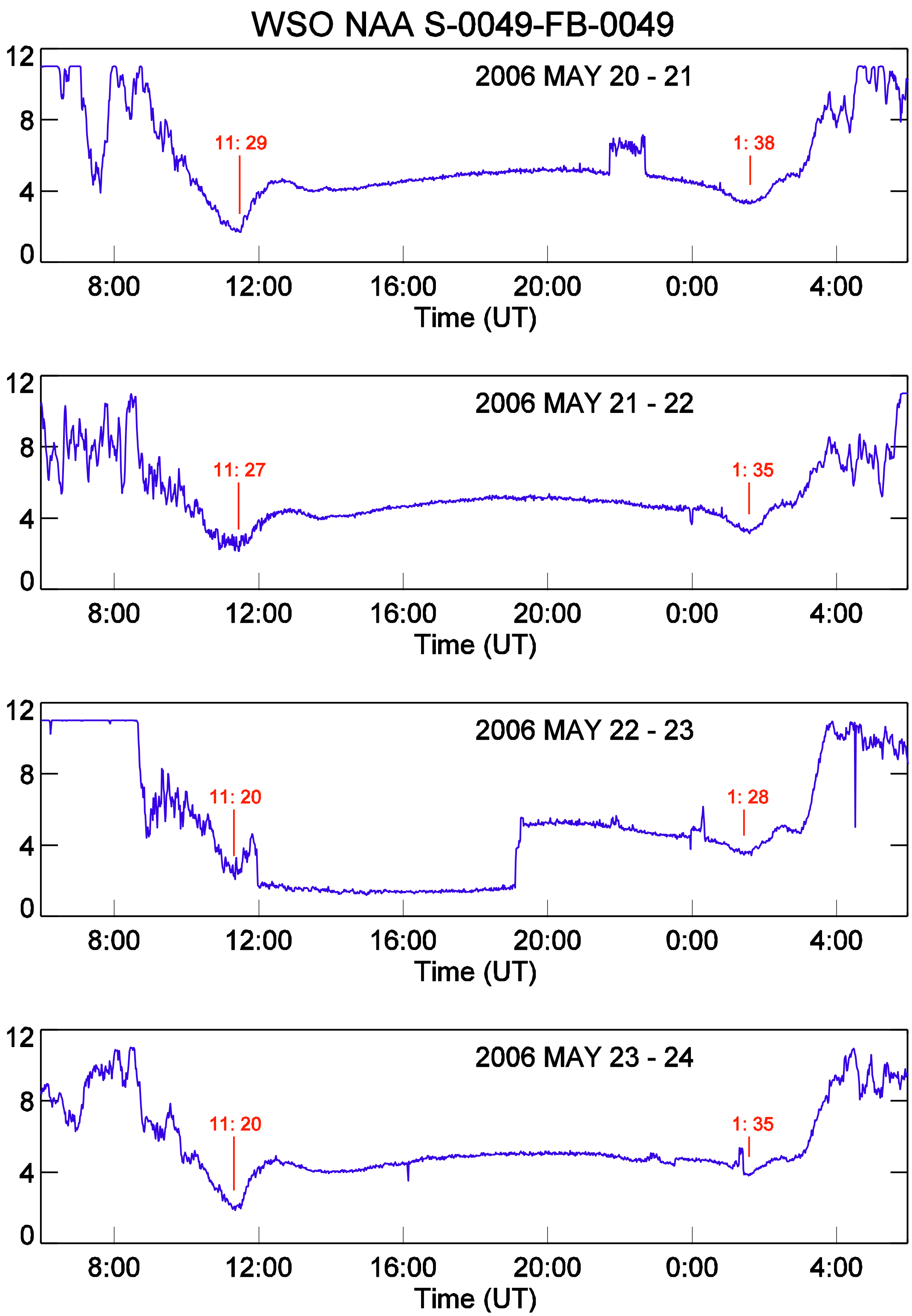
Stormy Night of SID Data



Sample Data

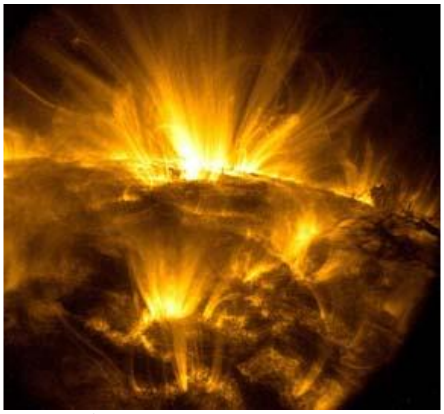
From WSO in Palo Alto, California, USA
Monitoring the transmitter NAA at Cutler, Maine, USA




WSO NAA S-0049-FB-0049
2006 MAY 20 - 21
11: 29
1: 38
2006 MAY 21 - 22
11: 27
1: 35
2006 MAY 22 - 23
11: 20
1: 28
2006 MAY 23 - 24
11: 20
1: 35
12
8
4
0
8:00
12:00
16:00
20:00
0:00
4:00
Time (UT)

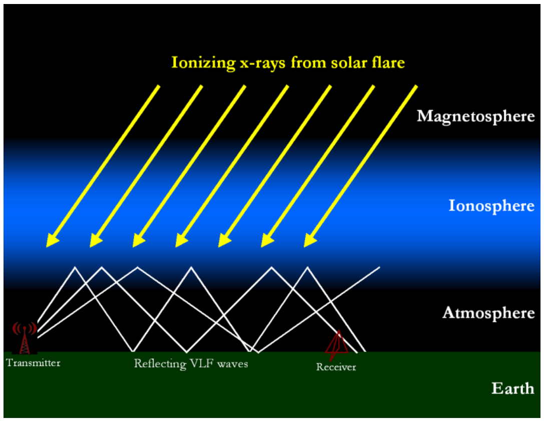
SID Monitor

Tracking Solar Flares Activity



Solar flares imaged by the TRACE satellite. Photo courtesy NASA.

The Sun spews out a constant stream of X-ray and extreme ultraviolet (EUV) radiation. This energy, along with that from cosmic rays, affects the Earth's ionosphere, starting some 60 km above us. When solar energy or cosmic rays strike the ionosphere, electrons are stripped from their nuclei. This process is called ionizing, hence the name ionosphere. It is the free electrons in the ionosphere that have a strong influence on the propagation of radio signals. Radio frequencies of very long wavelength (very low frequency or "VLF") "bounce" or reflect off these free electrons in the ionosphere thus, conveniently for us, allowing radio communication over the horizon and around our curved Earth. The strength of the received radio signal changes according to how much ionization has occurred and from which level of the ionosphere the VLF wave has "bounced."



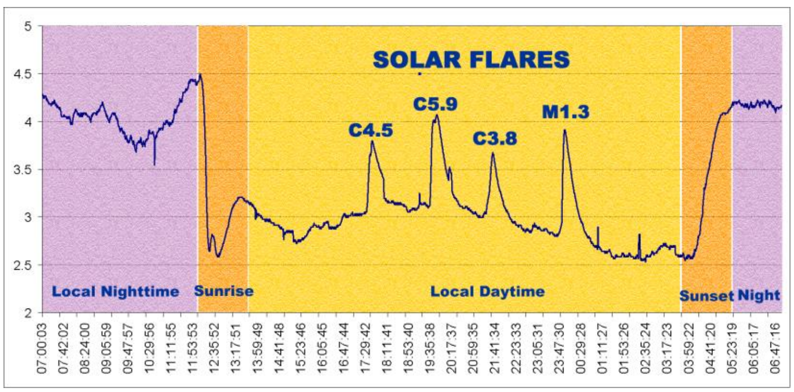
The Earth's ionosphere and reflecting of VLF radio waves.
Image courtesy of Morris Cohen, Stanford University

The ionosphere has several layers created at different altitudes and made up of different densities of ionization. Each layer has its own properties, and the existence and number of layers change daily under the influence of the Sun. During the day, the ionosphere is heavily ionized by the Sun. During the night hours the cosmic rays dominate because there is no ionization caused by the Sun (which has set below the horizon). Thus there is a daily cycle associated with the ionizations.

In addition to the daily fluctuations, activity on the Sun can cause dramatic sudden changes to the ionosphere. The Sun can unexpectedly erupt with a solar flare, a violent explosion in the Sun's atmosphere caused by huge magnetic activity. These sudden flares produce large amounts of X-rays and EUV energy, which travel to the Earth (and other planets) at the speed of light. When the energy from a solar flare or other disturbance reaches the Earth, the ionosphere becomes suddenly more ionized, thus changing the density and location of its layers. Hence the term "Sudden Ionospheric Disturbance" (SID) to describe the changes we are monitoring and also the nickname of our space weather monitoring instrument, SID.

Find potential flares in your SID data

Solar SID data is somewhat similar to that from a seismograph. On the graph below, the horizontal axis represents time, in this case about 24 hours. The vertical axis represents strength of the VLF signal being received. (The actual measured values of this aren't important, only the amount of change.) As you learned above, the strength of the VLF signal changes depending upon the ionization of the Earth's ionosphere. Solar flares show up on SID data as spikes above (or occasionally below) the normal signal strength level. Four solar flares are labeled on the data graph below.

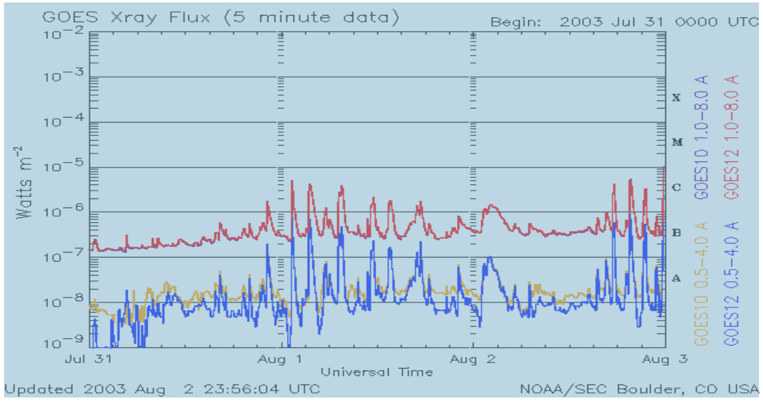


SID data graph showing flares. Colors and labels added for clarity.

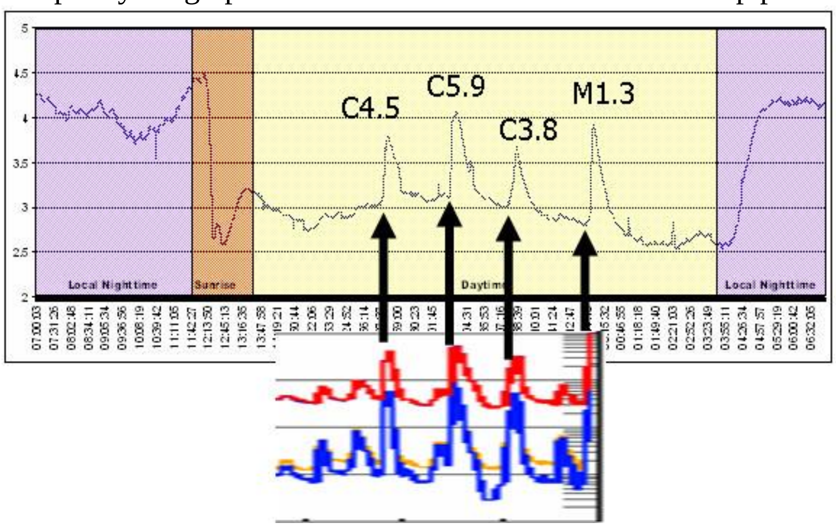
Look up your potential flare to see if a GOES satellite also picked it up

Look for any large spikes (either up or down) in your data. Check for the date and time (in UT). If you think you might be seeing a flare happening right now, or in the last few hours, check: http://www.sec.noaa.gov/rt_plots/xray_5m.html
If you think you have found a flare from a previous day, check:
http://www.lmsal.com/SXT/plot_goes.html?goes=Access+GOES+Data

Both these sites show data similar to yours, though taken from the Geostationary Operational Environmental Satellites (GOES) that circle the Earth in a geosynchronous orbit over the equator. The GOES graphs usually show data for the last few days (note that times are given in UT). The graph is updated every 5 minutes, so if a solar flare is happening right now, you can watch the changes in the graph! A sample GOES graph is below. The different colored lines represent data from different channels and satellites. You usually only need pay attention to the uppermost line.



Now you can compare your graphs with those from GOES and match up potential flares:



If your data and the GOES data match up, you have most likely found a flare! If the GOES data do not show a spike when your data do, you may have picked up something else. The most common is electrical interference.

Find the strength of your flare

If your flare happened more than a day ago, you can find out its strength in a list of flare events kept by the National Oceanic and Atmospheric Administration's (NOAA) Space Environment Center. These events are picked up from the GOES data, like that above, and summarized in catalogs:

http://www.sec.noaa.gov/ftpmenu/indices/events.html

Once at this site, click on the (UT) date on which you think you found your flares. (If you need the list from a previous year, use the "To parent directory" link.) You will find a page that looks something like this:

```
:Product:  20050831events.txt
:Created:  2005 Sep 01 2102 UT
:Date: 2005 08 31
# Prepared by the U.S. Dept. of Commerce, NOAA, Space Environment Center.
# Please send comments and suggestions to SEC.Webmaster@noaa.gov
#
# Missing data: ////
# Updated every 30 minutes.
#                     Edited Events for 2005 Aug 31
#
#Event   Begin   Max     End  Obs  Q  Type  Loc/Frq   Particulars       Reg#
#-------------------------------------------------------------------------------
7520 +    0018   0023    0033  G12  5  XRA  1-8A      B1.6    1.3E-04    0806
7520      0024   0024    0024  G12  5  XFL  S18E35   5.0E+01 8.4E+01 0806

7530 +    0052   0110    0123  G12  5  XRA  1-8A      B5.0    5.9E-04    0806
7530      0055   0111    0122  G12  5  XFL  S18E34   8.5E+02 2.1E+03 0806

7540     0155   0156    0156   PAL  G  RBR  410      480    ….
```

Sample Goes Catalog Entry (highlights added)

First, check that the "**Date**" given on the third line is the date you wanted. (Don't get confused by the "Created" date). The only other columns you need to worry about are the **Type**, **Particulars**, and **Reg#**. (If you would like to understand everything in the reports, read http://www.sec.noaa.gov/ftpdir/indices/events/README.)

Type: This tells the type of event being cataloged. Solar flares will be listed as **XRA**. You can ignore all lines without XRA.

Particulars: This column tells how strong a flare GOES detected. To understand it, you need to know how solar flares are classified:

> *B class flares:* These are the smallest flares and occur often. SID is not sensitive enough to detect them.
> *C class flares*: These are the next strongest flares, though they are usually still small. SIDs are usually able to detect flares Class C2.0 or above.
> *M class flares:* Are larger yet and occur less frequently. These should be very apparent on your SID graphs.
> *X class flares*: These are huge and easy to detect. If aimed at the Earth, they can cause major disruptions in communications, radio, and power grids. Some X class flares are too much for SID to handle and they will peak off the charts, causing a plateau effect.

The number after the flare class gives a measure of strength, e.g. B1.6 or C8.3. The numbers work like the Richter seismic scale -- a base-10 logarithmic scale where each whole number increase in magnitude represents a tenfold increase in energy.

Reg #: This column tells you which active region of the Sun produced the flare. You will use this number in the next part of the activity.

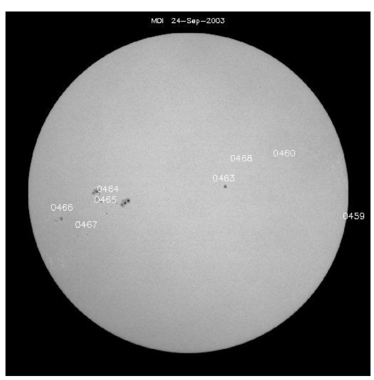
Trace your flare back to the Sun

Active regions are places on the visible surface of the Sun containing strong magnetic fields in complex configurations and usually in a constant state of change and flux. Active regions are often associated with sunspots. They are most often the source of the solar flares you have detected.

Solar active regions

Active regions are given consecutive numbers by scientists as they appear on the disk. If you have detected a flare and want to know where on the Sun it came from, look at REG# in the GOES catalog listing, as you did above. Then, using the time and region number of a flare, you can see a picture of the active region on the Sun itself! Go to **http://sohowww.nascom.nasa.gov/** and hit "Sunspots" in the upper right corner.

The current day's solar active regions will be shown there. (If the disk is blank, there are no active regions for that day.) If you need to check for previous days' images, hit the "List of all available daily images" near the bottom of that page.



Example of a picture of the Sun with active regions labeled.
Image courtesy MDI instrument on SOHO spacecraft.

Missing flares?

Sometimes your flare will show up in the GOES data graphs but not the catalog. The GOES data is reduced by hand, and often flares are "missed" being added to the catalog, or they are determined for some reason not to be included in the catalog. If you find flare signatures in your SID data, and if those flares also appear on the GOES graphs, but they are not listed in the catalog, then you may have found flares overlooked or ignored by the GOES cataloger. If you do find a flare that appeared in the GOES data but not the catalog, you might want to contact the GOES personnel to ask about the omission. Check the GOES website for contact information.

Remember that the GOES satellites are detecting solar flares as they are emitted from the Sun. Your SID monitor is detecting changes to the Earth's ionosphere caused by those same flares. So while your monitor and the satellites are tracking different effects, they are based on the same phenomena.

Learning the history of your flare's active region

Starting at **http://sohowww.nascom.nasa.gov/** hit "Sunspots"), you can trace back the history of your active region. Using the "List of all available daily images" link at the bottom, work your way back in time until your find the region just appearing. If the region appears from over the Sun's eastern (left side) limb, then you can look for it on the *farside*, or back side, of the Sun. You've find images at:

http://soi.stanford.edu/data/full_farside/

It will take you a little while to understand how to read these images, but the webpage gives you some help. And it's worth the effort when you discover your active region first appearing, perhaps on the far side of the Sun!

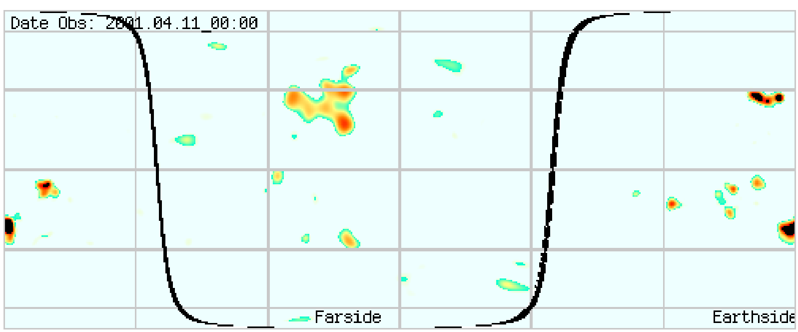


Image of the Sun, including side facing Earth and side away from Earth.
Image courtesy Phil Scherrer, Stanford University.
Mercator projection, similar to this of the Earth:

Image from http://www.world-atlas.us/

Name: ___________________________

Solar Flare Tracking Sheet

Use one sheet for every flare you are tracking

1. Note the date and time in UT (Universal Time) of your potential SID flare and the monitor, location, and transmitter that picked it up:

   ___________________________ ______________________________
   Flare Date (UT) *Flare Time (UT)*

   _______________ __________________________ ___________
   Monitor ID *Monitor Location* *Transmitter*

2. Compare your graph with the GOES data and check one of the following:

   _____ My flare was in the last few days, and I found it at:
   http://www.sec.noaa.gov/rt_plots/xray_5m.html

   _____ My flare was from previous days, and I found it at:
   http://www.lmsal.com/SXT/plot_goes.html?goes=Access+GOES+Data

   _____ I did not find my flare in the GOES data
   If your data showed something that the GOES data did not, you have probably found electrical interference or some other event. No need to go further on this sheet.

3. Looking at the GOES graph that shows your flare, estimate how strong it might be. (Do this by using the topmost line on the graph, find the peak of your flare and read across the graph to the labels on the right side).

   It looks like my flare is a _________ class flare.
   C / M / X

4. Check the GOES catalog (list) of flares to assure your flare was cataloged and to determine how strong your flare actually was. (Flares less than about 1 day old will not appear in the catalogs yet.)

   http://www.sec.noaa.gov/ftpmenu/indices/events.html
   Find Type = XRA and the "Particulars" column will tell you the strength
   (If you need the list from a previous year, use the "To parent directory" link.)

   ______ My flare appeared in the GOES catalog, with a strength of
   _____________ (*e.g. C4.2, X7)*

   ______ My flare did not appear in the GOES catalog (although it did appear on the GOES data graph in #2 above) (*sometimes this happens*)

5. In the GOES catalog above, find the solar active region number from which your flare emanated (in the "Reg#" column):

   My flare emanated from this active region on the Sun: **_______________**

6. Now look for an image of that active region on the Sun:

   Go to **http://sohowww.nascom.nasa.gov/**
   And hit "Sunspots" near the upper right corner

   I found my solar active region image at this website:
   http://sohowww.nascom.nasa.gov/data/synoptic/sunspots_earth/______________

7. Track when your active region first appeared on the Sun. Check the previous images on the SOHO site above. If the images show your active region rotated into view around the eastern (leftmost) limb of the Sun, then check the farside images on:
   http://soi.stanford.edu/data/full_farside/

   The active region that caused my flare first appeared on the Sun on:
   ________________ (*date*, *in UT time*)

Suggestions for Further Activities and Research Projects

Students might wish to compare data from other SID sites. This is available at http://sid.stanford.edu/database-browser/

Going further with the sunrise and sunset data analyses

The sunrise and sunset signatures have an unusual shape. Are these shapes consistent across monitors and/or sites? Do they change with longitude, with latitude? Do they change with season? Could weather or thunderstorms be influencing the shape of the signature? What else might affect the signature shapes?

Can you determine the height of the ionosphere by looking at the differences between the transmitter and receiver sunrises?

Does the length, i.e. extent of time of the sunrise/set signature, change during the year? At your site? At others? Does the length change with different monitors, different transmitters, different latitudes, different longitudes, and/or different seasons? Does the sunset signature differ when there has been significant solar activity during the day?

The sunrise and sunset signatures have dips and rises that correspond to different ionization events. How long before actual sunrise is the first dip? What could be causing that? Are the sunrise and sunset signatures similar? If not, why not? What about for other monitors at other sites? These are difficult questions. Exploring them will require you to develop a deep understanding of the ionosphere.

Once you gather data and think you have discerned some answers, see if you can predict the sunrise and/or sunset effects for your monitor at different times of the year. How about for a distant SID monitor, or for a monitor that is tracking a different frequency? The ability to accurately predict events is a good test of whether your discoveries ("theories" or understandings) are correct or not.

Sunrise on Earth. Photo courtesy NASA.

Does latitude affect ionospheric response to flares? If so, in what ways?

Students might attempt to compare solar flare signatures from various SID monitors around the world to find out if latitude affects the signatures and hence the ionospheric response to flares. Try comparing the graphs from known solar events with each other and with data from the GOES satellite. You may have to adjust the times to allow the events to line up. To find a list of known flares as detected by the GOES satellites, see http://www.sec.noaa.gov/ftpmenu/indices/events.html

As you compare your data, keep in mind that different monitors will be calibrated slightly differently, thus having their data values show up between -5 and 5, or -2 and 4. It is not the absolute values of the data that are important -- rather the size of the change from the baseline. Students might want to normalize their data, or convert to a common baseline. For instance, they might convert all data into values between 0 and 1. Different sites' computer clocks might be significantly different as well. Take this into account when matching up flares.

Students start by comparing SID events from monitors at various latitudes. Are the shapes of the responses the same? The timing? The length of the response? How do the responses differ depending upon the transmitter being tracked? How do your data compare with the GOES data?

Unidentified Events?

If you have unidentified signals, then your students may be picking up electrical interference from somewhere or something. Most likely it is a local disturbance caused by somebody turning on a machine nearby. If the disturbance is regular and periodic that's a big hint that it might be interference. Or, if certain other sites pick up the event as well, then it may have been caused by a large thunderstorm somewhere between the transmitter and receiver. Or, they may have picked up a gamma ray burst. Or, their disturbance might have been related to an auroral storm. Or, it might be worth checking cosmic ray monitors for particles or geomagnetic indices for CME impact effects. To track these down, have students compare their local data with other sites' data, both those tracking the same transmitter and different transmitters. What can they discover based on which sites showed the event and which didn't? Could they "triangulate" to determine the potential ionospheric source of the disturbance? Note that unidentified events might happen in the nighttime as well as daytime.

SID Antennas

"Antennas," to quote a friend, "are one of life's eternal mysteries." The SID Manual describes how to build a couple loop antennas, one twice the diameter of the other. But the options for size, shape, materials, and wire are almost unlimited. Why? What is the best design and size for a SID antenna, for an AWESOME one? What are the tradeoffs? What materials can be used? What materials should be avoided? Most of these answers are not well known. If you have some advanced students interested in a challenging task, perhaps they would like to experiment with antenna designs. To get started, try reading: Antenna Basics (http://www.electronics-tutorials.com/antennas/antenna-basics.htm), Loop Antennas (http://www.frontiernet.net/~jadale/Loop.htm) and our webpage on antennas (http://sid.stanford.edu/SID/educators/antennas.html).

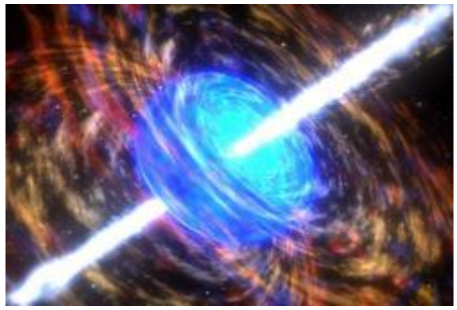
Lightning Phenomena and Nighttime Events

Lightning. Photo courtesy of Alan Moller.

As your students know, solar activity will affect the ionosphere only during the daytime. But many phenomena such as lighting storms, sferics, and whistlers have a dramatic effect on the nighttime ionosphere, when effects from the Sun can no longer drown them out. Stanford's STAR Laboratory - VLF Group (http://www-star.stanford.edu/~vlf/) investigates the Earth's electrical environment, lightning discharges, radiation belts, and the ionosphere. The AWESOME instrument data is broad-band and much more sensitive than the SID instrument's and thus more useful for nighttime ionospheric research.

By comparing their data with data from other SID sites, can your students identify lightning storms being picked up? Using weather data, can your students locate these storms? How close to the direct path between site and transmitter does a storm have to be to register? A couple websites might help students get started: http:www.vlf.it/Thierry/waveguide_propagation.html (which tells how waveguides work) and http:/www.vlf.it/storm_monitor/stormmonitor.htm (shows how to build a particular circuit to monitor lightning) and http://www.vlf.it/parmigiani-frozen/frlight.htm (frozen lightning).

Gamma Ray Events



Gamma-Ray-Burst. Image from NASA / SkyWorks Digital

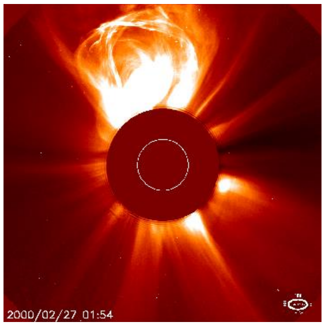
Gamma-ray bursts (see http://imagine.gsfc.nasa.gov/docs/science/know_l1/bursts.html) are short-lived explosions of gamma-ray photons, the most energetic form of electromagnetic radiation. Some of them are believed to be associated with supernovae, the birth of black holes from deaths of especially massive stars, produced during neutron star mergers, or emanating from starquakes on a magnetar (a super-magnetized neutron star). Lasting anywhere from a few milliseconds to several minutes, gamma-ray bursts shine hundreds of times brighter than a typical supernova and about a million trillion times as bright as the Sun.

Gamma ray bursts are rare and spontaneous events. We wouldn't expect students to use their monitors solely to wait for these to occur. However, if your students pick up a significant and unexplained change to the ionosphere, they may have detected a gamma ray burst. See http://grb.sonoma.edu/ (Gamma-ray Burst Real-time Sky Map) to check lists of current and known gamma ray bursts. There has been very little research done to determine if the SID monitor can or cannot pick up gamma ray events. Perhaps your students will be the first to find out!

Enormous gamma-ray flares affect our lower ionosphere to such a massive degree that, by watching and measuring its response to and recovery from the flare, scientists learn about the dynamics of these upper atmospheric regions. The full story about a gamma ray event picked up by AWESOME-like monitors can be found at http://news-service.stanford.edu/news/2006/march1/ainansr-030106.html (Big gamma-ray flare from star disturbs Earth's ionosphere).

The recent discovery of terrestrial gamma-ray flashes (TGFs) opens broad questions about the nature of the physical processes associated with lightning strikes, in particular, those that produce the extremely high electric fields and highly relativistic electrons responsible for gamma-ray emission. Energy levels from these TGFs rival the energy levels of powerful cosmic sources such as black holes and collapsing stars, except they originate in our own atmosphere. Most TGFs are closely linked with individual lightning strokes. However, the nature of the physical processes that generate TGFs remains unknown. We do not know if the SID monitors are capable of detecting these high-energy local transmissions. Are your students interested in finding out?

Effects of Coronal Mass Ejections on the Earth's ionosphere



A Coronal Mass Ejection explodes on the Sun.
Image courtesy LASCO/SOHO.

Huge clouds of hot plasma, called Coronal Mass Ejections (CMEs) are occasionally expelled from the Sun. A CME may accelerate ions and electrons and travel through interplanetary space to the planets. These CMEs can have a significant affect on the Earth's atmosphere and magnetosphere. Besides triggering beautiful auroras, these solar storms can damage satellites, disrupt power grids and electrical systems, interfere with communications, and disturb animal movements. They can even threaten astronauts and high-flying airplanes with their radiation! These events are part of space weather, the influence of the Sun on the Earth and other planets. To learn more about space weather, see http://solar center.stanford.edu/solar-weather/.

The effects of CMEs on the Earth are usually most apparent by disruptions in the Earth's magnetic field, best sensed by a magnetometer. However, it is unknown whether CMEs can have a significant and detectable impact on the ionosphere. And, even if they do, we do not know whether the SID or AWESOME monitors might be able to detect these events. You can start learning about CMEs at http://solarscience.msfc.nasa.gov/CMEs.shtml
The LASCO instrument (http://lasco-www.nrl.navy.mil/) on the SOHO spacecraft tracks and images CMEs. Perhaps your students would like to search SID data to determine if CMEs do have a measurable impact on the ionosphere that can be tracked by the monitors. They might start by checking geomagnetic indices for CME impact effects.

Ionospheric Predictors to Major Earthquakes

There is some intriguing research about whether large earthquakes are associated with ionospheric changes. A good overview is the article by Friedemann Freund, "Predicting Earthquakes," in The Economist, 14 December 2005.

Iranian earthquake. BBC image.

In the laboratory, the crushing of rock crystalline structures generates electromagnetic fields. The theory is that similar events in the Earth can affect the ionosphere and thus show up as precursors to large earthquakes. This research is still controversial and, if there are effects, they may be too subtle for the SID instruments to pick up.

However, at least one research group claims to have found unusual sunset signatures associated with the devastating earthquake and tsunami of December 2004. The paper is: *Unusual Sunset Terminator behavior of VLF signals at 17kHz during the Earthquake episode of Dec., 2004* (http://www.ursi.org/Proceedings/ProcGA05/pdf/EP.18(01596).pdf). They found the sunset signature was shifted later by 9 minutes, a significant change. One would think that, for a monitor to pick up these changes, the epicenter of a large quake would need to fall on or near the line between the transmitter and receiver. However, these researchers and the transmitter were in India, a good ways from the epicenter.

If your students are interested in exploring the relationship between SID data and major earthquakes, here are some additional references where they might get started. Note that very little information of this sort has been written for students. Hence these papers will be difficult for them to decipher:

- Fraser-Smith, A. C., A. Bernardi, P. R. McGill, M. E. Ladd, R. A. Helliwell, and O. G. Villard, Jr., "Low-Frequency Magnetic Field Measurements near the Epicenter of the Ms 7.1 Loma Prieta Earthquake," *Geophys. Res. Letters*, *17*,1465-1468, 1990
- Hayakawa, M, O.A. Molchanov, T. Ondoh, & E. Kawai, Precursory signature of the Kobe earthquake on VLF subionospheric signal. *J Atmos Electr*, 16, p. 247, 1996.
- Molchanov, O. A., and M. Hayakawa, "Subionospheric VLF signal perturbations possibly related to earthquakes," *J. Geophys. Res.*, vol. 103, p. 17 489, 1998.
- Chakrabarti, S K, M Saha, R Khan, S Mandal, K Acharyya, R Saha. Unusual sunset terminator behavior of VLF signals at 17 kHz during the Earthquake episode of Dec. 2004. URSI General Assembly, 2005.

If your students do pursue something of this nature, make sure you make it clear to them that this is very new, challenging, and tentative research, that their SID or AWESOME monitor may not be sensitive enough to pick up the changes, and that they may or may not find any good results. On the other hand, it is possible they could make major discoveries…

Meteor Showers?

Are there VLF signals associated with meteor showers, or large meteors? So far, the answer seems “probably not”. But your students might want to do further studies. They could start at http://www.vlf.it/leonids/leonids.htm

What happens to the VLF signature during a total solar eclipse?

Where must the eclipse path be in relation to the transmitter and receiver? Start by looking at http:www.vlf.it/eclipse99/eclipse.htm. Are your students interested in using a SID monitor to track an upcoming solar eclipse? If so, we may be placing monitors in very northern regions of the Earth to track the eclipse of 1 August 2008. Have them contact us (sid@sun.stanford.edu) if they are interested in receiving data.

Electrical interference

Interference often causes a problem with SID data. Could you students do some investigations and experiments with understanding what types of devices might be causing electrical interference, and how far away from these devices your SID monitor should be? Try starting with http://www.vlf.it/localsignals/localsignals.html or http://www.vlf.it/nrs/nrs.htm.

Glossary

Active Region (solar) -- A localized, transient volume of the solar atmosphere characterized by complex magnetic fields, often associated with sunspots, flares, coronal mass ejections, plages, faculae, and other solar phenomena.

Angstrom -- A unit of length = 1.0E-08cm.

Astronomical unit (AU)--The mean Sun-Earth distance, a unit of measure widely used in expressing distances in the solar system. 1 AU = 149,600,000 km = 92,957,000 miles.

Aurora -- A colorful glow in the sky, often observed in a doughnut-shaped region around the magnetic poles ("auroral zone") and occasionally further equatorward. The aurora is generally caused by fast electrons from space guided earthward by magnetic field lines. Its light comes from collisions between such electrons and the atoms of the upper atmosphere, typically 100 km (60 miles) above ground. The name comes from an older one, "Aurora Borealis," Latin for "northern dawn," given because an aurora near the northern horizon (its usual location when seen in most of Europe) looks like the glow of the sky preceding sunrise. Also known as Northern Lights, Aurora Australis (Southern Lights), and polar aurora.

Auroral oval--the region in which aurora appears at the same time, corresponding to a "ring of fire" around the magnetic pole, often observed by satellites. It resembles a circle centered a few hundred kilometers nightward of the magnetic pole, and its size varies with magnetic activity. During large magnetic storms it expands greatly, making auroras visible at regions far from the pole, where they are a rare occurrence.

Auroral zone--the region on Earth where auroras are common, essentially a smeared-out average (over time and distance from the magnetic pole) of the auroral oval. Typical magnetic latitude is 63-65 degrees.

AWESOME Monitor -- **A**tmospheric **W**eather **E**lectromagnetic **S**ystem for **O**bservation **M**odeling and **E**ducation instruments which monitor changes in the Earth's ionosphere by tracking VLF signals as they bounce through the Earth's waveguide. Developed by the Space, Telecommunications, and Radioscience (STAR) Laboratory, a research group within the Department of Electrical Engineering of Stanford University in association with the Stanford Solar Center and NSF's Center for Integrated Space Weather Modeling (CISM).

Bartels Rotation Number -- The serial number assigned to 27-day recurrence periods of solar and geophysical parameters. The equatorial rotation rate of the Sun is very close to 27 days. Rotation 1 Day 1 in this sequence was assigned arbitrarily by J. Bartels to February 8, 1832.

Burst (radio) -- A transient enhancement of the solar radio emission, usually associated with an active region or flare.

Chromosphere -- The layer of the solar atmosphere above the photosphere and beneath the transition region and the corona. It is seen during eclipses as a bright red ring around the Sun, with the term *burning prairie* used to describe it.

CME – See Coronal Mass Ejection

Coordinated Universal Time – see Universal Time

Corona (solar) -- the outermost layer of the Sun's atmosphere, visible to the eye during a total solar eclipse; it can also be observed through special filters and best of all, by X-ray cameras aboard satellites. The corona is very hot, up to 1-1.5 million degrees centigrade, and is the source of the solar wind

Coronal Hole -- an extended region of the corona, exceptionally low in density (essentially a large open gap), and associated with photospheric regions. Coronal holes are closely associated with those regions on the Sun that have an "open" magnetic geometry, that is, the magnetic field lines associated with them extend far outward into interplanetary space, rather than looping back to the photosphere. Ionized material can flow easily along such a path, and this in turn aids the mechanism that causes high speed solar wind streams to develop.

Coronal mass ejection (CME)--a huge cloud of hot plasma occasionally expelled from the Sun. It may accelerate ions and electrons and travel through interplanetary space as far as the Earth's orbit and beyond. The leading edges of fast-moving CMEs drive giant shock waves before them through the solar wind at speeds up to 1200 km per second. When the shock reaches Earth, a magnetic storm may result. CMEs occurs on a time scale between a few minutes and several hours, and involve the appearance of a new discrete, bright, white light feature in a coronagraph field of view that displays a predominantly outward motion. The solar corona material is massive in size (they can occupy up to a quarter of the solar limb), and frequently accompanied by the remnants of an eruptive prominence, and less often by a strong solar flare. CMEs are the crucial link between a solar disturbance, its propagation through the heliosphere, and the effects on the Earth.

Cosmic rays/radiation -- A steady drizzle of high energy ions arriving at the solar system from the distant universe. Their energies are enormous, ranging from 1-2 billion electron volts to perhaps 100,000,000 that much, though the higher energies are rare. Their total energy flow is comparable to that of starlight. The origin of their huge energies is thought to come from expanding shock fronts created by huge cosmic explosions such as supernovae.

Dipole--a compact source of magnetic force, with two magnetic poles. A bar magnet, coil or current loop, if their size is small, create a dipole field. The Earth's field, as a crude approximation, also resembles that of a dipole, located near the Earth's center.

Drift--A magnetically trapped ion or electron moves as if it were attached to a magnetic field line. Drift is one of the features of such motion, namely its slow shift from one guiding field line to its neighbor. In the Earth's magnetic field, such drifts gradually move particles all the way around Earth. Viewed from far above the north magnetic pole, ions drift around the Earth clockwise, electrons counter-clockwise, resulting in an electric current circling the Earth, the ring current.

Earth radius (RE) -- the average radius of the Earth, a convenient unit of distance in describing phenomena and orbits in the Earth´s neighborhood in space. 1 RE = 6371 km = 3960 miles, approximately.

Eclipse (solar) -- occurs when the Moon passes between Earth and the Sun, thereby totally or partially obscuring Earth's view of the Sun. This configuration can only happen during a new moon, when the Sun and Moon are exactly lined up as seen from the Earth. Total solar eclipses are very rare events for any given place because totality is only seen where the Moon's shadow touches the Earth's surface, and only last for a few minutes.

Ecliptic -- the plane in which the Earth orbits the Sun

Electric charge -- that which causes electrons and ions to attract each other, and to repel particles of the same kind. The electric charge of electrons is called "negative" (-) and that of ions "positive" (+). Materials such as glass, fur and cloth acquire an electric charge by rubbing against each other, a process which tears electrons off one substance and attaches it to the other. Electric charges (+) and (-) may also be separated by a chemical process, as in an electric battery.

Electric current--a continuous flow of electrons and/or ions through a material which conducts electricity. A current usually flows in a closed circuit, without beginning or end. In daily life currents are generally driven through wires by voltages produced by batteries or generators. In space plasmas, some currents may be produced this way, but many are inherent to the way ions and electrons move through magnetic fields, e.g. their drifts.

Electric field -- the region in which electric forces can be observed, e.g. near an electric charge. As a field, it may also be viewed as a region of space modified by the presence of electric charges.

Electrical interference – see interference

Electromagnetic field/wave -- a combination of oscillating magnetic and electric fields, spreading in wavelike fashion through space at a speed of about 300 000 km/sec. Such waves include all forms of light--infra-red and ultra-violet, visible light, as well as radio waves, microwaves, X-rays and gamma rays.

Electron -- a lightweight particle, carrying a negative electric charge and found in all atoms. Electrons can be energized or even torn from atoms by light and by collisions, and they are responsible for many electric phenomena in solid matter and in plasmas.

Electron volt (ev)--a convenient unit of energy applied to ions and electrons, equal to the energy gains when such particles "fall" across a voltage difference of 1 volt. Gas molecules at room temperature have about 0.03 ev, on the Sun's face about 0.6 ev, typical electrons of the aurora 5000 ev, typical protons in the inner radiation belt 20,000,000 ev, typical cosmic ray protons near Earth 10,000,000,000 ev, and the highest energies of cosmic rays may reach up to 10,000,000,000 times more.

Energetic particles--charged atomic particles moving rapidly, often at a significant fraction of the speed of light. They can penetrate matter, ionize the material which they traverse, and emit energetic photons (e.g. of X-rays).

Energy -- loosely, anything that can cause a machine to move. For example, energy is contained in moving water, water raised to a high place, heat or magnetic fields. The energy of fast ions and electrons (measured in "electron volts") is a measure of their speed, and it enables them (for instance) to penetrate matter.

Extremely Low Frequency (ELF) -- that portion of the radio frequency spectrum from 30 to 3000 hertz.

Extreme ultraviolet light/energy/radiation (EUV) -- a portion of the electromagnetic spectrum from approximately 100 to 1000 angstroms.

Facula, pl. faculae -- A bright cloud-like feature located a few hundred km above the solar photosphere near sunspot groups, seen in white light. Faculae are clouds of emission that occur where a strong magnetic field creates extra heat (about 300 degrees K above surrounding areas).

Farside (solar) – The half of the Sun not seen from Earth at any given time is colloquially referred to as the "farside". It is somewhat akin to the back side of the Moon, although the Sun does not keep one side locked towards the Earth as the Moon does.

Filament (solar) -- a mass of gas suspended over the photosphere by magnetic fields and seen as dark lines threaded over the solar disk. A filament on the limb of the Sun seen in emission against the dark sky is called a prominence.

Flare (solar) -- a sudden eruption of energy on the solar disk, lasting minutes to hours, from which radiation and particles are emitted. Flares usually occur in the vicinity of active regions or sunspots. Their sudden brightening may be followed by the signatures of particle acceleration to high energies--X-rays, radio noise and often, a bit later, the arrival of high-energy ions from the Sun.

Frequency -- the number of back-and-forth cycles per second in a wave or wave-like process. Expressed this way, the frequency is said to be given in units of Hertz (Hz), named after the scientist who first produced and observed radio waves in the lab. Alternating current in homes in the US goes through 60 cycles each second, hence its frequency is 60 Hz; in Europe it is 50 cycles and 50 Hz.

Gamma ray bursts (GRB) -- short-lived sudden explosions of gamma-ray photons, the most energetic form of light. Lasting anywhere from a few milliseconds to several minutes, gamma-ray bursts shine hundreds of times brighter than a typical supernova and about a million trillion times as bright as the Sun, making them briefly the brightest source of cosmic gamma-ray photons in the observable universe. They can be associated with supernovae, pulsars, convergence of neutron stars or Black Holes, and other energetic cosmic cataclysms.

Gamma rays -- electromagnetic waves of the smallest wavelengths and highest frequencies known; the most energetic of waves in the electromagnetic spectrum. Gamma rays are generated by transitions within atomic nuclei such as those in radioactive atoms and nuclear explosions. This high energy radiation (energies in excess of 100 keV) is observed during large, extremely energetic solar flares.

Gauss -- The unit of magnetic induction in the cgs (centimeter-gram-second) system

Geomagnetic Field -- The magnetic field observed in and around the Earth. The intensity of the magnetic field at the Earth's surface is approximately 0.32 gauss at the equator and 0.62 gauss at the North Pole.

Geomagnetic Storm -- A worldwide disturbance of the Earth's magnetic field, distinct from regular diurnal variations.

Geosynchronous – The term applied to any equatorial satellite with an orbital velocity equal to the rotational velocity of the Earth. The net effect is that the satellite is virtually motionless with respect to an observer on the ground.

GMT -- Greenwich Mean Time. See Universal Time

GOES satellites – A collection of **G**eostationary **O**perational **E**nvironmental **S**atellites circling the Earth in a geosynchronous orbit, allowing them to hover continuously over one position on the surface. The geosynchronous plane is about 35,800 km (22,300 miles) above the Earth, high enough to allow the satellites a full-disc view. They provide a constant vigil for the atmospheric triggers for severe weather conditions such as tornadoes, flash floods, hail storms, and hurricanes. They also monitor solar flares and activity on the Sun.

Heliopause -- The region in space where the Sun's atmosphere merges with interstellar space. The position of the heliopause depends both on the strength of the solar wind and on the properties of the local interstellar medium.

Heliosphere -- The region in space that extends to the heliopause. The heliosphere is the cavity around the Sun in the local interstellar medium that is produced by the solar wind. The heliosphere contains most of the solar system, but not the most distant comets such as in the Oort cloud.

High Frequency (HF) -- that portion of the radio frequency spectrum between 3 and 30 MHz.

IMF—See Interplanetary Magnetic Field

IMF polarity -- the general direction of interplanetary magnetic field lines in a certain location (e.g. near Earth), i.e. whether the field lines head away from the Sun ("away polarity") or towards it ("towards polarity"). The IMF polarity determines which of the polar caps of the Earth is magnetically linked to the Sun and gets polar rain guided towards it.

Interference (electrical) -- electrical noise induced upon the signal wires that obscures the wanted information signal; inhibition or prevention of clear reception of broadcast signals.

Interference (waves) -- The variation of wave amplitude that occurs when waves of the same or different frequency come together.

International Heliophysical Year (IHY) 2007-9 -- an international science and education based celebration of the 50th anniversary of the International Geophysical Year 1957. Its goal us to advance our understanding of the fundamental processes that govern the Sun, Earth, and heliosphere and to demonstrate the beauty, relevance, and significance of space and Earth science to the world. See http://ihy2007.org/.

Interplanetary magnetic field (IMF) -- The magnetic field carried with the solar wind. The IMF is kept out of most of the Earth’s magnetosphere, but the interaction of the two plays a major role in the flow of energy from the solar wind to Earth’s environment.

Interplanetary shock -- the abrupt boundary formed at the front of a plasma cloud (e.g. one from a coronal mass ejection) if it pushes its way through interplanetary space much faster than the rest of the solar wind.

Ion -- Usually, an atom from which one or more electrons has been torn off, leaving a positively charged particle. "Negative ions" are atoms which have acquired one or more extra electrons. Clusters of atoms can also become ions.

Ionization -- The process by which a neutral atom, or a cluster of such atoms, becomes an ion. This may occur, for instance, by absorption of light ("photoionization") or by a collision with a fast particle ("impact ionization").

Ionosphere -- A region covering the highest layers in the Earth's atmosphere containing an appreciable population of ions and free electrons. The ions are created by sunlight ranging from the ultra-violet to X-rays and from cosmic rays. The ionosphere significantly influences radio wave propagation of frequencies less than about 30 MHz.

LASCO – The Large Angle and Spectrometric Coronagraph Experiment aboard the Solar and Heliophysics Observatory (SOHO) spacecraft. See http://lasco-www.nrl.navy.mil/

Low Frequency (LF) -- That portion of the radio frequency spectrum from 30 to 300 kHz.

Magnetar – a super-magnetized neutron star.

Magnetic field --a region in which magnetic forces can be observed. See also "electromagnetic field."

Magnetic field lines -- lines in space, used for visually representing magnetic fields. At any point in space, the local field line points in the direction of the magnetic force which an isolated magnetic pole at that point would experience. In plasma, magnetic field lines guide the motion of ions and electrons and direct the flow of some electric currents.

Magnetic poles -- A term with two meanings: 1) the points on the surface of the Earth towards which the compass needle points. (Several slightly different definitions exist, because the field is not exactly that of a dipole.) 2) A concentrated source of magnetic force, e.g. a bar magnet has two magnetic poles near its ends.

Magnetic storm -- A large-scale disturbance of the magnetosphere, often initiated by the arrival of an interplanetary shock originating at the Sun. A magnetic storm is marked by the injection of an appreciable number of ions from the magnetotail into the ring current, a process accompanied by increased auroral displays. The strengthened ring current causes a world-wide drop in the equatorial magnetic field, taking perhaps 12 hours to reach its greatest intensity, followed by a more gradual recovery.

Magnetogram -- a graphic representation of solar magnetic field strengths and polarity.

Magnetometer – an instrument for measuring magnetic fields.

Magnetopause --The boundary of the magnetosphere, separating plasma attached to Earth from the one flowing with the solar wind.

Magnetosheath -- The region between the magnetopause and the bow shock, containing solar wind which has been slowed down by passage through the bow shock. As the magnetosheath plasma streams away from the bow shock, it gradually regains its former velocity.

Magnetosphere--The region around Earth, bounded by the magnetopause, whose processes are dominated by the Earth's magnetic field.

Magnetotail -- The long stretched-out night side of the magnetosphere, the region in which substorms begin. It starts about 8 Earth radii (RE) nightward of the Earth and has been observed to distances of at least 220 RE.

MDI – see Michelson Doppler Imager

Medium Frequency (MF) -- That portion of the radio frequency spectrum from 0.3 to 3 MHz.

Mercator projection (maps) -- The Mercator projection is a cylindrical map projection onto a flat surface; devised by the Flemish geographer and cartographer Gerardus Mercator in 1569.

Michelson Doppler Imager (MDI) – an instrument on the SOHO spacecraft, designed to study the interior structure and dynamics of the Sun. MDI is a project of the Stanford-Lockheed Institute for Space Research and is a joint effort of the Solar Oscillations Investigation (**SOI**) in the W.W. Hansen Experimental Physics Laboratory of Stanford University and the Solar and Astrophysics Laboratory of the Lockheed-Martin Advanced Technology Center. See http://soi.stanford.edu/

Northern Lights--an older name for the polar aurora.

Orbit -- the line followed by a spacecraft or a celestial body in motion around an object.

Particle -- in general, a charged component of an atom; that is, an ion or electron.

Photon --colloquially, a "packet of light." Although light spreads as an electromagnetic wave, it can be created or absorbed only in discrete amounts of energy, known as photons. The energy of a photon is greater the shorter the wavelength--smallest for radio waves, larger for visible light, largest for X-rays and gamma rays.

Photosphere--The layer of the Sun from which all visible light reaches us. The Sun is too hot to have a solid surface and the photosphere consists of a plasma at about 6000 degrees centigrade. Sunspots and faculae are observed in the photosphere.

Plage – a bright feature found in the vicinity of most active sunspot groups; occurs on a larger scale and is brighter than a facula. Plage is French for "beach," because each plage looks like light-colored sand against the darker structures around them.

Plasma -- any gas containing free ions and electrons, and therefore capable of conducting electric currents. A partially ionized plasma such as the Earth's ionosphere is one that also contains neutral atoms.

Polar orbit --a satellite orbit passing over both poles of the Earth. During a 12-hour day, a satellite in such an orbit can observe all points on Earth.

Prominence -- A term identifying magnetic field induced cloud-like features in the solar atmosphere. The features appear as bright structures in the corona above the solar limb and as dark filaments when seen projected against the solar disk.

Proton -- an ion of hydrogen and one of the fundamental building blocks from which atomic nuclei are made.

Radiation --a term with two broad meanings: 1) In the narrow sense, some type of electromagnetic wave: radio, microwave, light (infra-red, visible or ultra-violet), X-rays or gamma rays are all types of radiation. 2) Colloquially, the full term is "ionizing radiation" and means any spreading emission which can penetrate matter and ionize its atoms. That includes X-rays and gamma rays, but also high-energy ions and electrons emitted by radioactive substances, accelerated by laboratory devices or encountered in space (e.g. the radiation belt and cosmic rays, also known as cosmic radiation).

Radiation belt --The region of high-energy particles trapped in the Earth's magnetic field.

Radio propagation -- a term used to explain how radio waves behave when they are transmitted from one point on the Earth to another.

Radio waves -- Radio waves have the longest wavelengths in the electromagnetic spectrum, ranging from about the size of a football to many miles in length.

Radioactivity --Instability of some atomic nuclei, causing them to change spontaneously to a lower energy level or to modify the number of protons and neutrons they contain. The 3 "classical" types of radioactive emissions are (1) alpha particles, nuclei of helium (2) beta-rays, fast electrons and (3) gamma-rays, high-energy photons.

Ring current -- In the magnetosphere, a region of current that flows in a disk-shaped region near the geomagnetic equator in the outer of the Van Allen radiation belts. The current is produced by the gradient and curvature drift of trapped charged particles. The ring current is greatly augmented during magnetic storms because of the hot plasma injected from the magnetotail.

Reflect -- To throw or bend back (light, for example) from a surface.

Refract – To bend or change direction, as in the light refracted into a rainbow.

Sferics -- a jargon term for radio signals induced by lightning.

Shock -- A sudden transition at the front of a fast flow of plasma or gas when that flow moves too fast for the undisturbed gas ahead of it to get out of its way. Also occurs when a steady fast flow hits an obstacle.

SID Monitor – see Sudden Ionospheric Disturbance Monitor

SOHO – see Solar and Heliospheric Observatory

Solar and Heliospheric Observatory (SOHO) – A joint ESA/NASA spacecraft launched in 1995 and containing a battery of instruments to study the structure and dynamics of the Sun. See http://sohowww.nascom.nasa.gov/

Solar corona— see Corona

Solar Cycle -- The approximately 11-year quasi-periodic variation in frequency or number of solar active events. See also "Sunspot cycle."

Solar energetic particles -- high energy particles occasionally emitted from active areas on the Sun, usually associated with solar flares and coronal mass ejections. The Earth's magnetic field keeps them out of regions close to Earth (except for the polar caps) but they can pose a hazard to space travelers far from Earth.

Solar flare – see Flare

Solar wind -- The outward flux of solar particles and magnetic fields from the Sun. The solar wind is produced primarily in the cooler regions of the corona, known as coronal holes, and flows along the open magnetic field lines. Typically, solar wind velocities are 300-500 km per second.

Space Weather--the popular name for energy-releasing phenomena from the Sun and its effects on planetary systems. Space weather conditions can influence the performance and reliability of space-borne and ground-based technological systems and endanger human life or health.

Substorm (auroral) -- a process by which plasma in the Earth's magnetotail becomes energized at a fast rate, flowing earthward and producing bright auroras for typical durations of half an hour.

Sudden Ionospheric Disturbance (SID) – an abnormally high plasma density in the Earth's ionosphere caused by an occasional sudden solar flare; SIDs often interrupt or interfere with telecommunications systems.

S**udden Ionospheric Disturbance (SID) Monitor** - an instrument which tracks sudden changes to the Earth's ionosphere caused by solar flares.

Sun -- the star at the center of our solar system. The Sun keeps Earth warm and sustains life on it, and it also emits the solar wind and occasional bursts of solar energetic particles.

Sunspot -- concentrations of magnetic flux, typically occurring in bipolar (i.e. two-part with positive and negative poles, like a magnet) clusters or groups. They appear dark because they are cooler than the surrounding photosphere. They are cooler than the surrounding photosphere because the magnetic field interferes with the outflow of solar heat in that region.) Sunspots tend to be associated with violent solar outbursts of various kinds.

Sunspot cycle (or solar cycle)--an irregular cycle, averaging about 11 years in length, during which the number of sunspots (and of their associated outbursts) rises and then drops again. Like sunspots, the cycle is magnetic in nature, and the polar magnetic field of the Sun also reverses each solar cycle, making the true cycle about 22 years long.

Sun-synchronous orbit --a near-Earth orbit resembling that of a polar satellite, but inclined to it by a small angle. With an appropriate value for the inclination angle, the equatorial bulge causes the orbit to rotate during the year once around the polar axis. Such a satellite then maintains a fixed position relative to the Sun and can, for instance, avoid entering the Earth’s shadow.

Supernova—1) a large explosion at the end of the evolutionary process of a very massive star.2) an explosion of material from a white dwarf star after it has been accumulating mass from a binary companion. An enormous amount of energy is released in these explosions.

Synchronous orbit -- a circular orbit around the Earth´s equator, at a distance of 6.6 Earth radii. At this distance the orbital period is 24 hours, keeping the satellite "anchored" above the same spot on Earth. This feature makes the synchronous orbit useful for communication satellites and satellites transmitting TV programs.

Terrestrial gamma-ray flashes (TGFs) -- bursts of gamma rays in the Earth's atmosphere, probably caused by electric fields produced above thunderstorms . TGFs have been recorded to last 0.2 to 3.5 milliseconds, and have energies of up to 20 MeV.

Terminator -- the dividing line between the bright and shaded regions (usually shaded from the light of the Sun) of the disk of a moon or planet.

Ultra High Frequency (UHF) -- Those radio frequencies exceeding 300 MHz.

Ultraviolet (UV) -- electromagnetic radiation lying in the ultraviolet range , i.e. wavelengths shorter than visible light but longer than X-rays. UV cannot be seen by the eye.

Universal Time (UT) -- By international agreement, the local time at the prime meridian, which passes through Greenwich, England; also known as Greenwich Mean Time or Coordinated Universal Time.

Very High Frequency (VHF) -- That portion of the radio frequency spectrum from 30 to 300 MHz.

Very Low Frequency (VLF) -- That portion of the radio frequency spectrum from 3 to 30 kHz.

Visible light – see White Light

Waveguide (Earth's ionosphere) – a structure that guides electromagnetic waves along its length. The space between the Earth's surface and the ionosphere makes an excellent waveguide for VLF radio transmissions.

White Light, visible light -- Sunlight integrated over the visible portion of the spectrum (4000 - 7000 angstroms) so that all colors are blended to appear white to the eye.

X-ray Burst – In solar-terrestrial terms, a temporary sudden enhancement of the X-ray emission of the Sun. These bursts can also be caused by thermonuclear explosions on the surface of a neutron star accreting material from a binary companion.

X-rays-- a type of high-energy electromagnetic radiation with wavelengths of about 10^{-10} meters. X-ray photons are generated by energetic electron processes. The hot outer atmospheres, or coronas, of normal stars such as our Sun produce X-rays, as do the cataclysmic explosions of supernovae, accreting or merging neutron stars, and Black Holes.

Whistlers -- A type of VLF electromagnetic signal generated by some lightning discharges. Whistlers propagate along geomagnetic field lines and can travel back and forth several times between the Northern and Southern Hemispheres. So named from the sound they produce in radio receivers.

Glossary Credits:

a) *David Stern's glossary (http://www-spof.gsfc.nasa.gov/Education/Intro.html.)*
b) *Stanford Solar Center's glossary (http://solar-center.stanford.edu/gloss.html)*
c) *NOAA glossary (http://www.sel.noaa.gov/info/glossary.html)*
d) *Deborah Scherrer*