Teacher's Guide

Solar Storms and Satellites

Introduction

Solar storms have long been known to affect delicate electronic circuitry in satellites orbiting the Earth. Given that the commercial, military and scientific satellite resources exceed $200 billion dollars, the issue of satellite vulnerability to solar storm damage is not only a serious consideration in satellite design, but also a highly controversial topic when specific instances are examined in detail.

Objective

Students will read to be informed.

Procedure

1) Students read "Forecasting Solar Storms" and answer the questions.

2) Discuss the answers and the article.

3) Students read "Solar Storm Eyed as Satellite Killer".

4) Construct a graphi organizer to compare and to contrast the two articles. Some of the items mentioned in both are $200 million Telstar 401 satellite, and the SOHO satellite. Both articles also mention the 1997 event, Stephen P. Maran's quote, " This is the first time a solar event has been captured from cradle to grave". It took the January 7 event, 3 3/4 days to reach the Earth, and other spacecraft that monitored the event.

5) Answer the remaining questions.

Materials

—A copy of "Forecasting Solar Storms" for each student.

—Student question sheet

—A copy of "Solar Storm Eyed as Satellite Killer"

—Student question sheet

Key Terminology:

Coronal Mass Ejection: A sudden expulsion of matter from the coronal regions of the Sun with typical speeds of millions of kilometers per hour.

Magnetic sub-storm: A rapid change in a portion of the magnetic field of the earth lasting hours to minutes.

Forecasting Solar Storms

Dr. Sten Odenwald (Raytheon ITSS and NASA Goddard Space Flight Center)

Solar storms are a problem. A big problem. Chances are you have never heard of them at all because, unlike the conventional storms that produce rain and thunder, solar storms are remote and distant. It really all depends on where you are and who you are. If you are an astronaut walking on the moon, a solar storm could give you a lethal dose of radiation in a matter of a few minutes. If you happened to be in Quebec on March 13, 1989, your entire province would have been blacked-out by a solar storm-induced power outage. If you were dialing '911' from a cellphone, the solar storm would have prevented your call from going through.

Scientists have spent a lot of time trying t predict solar storms so that, like hurricane warnings, we can have at least some forewarning of their approach. When solar storms buffet the earth's magnetic field they can, and often do, raise havoc with radio communication, power transmission, and even satellite functions. Nothing in our high-tech world seems to be entirely immune from the outfall from solar storms.

The sun and the wind from the sun are under around the clock surveillance by a network of ground-based, and satellite-based observatories such as SOHO, the Solar Heliospheric Observatory, and ACE, the Advanced Composition Experiment, to name a few. Other spacecraft orbiting the earth measure the changes in the earth's magnetic field and the populations of high-energy trapped particles which circulate within this vast magnetic bottle. Our sun has only recently begun to emerge from its lowest point in the famous 'sunspot cycle'. This ebb and flow of solar activity lasts an average of 11 years fro peak to peak, with the current cycle, Number 23, destined to reach maximum in the summer of 2000.

Even though near its low point in the cycle, the sun has treated scientists to many spectacula storms which have reached earth and, in so doing, demonstrated that space weather forecasting is not an idle activity. On January 7, 1997, a region of intense activity on the sun's eastern sector launched a billion-ton gas cloud called a coronal mass ejection (CME) which, 3 3/4 days later, reached Earth. Its transit and arrival was monitored by 20 scientific research satellites as part of the International Solar-Terrestrial Physics program (ISTP). According to NASA astronomer Dr. Stephen Maran, "This is the first time a solar event has been captured from cradle to grave".

A small part of the million kilometer-wide cloud brushed by the earth, and shook the magnetic field of the earth for over 24 hours like a flame flickering in a breeze. This geomagnetic storm and the particles comprising it allegedly affected the operation of a $200 million Telstar 401 communications satellite which had to be taken out of commission on January 17 according to articles published in Sky and Telescope magazine (July, 1997 page 20) and Aviation Week and Space Technology (January 27, 1997 page 61-62).

With the upcoming 'solar maximum' approaching, and with our rapidly escalating dependence on satellite communication technology in the 21st century, additional space weather forecasting satellites will be launched so that as the older satellites reach the ends of their operating lifetimes, new generations of early-warning satellites will be on the scene to give scientists the data they need to make accurate forecasts in the next century.

Solar Storm Eyed as Satellite Killer

Dr. Sten Odenwald (Raytheon ITSS and NASA Goddard Space Flight Center)

On January 7, 1997 it seemed to be an ordinar day on the Sun. White light photographs taken at several ground-based solar observatories showed the surface to be quite ordinary. In fact, to the eye and other visible wavelength instruments, the images showed nothing at all. Not so much as a single sunspot.

But X-ray photographs taken by the YOHKOH satellite from earth orbit revealed some serious trouble brewing. High up above the solar surface in the tenuous atmosphere of the corona, invisible lines of magnetic force, like taught rubber bands, were coming undone. On January 6th, satellite images showed a coronal stor brewing from a small region of the corona, only a few hundred times the size of the Earth.

By Tuesday, January 7, solar astronomers recognized that a major Coronal Mass Ejection event was in progress, and in a sequence of daily X-ray images, the details of the event played themselves out in a deadl dance of magnetic fields, plasma and electromagnetic radiation.

The dance lasted several days, but by its end, a cloud of plasma was hurled away from the Sun at l million miles an hour. It crossed the orbit of Mercury in less than a day. By Wednesday it had passed Venus: An expanding cloud over 30 million miles deep, spanning the space between the orbits of Mercury and Venus. As NASA astronomer Stephen Maran noted about the 20 satellites that had monitored this event, "This is the first time a solar event has been captured from cradle to grave".

Despite the scientific excitement over this storm, it had other repercussions that were far less welcomed. The problem is that, even with detailed information about an incoming solar cloud, short of moving the earth out of the way, there was nothing we could do in the face of this looming calamity. All scientists could do was to sit back and cross their fingers that the Earth's magnetic field would repel most of the cloud like some gigantic securit blanket. After all, it had done so for million of years in the past! But today, our daily sphere of activity extends off the surface of the Earth and far into space.

High up above the United States, AT&T's $200 million Telstar 401 satellite was busy relaying television programming between many destinations across the continent. Public Broadcasting Stations, ABC News and even the Home Shopping Channel were among its regular paid subscribers for the precious few channels that the satellite could re- broadcast back to our home television sets and to cable channel owners on the ground. Telstar 401 was launched from Cape Canaveral on December 13, 1993 and was the first of a fleet of modern communications satellites developed by Lockheed-Martin, and equipped with many new technologies.

It was designed to last 12 years, but on Saturday, Januar 11 AT&T announced that it was having some communications difficulties with the satellite. Its day of reckoning had arrived, as the interplanetary coronal stor cloud, now over 30 million miles wide, slammed into the Earth's magnetosphere. Even the images from the YOHKOH satellite began to deteriorate as the plasma particles and magnetic fields invaded the delicate electronic circuitry, corrupting the images with noise.

In a report by Aviation Week and Space Technology (AWST) magazine (January 27, 1997, p. 61) the Telstar satellite "...suffered a massive power failure on Jan. 11 rendering it completely inoperative. Scientists and investigators believe the anomaly might have been triggered by an isolated but intense magnetic substorm, which in turn was caused by a coronal mass ejection...spewed from the Sun's atmosphere on Jan. 6". Some scientists were not so ready to implicate the solar storm in the damage to the satellite. Robert Hoffman, a NASA scientist, is quoted in AWST as saying that although the satellite was located in an affected area of the magnetosphere, "We have no idea what caused the failure".

Despite a number of attempts at diagnosing and repairing the problem with Telstar 401, on Saturday, January 17 AT&T had given up the effort and announced that they had lost the satellite. Paradoxically, no militar satellites were apparently affected by this particular storm, and Hughes Space and Communications which manufactured over 40% of the commercial satellites now in orbit had also not received any reports of any anomalies related to the storm. According to AWST, Lockheed Martin which built the Telstar 401 satellite was investigating whether the failure could have been due to some problem in its design. Three earlier-model satellites were also disabled in 1994 by a solar storm which triggered electrical failures in these satellites: Intelsat K and two Canadian Anik television satellites. Two of them made partial recoveries but the third was lost completely. (AWST January 31, 1994 p. 28).

Satellite engineers and scientists are cautious to admit the sun was ultimately to blame when hundreds of millions of dollars are at stake and law suits could result from the wrong answers. For reasons of national security, there is also a good reason not to provide information about how vulnerable our military satellites may be to solar stor 'attack', perhaps emboldening an enemy to launch their own activities under the cloak of a solar storm event.

Many newspapers stories were ultimately filed about the January 1997 solar storm and its fallout, and on January 30, 1997 even George Will at the Washington Post, who normally covers political stories, wrote "Astronomy's Answer", an anguished editorial about space calamities that can, and will, affect us.

Name _____ Date_____

Reading to be Informed

"Forecasting Solar Storms"

1. **When a powerful solar wind buffets the Earth's magnetic field, what havoc can occur?**

2. **Name a satellite mentioned in the article and describe the events it photographed.**

3. **What was probably caused as a result of the power surge?**

4. **According to the article, what are the implications for future forecasting. and why do you think scientists consider forecasting to be so important?**

5. **Name some electronic gadgetry, according to the article, that is prone to disruption.**

6. **Summarize the article in your own words.**

7. **Why might a solar storm impact your life, and how might space weather forecasting be useful to you?**

Name _____

Date_____

Reading to be Inform

"Solar Storm Eyed as Satellite Killer"

1. In your own words, describe the solar storm and its results.

2. What is the meaning of the quote "This is the first time a solar event has been captured from cradle to grave" ?

3. What was the cost of the Telstar 401 satellite?

4. The satellite was insured for $145 million. For what percent of the original cost was the satellite insured?

5. The satellite was launched in _____ and was designed to operate for _____ years. What would that cost breakdown per year be, assuming that the value of the satellite decreased by 10% the first year, 9% the second year, and 8% the third year? (Remember, the satellite was launched in 1993, therefore for this case, year one will be 1994.)

1994
1995
1996

6. Why would we not include 1997 in the cost breakdown?

7. The CME cloud was traveling at a speed of 1 million kilometers/hr, how far was the cloud after Day 1, Day 2, Day 3 and Day 4? Explain what you think will happen when it reaches the Earth.

8. What do you think about solar storms and their impact on you in the future?

Sample Responses For Graphic Organizer

(Students may choose an organizer such as a Venn Diagram)

"Forecasting Solar Storms"

Trying to predict when a solar storm will happen.
Why we should forecast solar storms.
Solar storms affect the earth, like blackouts.
Solar storms raise havoc with radio transmissions and satellites.
Solar cycle
Improvements being made in science
Mainly about forecasting solar storms

Common Elements to the Stories:

Solar Storms
Telestar 401 satellite
$200 million dollar
Same author
NASA
TV and radio quotes
Studying about space
ACE and SOHO
Both had the quote by Stephen Moran, "This is the first time a solar event has been captured from cradle to grave".

"Solar Storm Eyed As Satellite Killer"

Coronal mass ejections
Magnetic field
Mostly one event
Communications disruptions
Telestar - what it does, where it was launched, and who made it
Maybe solar storms are satellite killers
YOHKOH
Talks about one major event
Mainly about solar storms destroying a satellite

Selected Responses

"Solar Storm Eyed as Satellite Killer"

1. In your own words, describe the solar storm and its results.

A solar storm is a discharge of particles from the Sun that can cause the Northern Lights, blackouts, and communication problems.

A solar storm is when particles shoot from the Sun and can cause Earth a lot of trouble. It can cause a power surge and the electricity can go out.

A solar storm is where a lot of particles fly out from the Sun. One thing that they can do is interfere with communications.

The solar storm described is radiation, magnetic forces, and particles from the Sun. It's results are blackouts and non-communication. It also causes the Aurora Borealis, they are a bluish greenish color.

A solar storm is a storm on the Sun. Power surges can happen and also lots of radiation is in space.

A solar storm is when billions of particles meet the atmosphere and cause the aurora. Some results are cell phone not working and magnetic fields are disrupted.

The solar storm is when blasts of energy shoot out from the Sun. They sometimes mess with the Earth's magnetic field. They can also disrupt cell phone connections.

A solar storm is like a huge nuclear bomb, only out in space. So by the time the storm reaches the Earth, it's not so powerful. We only get our radio communications messed up and other things like power transmitters messed up.

Solar storms are ejections of particles from the Sun. They can do a lot of damage to satellites.

2. What is the meaning of the quote "This is the first time a solar event has been captured from cradle to grave" ?

It means that this is the first time a solar event has been seen from the time it starts until the time it ends.

It means that it's the first time a solar event has been captured from beginning to end.

They saw the storm from satellites when it started until it ended.

Selected Responses

"Solar Storm Eyed as Satellite Killer"

3. What was the cost of the Telstar 401 satellite?

The cost of the Telstar 401 satellite was $200 million.

The satellite cost 200 million dollars.

The satellite cost 200,000,000 dollars.

4. The satellite was insured for $145 million. For what percent of the original cost was the satellite insured?

The satellite was insured for 72.5 %.

The percentage insured for the Telstar 401 satellite was 72.5% of the original $200 million.

5. The satellite was launched in _____ and was designed to operate for _____ years. What would that cost breakdown per year be, assuming that the value of the satellite decreased by 10% the first year, 9% the second year, and 8% the third year? (Remember, the satellite was launched in 1993, therefore for this case, year one will be 1994.)

1994 $180,000,000
1995 $163,800,000
1996 $150,696,000

6. Why would we not include 1997 in the cost breakdown?

We would not include 1997 in the breakdown because the satellite suffered a massive power failure and they lost it.

The storm that disabled it was on January 7th and this is close to the beginning of the year.

We would not include 1997 in the cost breakdown because that is when the cloud messed it up.

You would not include 1997 in the cost because the satellite was disabled by a solar storm then.

Selected Responses

"Solar Storm Eyed as Satellite Killer"

7. The CME cloud was traveling at a speed of 1 million kilometers/hr, how far was the cloud after Day 1, Day 2, Day 3 and Day 4? Explain what you think will happen when it reaches the Earth.

Day one - 24 mil. km; Day two - 48 mil km; Day three - 72 mil. km; Day four - 90 mil. km

I think that when it reaches the Earth it will cause a blackout.

The CME cloud will mess up satellites.

I think that the magnetic field will block most of it, but what comes down may affect a power outage.

8. What do you think about solar storms and their impact on you in the future?

I think in the future solar storms ,I feel, will not impact us as much because we'll have better forecasting and ways of protecting us a little. I think solar storms are a very interesting thing we should continue to study.

I think that solar storms are interesting to learn about but they cause many things to go wrong on Earth, like putting out cell phones and causing satellite disruptions that take a while to repair.

I think that solar storms will cause blackouts and suspenseful moments in my life, but not much else.

I think that the storms are neat and the impact on ones life is strange. Well in the future we may have space colonies and a solar storm could be disastrous.

I think that it is weird all this stuff that is going on out in space that I don't know about. The worst thing that can happen is a blackout, I think.

I think that solar storms will not have a huge effect on me because I like power outages and I don't have a television or a phone.

Selected Responses

"Forecasting Solar Storms"

1. When a powerful solar wind buffets the Earth's magnetic field, what havoc can occur?

When a powerful solar wind buffets the Earth's magnetic field, havoc with radio communication, power transmissions, and even satellite functions can occur.

Havoc can occur with radio communication, power transmissions, and satellite functions.

When solar storms buffet the Earth's magnetic field, they can raise havoc with radios, power transmissions, or even satellite functions.

Powerful solar winds can cause radio communication trouble, power transmission trouble, and also satellite trouble. Blackouts can occur and even powerful explosions.

2. Name a satellite mentioned in the article and describe the events it photographed.

One satellite mentioned was SOHO. This photographs the Sun and detects the wind from the Sun.

SOHO is a satellite mentioned in the article, that is the Solar Heliospheric Observatory. It photographs the Sun and the wind from the Sun.

The Ace, Advanced Composition Experiment, photographed the Sun and the wind from the Sun.

Two satellites mentioned are the SOHO and ACE. They measure the changes in the magnetic field, also high energy particles which circulate past.

The satellite SOHO took pictures of gas clouds which are called coronal mass ejections.

3. What was probably caused as a result of the power surge?

On March 13, 1989, the entire province would have been blacked out.

If you lived in Quebec on March 13, 1989 your entire province would have been blacked out because of a solar storm induced power outage.

The black out in Quebec on March 13, 1989 was probably caused as a result of the power surge.

In result of the power surge, a $200 million Telstar 401 satellite was knocked out.

Selected Responses

"Forecasting Solar Storms"

4. According to the article, what are the implications for future forecasting. and why do you think scientists consider forecasting to be so important?

According to the article, the implications for future forecasting are that as the older satellites kind of die out, new satellites will already be there. I think scientists should consider forecasting so important because they will need to prepare to know when havoc and catastrophe can be prevented.

The implications for future forecasting was to launch the new and improved satellites so that as the older satellites reach the ends of their operating lifetimes, new generations of early warning satellites will be on the scene to give scientists data. They need to make accurate forecasts. I think scientists consider forecasting so important because it helps other people to know what's going on and to be ready for what comes.

The implications for future forecasting are that more satellites will be giving the scientists more accurate forecasts in the next century. Forecasting is so important so that we know when communication may go down.

According to the article, some implications for future forecasting would be to be looking for more solar storms to know when to tell us to put away our satellites and to be able to forecast when a solar maximum is coming, which means major solar storm.

Some implications for future forecasting are that additional space weather forecasting satellites will be launched so that new generations of satellites will give scientists the data needed to make more accurate forecasts in the future, thus preventing damages.

5. Name some electronic gadgetry, according to the article, that is prone to disruption.

Some electronic gadgetry that is prone to disruption are the satellites and the cell phones.

Some things that are prone to disruptions are power transmissions, satellite functions, and radio communications.

6. Summarize the article in your own words.

Solar storms have been a problem over the years. Some places in the world have been affected by these storms. Scientists have been trying to study the storms so if it was to happen again we would have some kind of warning. The satellites have brought back a lot of information about the sun and the wind from the sun which helps the scientists to keep track of what is going on. Scientists now have a new generation of early warning satellites that will be launched to take the place of the old ones. Scientists now expect to get the data they need to make better updated forecasts about solar storms.

Selected Responses

"Forecasting Solar Storms"

Solar storms are a big problem and can blackout your entire province. Scientists have been trying to predict solar storms so that we can have at least some forewarning of their approach. With the upcoming 'solar maximum' approaching, additional space weather forecasting satellites will be launched so that the new generations of satellites will give scientists the data to make accurate forecasts in the next century.

Solar storms are a big problem. This article tells how solar storms are made. They are made from the sun, a wind from the sun makes the Earth's magnetic field circulate with vast magnetic particles. Scientists are figuring out a way to get the forecast for the future that will help in the next century by replacing old satellites with new ones.

7. Why might a solar storm impact your life, and how might space weather forecasting be useful to you?

The solar storm may impact my life because we would have no way to communicate and no way to tell what would happen next because the phones and probably the television would be blacked out. Space weather forecasting is useful to me because I will have an idea of what will happen and I could be prepared.

A solar storm would impact my life because blackouts and the use of satellites and cell phones may be disrupted. Space weather forecasting would be useful so I would know when to put away supplies and so scientists know when to put away satellites.

A solar storm might impact your life because the Aurora colors are so beautiful. You would remember them forever, they might inspire you. Also if there was a blackout, you would also remember that event. You could be prepared.

A solar storm might impact me by causing a blackout. As a result, all electronics could go out and this would affect us greatly. Space weather forecasting would be useful because they could warn us when these storms would or will happen, and they can tell us what to do and how to deal with the blackouts before they happen.