

Title: *An Introduction to Space Weather*

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Publisher: Cambridge University Press

ISBN: 978-0-521-71112-8

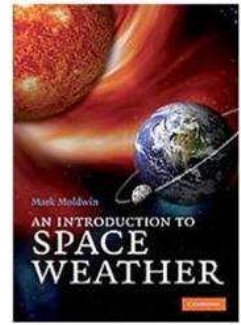
Date published: 2008, (current printing 2013)

Length: 134 pages, 4 page index

Status: In print

Availability: Softcover, 65 USD, hardcover, 172 USD (used much cheaper)

Reviewer: Whitham D. Reeve



This is the third in a series of reviews of books about space weather. The questions that come to mind and that I will try to answer in this review are (not necessarily in order): 1) Is this little book worth the high list price; 2) Has the author written a good book on space weather and 3) Why would we be interested?

This is an extremely expensive little book at 172 USD (hardcover), about \$1.25/page. It is listed as a textbook on the Cambridge University Press website and the back cover says it is “... *one of the first undergraduate textbooks on space weather aimed at non-science majors*”. Show me a college student who can afford to pay that many frog-hides for a 138 page textbook. Even the paperback version is expensive. One should try to find a used copy or another book to learn about space weather. Unfortunately, if you are taking a course that specifies this book, you are stuck. I purchased my paperback copy as “new” from Amazon.com with a 40% discount and with hope that I can resell it. The book is just not worth the full price. I think readers could do better by buying the encyclopedic 700+ page *Understanding Space Weather and the Physics Behind It* [Knipp], which I will review in the future.

Although I have discussed the definition of space weather in previous reviews, it is interesting to see how the author handles it. In chapter 1, he uses a quote from National Space Weather Program Strategic Plan, 1995, Office of the Federal Coordinator for Meteorological Services and Supporting Research, FCM–P30–1995, Washington, DC. According to this, space weather “*refers to conditions on the Sun and in the solar wind, magnetosphere, ionosphere, and thermosphere that can influence the performance and reliability of space-borne and ground-based technological systems and can endanger human life or health. Adverse conditions in the space environment can cause disruption of satellite operations, communications, navigation, and electric power distribution grids, leading to a variety of socioeconomic losses.*” This sounds like all space weather is bad. Can that be so? Although our hair might have been mussed by past space weather events, how is it that we managed to survive until now? The usual answer is that we were not so reliant on technologies that can be damaged by space weather until relatively recently.

The author has done a good job of distilling a very broad technical subject into a little more than a hundred pages. He writes in a way to make the subject interesting and only occasionally gets off-track. The book is easy to read and goes into the details of how space weather affects certain technologies. This is in contrast to most similar books that dismiss the details by simply saying things like “Space weather can affect GPS”. The author occasionally uses simple algebraic equations to describe various processes and relationships, but this is not a book on solar physics. The index is inadequate but reflects the contemporary book publishing methods of charging more while delivering less.

The book is adequately illustrated with black-white line drawings and photographs and includes twelve color plates. The illustrations are well-done and the captions are appropriate. And, yes, a picture of a transformer damaged during a geomagnetic storm in 1989 is included. This is the same blurry picture used in just about every doomsday description of space weather, and it has become sort of *poster-child*. One could easily conclude it is the only transformer ever to be damaged by space weather. I know power engineers have done a lot of work since 1989 to improve power system protective relaying but, unfortunately, that is not mentioned in this (or any other contemporary) book on space weather. Even though there may be outdated electric transmission line infrastructure still existing in the US electrical grid that is vulnerable, there is no discussion in this book about upgrades and retrofits that have been made versus obsolescence in the last 20-30 years.

An Introduction to Space Weather contains eight chapters and three appendices. Each chapter starts with a list of *Key Concepts* and ends with a set of problems that readers can use to test their knowledge. Although no solutions are available, the problems encourage motivated readers to review and research. Before the problem sets there are *Supplement* sections that provide general information related to the main text. The supplements include units of measure, a description of the electromagnetic spectrum and Kepler's laws and gravity, among other concepts. These are helpful for readers not already familiar with them. It is in one of these supplements that the author defines the Doppler shift associated with a moving source and observer, but he gets the signs wrong in his equation. Using his equation, the Doppler frequency is lower when the source and observer are moving toward each other, which is contrary to reality. Fortunately, this error is not representative of the other material.

As mentioned above, the author starts out describing what space weather is, and he also goes into a little of the history of Sun observing. The next four chapters describe the Sun, heliosphere, Earth's space environment and Earth's upper atmosphere. This is a logical progression – from the source to the recipient – and is used in all books I have read on space weather including the one I previously reviewed – ***The Sun, The Earth and Near Earth Space ~ A Guide to the Sun-Earth System*** [Eddy].

In chapter 2, *The Variable Sun*, we learn in 19 pages about electromagnetic radiation, heat transfer, how the Sun is structured (chemical makeup, core, atmosphere, magnetic field and so on) and how it varies over time – the solar cycle. However, the discussion is limited to the 11 year sunspot cycle and 22 year magnetic cycle. These are the most obvious cycles and most people can experience a few such cycles during their lifetime. However, not mentioned here are other cyclic variations that last thousands and millions of years. Humans have not been scientifically observing these longer cycles in real time but there is much evidence of their existence; for example, see [Hathaway2015].

The heliosphere is discussed in chapter 3. A technical definition of the heliosphere is the interplanetary space where the solar wind flows supersonically, producing a shockwave as it moves outward. The heliosphere ends where the wind has slowed and is balanced by the interstellar wind. The speed of longitudinal waves (sound waves) in the solar wind is about 40 km s^{-1} so anything moving through it at a higher speed produces shockwaves. The solar wind speed itself is around 380 km s^{-1} , on average, but can vary considerably depending on solar activity.

Of particular interest in the study of space weather are coronal mass ejections (CME) from the Sun. We are told a CME can contain a trillion (10^{12}) kilograms of hot coronal matter as it is blasted away from the Sun, moving at

up to 2000 km s^{-1} (for comparison, the mass of a fully loaded long-range Boeing 777 airplane is about 350 thousand kg and its cruising speed is 15 km s^{-1}). CMEs usually are associated with strong solar flare events. CMEs carry part of the Sun's magnetic field, which can interact with Earth's magnetic field and cause geomagnetic storms. These storms can cause problems with electric transmission lines and pipelines – problems that are described in more detail later in the book and discussed below.

The next two chapters on Earth's space environment (chapter 4) and Earth's upper atmosphere (chapter 5) are straight-forward. However, I feel the discussions about the Van Allen Radiation Belts in chapter 4 and the ionosphere in chapter 5 are too abbreviated. The book was published in 2008 and we know much more now about the radiation belts, so that deficiency can be overlooked. On the other hand, chapter 5 should include more detail and illustrations showing how energetic particles and radiation from the Sun interact with air molecules and atoms in Earth's upper atmosphere to form the ionosphere. The ionosphere is of great interest to radio astronomers because of how it affects celestial radio waves on their way to radio telescopes.

Chapter 6 in *An Introduction to Space Weather* covers the technological impacts of space storms and chapter 7 the perils of living in space. Chapter 6 goes into considerable detail about the problems space weather has caused or can cause with satellites. There have been a number of failures including outright electronic failures and computer upset or reset thought to have been caused by surface charging and discharging and radiation damage. With very few exceptions, books on space weather, including this one, recall failures in early satellites but say nothing about problems, if any, with modern spacecraft. It is rarely admitted that the actual cause of most satellite failures either is unknown or nobody is talking because of potential liabilities. Those early failures having good correlation with solar events likely were caused by space weather but without physical examination of the failure the causes are at best conjecture. There is little question that satellite engineers have learned a lot from failures over time and, thus, make each new satellite more robust against the many perils of space.

Other technological impacts involve global navigation satellite systems (GNSS), the most familiar of which is the Global Positioning System (GPS). In addition to the spacecraft computer upset problems noted above, space weather also effects terrestrial navigation accuracy because of ionospheric variations. However, in reality, there are much more dangerous and likely threats to GNSS operation, specifically, human-caused spoofing and jamming. However, these problems are never put into proper perspective in space weather books including the one under review here.

Chapter 7 could be retitled "Getting Religion" because there are many terrible ways to die in space and most of the ways that could be caused by space weather are discussed here. There is no question that space is a dangerous place and a human does not have to be very high above Earth's surface to experience that danger. Aircraft flight crews and passengers are increasingly exposed the higher they fly. The human body can repair some radiation damage but there are limits that only can be described statistically. Biological damage by radiation is a serious problem, yet to be completely solved, for any type of human space travel including Earth-orbiting space stations and trips to the Moon and Mars.

The last chapter (8) covers *other* space weather phenomena including space weather effects on Earth's climate. Every climate change study includes models of this and models of that. The results depend on the model, who runs it and in some cases their desired result. The author acknowledges that the Sun's effects are under-appreciated: "*We are now coming to realize that our Sun is not a constant star and its variability can have a*

significant influence on Earth.” Climate change is not the only problem potentially caused by space weather. There are asteroids and comet impacts and even *nearby* supernova – massive star explosions. The discussion indicates that a supernova within 50 to 100 light-years of Earth could be a very serious problem for us and everything else on Earth. This revelation must be viewed statistically. The book indicates there could be around 14 000 stars within 100 LY of Earth and the probability of a supernova in that population is one every few hundred million years. I feel much better now.

While on the subject of other space weather phenomena, this book (like all other space weather books I have read) does not mention the possible effects of geomagnetic variations on climate. Many paleomagnetic studies have shown that Earth’s magnetic field has widely varied over time including numerous complete and near reversals. The complete reversals are aperiodic with a characteristic time in the neighborhood of 250 000 years. In the near-term, the geomagnetic field has experienced a general weakening trend over the last 175 years with a few percent increases in some areas of the world and decreases in others. Earth’s magnetic field shields life from the harmful effects of solar and cosmic radiation, but its long-term effects on climate seem to be ignored.

To answer the questions posed at the beginning of this review: 1) No, ***An Introduction to Space Weather*** is not worth the high list price but it is worth a lower price, say, 20 USD; 2) Yes, the author has written a good book on space weather and 3) Space weather is important aspect of our lives nowadays. However, every day I see ignorance-based hysteria force-fed to an uninformed public by a science-illiterate news media. It is quite easy to dismiss a lot of this as just plain hype and schlock news. On the other hand, intelligent accounts written by professionals are truly informative but because of their cost, as is the case for the book reviewed here, generally are of little interest to most people.

Citations:

- [Eddy] Eddy, J., *The Sun, The Earth and Near Earth Space ~ A Guide to the Sun-Earth System*, NASA, 2010 (Reviewed in the November-December 2017 issue of *Radio Astronomy*)
- [Hathaway2015] Hathaway, D., *The Solar Cycle*, *Living Reviews in Solar Physics*, 2015, available at <https://arxiv.org/abs/1502.07020>
- [Knipp] Knipp, D., *Understanding Space Weather and the Physics Behind It*, MIT Press, 2011



Reviewer - Whitham Reeve is a contributing editor for the SARA journal, *Radio Astronomy*. He obtained B.S. and M.S. degrees in Electrical Engineering at University of Alaska Fairbanks, USA. He worked as an engineer and engineering firm owner/operator in the airline and telecommunications industries for more than 40 years and now manufactures electronic equipment used in radio astronomy. He has lived in Anchorage, Alaska his entire life. Email contact: whitreeve(at)gmail.com

Space weather are solar and cosmic background effects on satellites and astronauts, the ionosphere, and ground systems. Our solar system is not quite as empty as the word "space" implies: Photons, electrons and protons (plus ions) from the Sun fill most of the solar system (the heliosphere), driving back the galactic cosmic rays (GCR) coming from other places in the galaxy. In this article, I try to explain the basics of space weather suited to the understanding of computer scientists, as I have struggled quite a bit with solar physics concepts since 2004, when I started working for SWENET (ESA's space weather european network), which in 2015 became a part of SSA (ESA's space situational awareness programme). "Space weather refers to conditions on the Sun and in the solar wind, magnetosphere, ionosphere, and thermosphere that can influence the performance and reliability of space-borne and ground-based technological systems and can endanger human health. Adverse conditions in the space environment can cause disruption of satellite operations, communications, navigation, and electric power distribution grids, leading to a variety of socioeconomic losses." US National Space Weather Program. Image of auroras at visible wavelengths (credit: spaceweather.com). Introduction to Space Weather. The range of space weather scales is extremely challenging. Relevant time scales vary from 10^{-9} s (plasma fluctuations in the solar atmosphere) to 10^8 s (solar cycle). European Space Weather Assessment and Consolidation Committee of the ESSC. What the Sun sends our way. COSPAR/ILWS Space Weather Science Roadmap team. Geomagnetic storms: couple into power grids, cause ionospheric disturbances affecting satellite-based navigation. Aurorae. Radiation storms: hazard to astronaut health. and satellite function; affect high-latitude radio communication; position errors on navigation. Space weather is a branch of space physics and aeronomy, or heliophysics, concerned with the time varying conditions within the Solar System, including the solar wind, emphasizing the space surrounding the Earth, including conditions in the magnetosphere, ionosphere, thermosphere, and exosphere. Space weather is distinct from but conceptually related to the terrestrial weather of the atmosphere of Earth (troposphere and stratosphere). The term space weather was first used in the 1950s and came into...