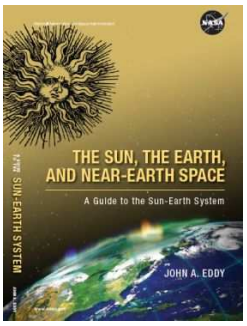
Title: ***The Sun, The Earth and Near Earth Space ~ A Guide to the Sun-Earth System***
Author: J. Eddy
Publisher: NASA
ISBN: 978-0-16-08308-8
Date published: 2010
Length: 301 pages, 3 page index
Status: Electronic – PDF and softcover available
Availability: Free download or $31.50 for paperback from Government Printing Office
Reviewer: Whitham D. Reeve

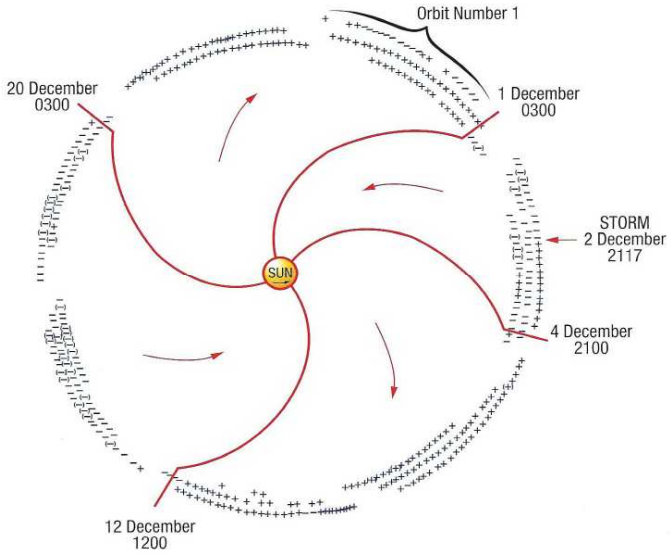


This review is the second in a series of four about *space weather*. The first was ***Solar Storms ~ 2000 Years of Human Calamity!*** by S. Odenwald (for the review, see [Reeve]). Future reviews will cover ***An Introduction to Space Weather*** by M. Moldwin and ***Understanding Space Weather and the Physics Behind It*** by D. Knipp. The present book is free in electronic form as Portable Document Format (PDF) files or it can be purchased from US Government Printing Office or from used book sellers as a paperback. To download the free version, go to NASA's International Living with a Star website {ILWS} and download the individual chapters or the entire book all at once (about 29 MB).

What is space weather and what does it have to do with amateur radio astronomy? Space weather describes the conditions in the environment outside of Earth's lower atmosphere. It is treated conceptually the same as terrestrial weather, which refers to conditions in Earth's lower atmosphere. Space weather includes conditions and events on the Sun and in the solar wind, near-Earth space and Earth's upper atmosphere. Even cosmic rays from far beyond the solar system come into play. Space weather can affect the operation of space- and ground-based technological systems and human health.

The Sun drives space weather (and terrestrial weather, too), but it also produces very powerful radio emissions especially during the peak of the solar cycle when it flares regularly. Amateur radio astronomers are particularly interested in the reception of solar radio bursts as well as how solar activity affects Earth's ionosphere and radio propagation. Radio bursts produced by solar flares are easily received directly by amateur radio telescopes in the HF, VHF and UHF bands. Solar flares also can be observed indirectly by monitoring their effects on terrestrial transmissions in the LF and VLF bands. The Sun's radio emissions may interfere with non-solar radio astronomy. Earth's magnetic field also is affected by solar activity. The connection of the Sun's magnetic field with Earth's field can cause huge variations in the latter and lead to pipeline and electric transmission line problems and other negative manifestations. Although bad space weather can potentially be harmful to humans, learning about the Sun and space weather and monitoring related radio emissions and geomagnetic variations can be very interesting and fun.

The Sun, The Earth and Near Earth Space provides a very useful and interesting non-technical, encyclopedic description of space weather and its ramifications. The book's main use to amateur radio astronomers is to bolster their general knowledge of the solar system's most powerful radio emitter, but it does not cover solar radio bursting in any detail. This book is in contrast to the hyperbolic reporting about space weather, especially in the hysterical news media. I found it very refreshing to read something that resists the "We're all gonna die!" mantra. This is not to say the book ignores the negative aspects of space weather because it does not, but it covers them intelligently. The book obviously is aimed at audiences in the United States because, unfortunately, most units of measure are non-metric (somewhat surprising for a book published by NASA).



The paper version of this book is printed on very heavy paper and probably is not something you would want to carry around, for example, on an airplane trip. It is colorfully illustrated and the illustrations are important and relevant to the discussions (example left from pg 120, which shows the magnetic polarities of the solar wind as the Sun rotates). Even the captions are first-rate, something one seldom sees in anything but good textbooks. I would not recommend attempting to read this book on a monochrome electronic reading device because the colored illustrations and text are important content.

The book is a step above a popular account but readers do not need any special technical knowledge to benefit from it. The book is well written and highly readable but the author occasionally resorts to flowery language. However, he never tries to impress his audience with jargon, and he devotes extra time to explaining both basic and advanced concepts. There are no equations or math.

The chapters are not numbered and are listed below for convenience of review, and I will take them in order. The book starts with the Sun and then quickly moves 93 million miles from there to near-Earth and Earth itself, not spending a whole lot of time in-between. Each chapter is broken into relatively short sections, making the book easy to put down and resume later.

- *An Overview*
- *The Sun*
- *The Solar Wind & Solar Variability*
- *The Near-Earth Environment*
- *Fluctuations in Solar Radiation at the Earth*
- *Variation in the Flow of Particles at the Earth*
- *Impacts of Solar Variability*
- *Effects on Human Life and Endeavor*
- *Effects of the Sun on Weather and Climate*
- *Forecasting Space Weather at the Earth and Beyond*
- *Reflections*
- *Appendices*

Included in the Appendices at the back of the book are a useful 26 page *Glossary of Technical Terms*, a list of eight articles and a few websites in *Sources for Additional Information*, list of *Tables*, attribution of *Images and Illustrations*, and 3-page *Index* that unfortunately is pretty weak considering the very wide range of topics that are covered.

The Sun, The Earth and Near Earth Space does not necessarily have to be read in sequence from front to back but, of course, someone new to space weather concepts should do just that. If readers are only interested in space weather effects, they can jump to the chapters that focus on those topics and skip the others.

An Overview is 10 pages and it quickly covers the whole subject of the Sun, Earth and space weather as a primer for the remaining chapters. *The Sun* follows next at about 30 pages. This chapter is a nice overview that includes easy-to-use schematic drawings and summary tables of various solar processes. Each topic, such as the

chromosphere and *corona*, is briefly described at just the right level and depth without resorting to astrophysics, but the information is not dumbed-down so that the technical reader will become bored.

Most people only look on the Sun as that extremely bright, constant light in the sky that can be obscured by clouds and goes away at night. Of course, that is grossly oversimplified because the Sun is far from constant as we learn in *The Solar Wind & Solar Variability*. There are many variabilities and time scales at play. Time scales range from seconds to centuries and much longer. The sunspot cycle, which has a nominal period of 11 years and is the most obvious of the Sun's cyclic variations, actually varies quite a lot from one cycle to the next and really consists of a 22 year magnetic cycle. Long-term solar variations have a largely unappreciated effect on Earth's climate.

The chapter *The Near-Earth Environment* gets into the layers of Earth's upper atmosphere, which have been given various names for convenience of study such as the *thermosphere*, *troposphere*, and *stratosphere* and so on. These are followed by the *geomagnetosphere* and *heliosphere*, the former representing the volumetric space influenced by Earth's magnetic field and the latter representing that huge volume of space influenced by the solar wind and solar magnetic field, which reaches out somewhere in the neighborhood of 15 billion miles.

The next two chapters in ***The Sun, The Earth and Near Earth Space*** – *Fluctuations in Solar Radiation at the Earth* and *Variation in the Flow of Particles at the Earth* – are about the small and large variations in the solar radiation and solar wind that affect Earth. There are very good illustrated explanations of how particles – electrons, protons and ions – are able to breach the Earth's protective magnetosphere through a process called magnetic reconnection and potentially cause problems at lower levels. The illustrations are some of the best I have seen to help explain how it is thought these mechanisms work. The author invokes familiar and appropriate analogies to explain some of the more technical aspects in these and other chapters; for example, comparisons are made to supersonic aircraft to explain how shock waves in the supersonic solar wind affect and interact with the stationary geomagnetosphere. The solar wind is no ordinary wind by terrestrial standards – its average speed is about 1 million miles per hour but its density is very low.

Following the two chapters on variability are three chapters on effects – *Impacts of Solar Variability*, *Effects on Human Life and Endeavor*, *Effects of the Sun on Weather and Climate*. These go into detail about how space weather can affect not only our technologies but also our bodies. It has long been known that humans in high altitude aircraft are exposed to higher radiation levels than people on the ground. As one might expect, flight crews receive the most radiation over time because it is not just the elevated radiation dose from one flight but the cumulative effects integrated over many such flights. The effects on astronauts and spacecraft are much greater. The Apollo missions to the Moon were high-risk from a radiation perspective (well, actually, from any perspective) but future missions to Mars, so far, do not have practical solutions to problems in this regard. High-energy particles from the Sun can affect ground-bound people as well. The descriptions are in terms of particle energies, measured in electron-volts, and are informative and easy to follow. Sections are titled *Impacts on the Upper Atmosphere*, *Restructuring the Ionosphere* and *Disturbing the Biosphere: The Lower Atmosphere, Oceans, and Land Surface*.

As in probably every book on space weather, the author hauls out the electrical transmission system failures caused by a coronal mass ejection in 1989 as an example of how CME induced current and voltage surges on powerlines can cause big problems. This singular event has become a sort of cliché, although it is not the only

occurrence. Not mentioned is that space weather induced problems in electric utility systems can be reduced or eliminated by applying new or different engineering practices in system and protective relaying design.

There are a number of other manifestations of bad space weather. For example, an event is described that occurred in 1958 and affected teletype and telegraph systems, technologies that are hardly relevant today. On the other hand, Global Navigation Satellite Systems (GNSS) such as the Global Positioning System (GPS) are modern technologies whose accuracy can be affected at least temporarily by bad space weather. A number of satellite failures and upsets have been blamed on bad space weather. Radio propagation in the HF range can be severely curtailed by solar flare effects on Earth's ionosphere (called *radio blackout*). Interference from solar radio bursting also affects radio communication systems. But not all is bad with space weather – several pages are devoted to the Aurora, probably the only positive thing associated with space weather and that is because it is fun to see and watch but usually only for people at the higher latitudes.

I was disappointed in the relatively scant coverage given in the last of these three chapters, *Effects of the Sun on Weather and Climate*. In only 23 pages, the author discusses correlations (and anti-correlations) between solar variabilities – mostly the 11 year sunspot cycle – and Earth's climate. The author gives less attention to longer cycles. A table is given showing four low sunspot eras since 1540 and also showing one relatively high sunspot era, which started in 1940 and appears to be in its declining phase. The rising and falling sunspot numbers in each cycle could be modulated with much longer periodicities and changes but these are not mentioned, probably because little is known about them. Other discussions cover research into ice cores taken from Antarctica, which supposedly provide proxy climate information going back hundreds of thousands of years, and using tree rings as proxies for ancient climates.

Investigators seem too eager to draw conclusions based on a couple hundred years of sunspot data, which are determined by arbitrary and highly subjective counting methods, particularly in the early days. The data reflect those methods, which then require subjective adjustments in efforts to improve consistency over the entire 200 year record. A single variability such as sunspot counts over a couple hundred years is a tiny speck compared to the age of the Sun and Earth or even the age of humanity. We simply do not know how sunspots have varied for longer than the existing record. As discussed by the author in the next chapter, solar radio flux measurements at about 2.7 GHz (10.7 cm wavelength) are better suited for space weather study purposes because they are based on calibrated measurements, but records exist for only about 60 years.

Curiously omitted from the climate discussions in this book are the effects of Earth's internal magnetic field. Even though it has quite a lot of variability over long time periods, including aperiodic reversals and changing strength, we have no idea how those variations affect or have affected Earth's climate. The author returns to the climate subject very briefly in his *Reflections* chapter at the end of the book but adds nothing to his arguments. To his credit, I think the author does try to give a balanced account of the Sun's effects on climate rather than make the reader sit in a politically correct echo chamber.

The last working chapter in ***The Sun, The Earth and Near Earth Space*** – *Forecasting Space Weather at the Earth and Beyond* – discusses the difficulties involved in space weather forecasting, a relatively young science. Solar events produce radiation that travels at the speed of light (670 million miles per hour) and require only a little more than eight minutes to reach Earth. The trouble is the instant we detect a flare or solar activity that could be sending damaging x-rays and extreme ultraviolet rays our way, the radiation has already arrived. Generally,

the more damaging heavier particles such as energetic protons and heavier ions travel slower and require 15 minutes to a couple hours to reach Earth. Coronal mass ejections require one to nine days. Sentinel spacecraft such as ACE and DSCOVR between Earth and Sun provide around 30 to 50 minutes warning for CMEs but essentially no warning for the faster particles. Therefore, investigators spend a lot of time developing Sun-Earth space weather models that provide forecasts based on statistical expectations. The current form of the these forecast is illustrated by this example in a November 2017 summary forecast provided by NOAA Space Weather Prediction Center: "`Solar activity is expected to be very low with a slight chance for C-class flaring throughout the forecast period (17-19 Nov) due to Region 2687.`" Other types of SWPC forecasts provide more detail and include estimated probabilities but the models that support these forecasts are still in their relative infancy.

The author says that electric utilities need about an hour to reconfigure their transmission and generation systems to avoid problems caused by geomagnetic induced currents and air traffic controllers require an hour or so to reduce the altitude of polar flights or to redirect them to reduce radiation effects resulting from a solar-induced event. However, having worked in both the electric utility and airline industries for decades, I would say these times are far too optimistic, mainly because of the assumption that everything will go according to plan. It is no secret that anything involving many people spread over a wide geographic area seldom goes according to plan, which invariably leads to finger-pointing and hyperventilating in the news media.

Considering the available warning times mentioned above, it is clear that the best solution at this time is improved prediction through modeling. Many spacecraft are presently gathering data about the heliosphere and geomagnetosphere with the purpose of improving our understanding of space weather and improving our predictions. On the other hand, according to the author, extended space missions to, for example, Mars could expose the crew each year to 16 times the cumulative radiation allowed for nuclear plant workers on Earth. Without adequate crew shielding, these missions are in effect delayed suicide missions and improved predictions probably will not do much to help them. Shielding requires a lot of metal and, thus, a lot of rocket fuel to lift it away from Earth's gravity.

If volume is an indication of difficulty, space weather forecasting is perhaps a dozen orders of magnitude more difficult than terrestrial weather forecasting. Everyone complains about inaccurate terrestrial weather forecasts. Even with thousands of weather stations and dozens of weather satellites, forecasts in many parts of the world are notoriously poor for even short time periods. The biggest problem with forecasting is that Earth's atmosphere is a highly nonlinear environment, and the Sun and near-Earth space environments are even more so. We are told that poor space weather can have grievous consequences for humanity, but so far we have only a tiny understanding of how space weather works. Given enough time I suppose that will change. Meanwhile, the sky is not falling.

In conclusion, ***The Sun, The Earth and Near Earth Space*** is a good book, well worth reading and well worth having on the bookshelf (or hard drive) for future reference. Even though the book's main subject is space weather, the information presented is of broad interest to the amateur radio astronomer or anyone curious as to how things such as the solar wind work. The price for the electronic version is zero, making it affordable and accessible to anyone with internet service.

Citations:

{ILWS} http://ilwsonline.org/ilws_publications.htm

[Reeve] Reeve, W., Review of ***Solar Storms ~ 2000 Years of Human Calamity!***, Society of Amateur Radio Astronomers, *Radio Astronomy*, September-October 2017

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