AGU PUBLICATIONS

JGR

Journal of Geophysical Research: Space Physics

COMMENTARY

10.1002/2017JA024219

Special Section:
Earth and Space Science is Essential for Society

Key Points:
- Space physics is the study of Earth's home in space
- Space physics is broadly relevant to society; space weather is only one of many impacts
- Space physics impacts policy decisions in many arenas, from homeland security to space exploration

Correspondence to:
P. A. Cassak,
Paul.Cassak@mail.wvu.edu

Citation:
Cassak, P. A., A. G. Emslie, A. J. Halford, D. N. Baker, H. E. Spence, S. K. Avery, and L. A. Fisk (2017), Space physics and policy for contemporary society, *J. Geophys. Res. Space Physics*, *122*, 4430–4435, doi:10.1002/2017JA024219.

Received 1 APR 2017
Accepted 7 APR 2017
Published online 20 APR 2017

Space physics and policy for contemporary society

P. A. Cassak[1], A. G. Emslie[2], A. J. Halford[3], D. N. Baker[4], H. E. Spence[5], S. K. Avery[6,7], and L. A. Fisk[8]

[1]Department of Physics and Astronomy, West Virginia University, Morgantown, West Virginia, USA, [2]Department of Physics and Astronomy, Western Kentucky University, Bowling Green, Kentucky, USA, [3]Department of Physics and Astronomy, Dartmouth College, Hanover, New Hampshire, USA, [4]Laboratory for Atmospheric and Space Physics, University of Colorado at Boulder, Boulder, Colorado, USA, [5]Institute for the Study of Earth, Oceans, and Space, University of New Hampshire, Durham, New Hampshire, USA, [6]Woods Hole Oceanographic Institution, Woods Hole, Massachusetts, USA, [7]Cooperative Institute for Research in Environmental Sciences and Electrical, Computer, and Energy Engineering, University of Colorado at Boulder, Boulder, Colorado, USA, [8]Department of Climate and Space Sciences and Engineering, University of Michigan, Ann Arbor, Michigan, USA

Abstract Space physics is the study of Earth's home in space. Elements of space physics include how the Sun works from its interior to its atmosphere, the environment between the Sun and planets out to the interstellar medium, and the physics of the magnetic barriers surrounding Earth and other planets. Space physics is highly relevant to society. Space weather, with its goal of predicting how Earth's technological infrastructure responds to activity on the Sun, is an oft-cited example, but there are many more. Space physics has important impacts in formulating public policy.

1. Introduction

This Commentary is being written in an uncertain and pivotal time in U.S. history. At unprecedented levels, many elected officials and political appointees are ignoring evidence-based science in policy making, politicizing science, and questioning the importance of Federal investments in basic science research [e.g., *Science News Staff*, 2017]. U.S. scientists are concerned that the free sharing of science research is in jeopardy [*Mervis*, 2017].

The authors reaffirm the core beliefs that science should be nonpartisan, basic science research is crucial to the advancement of society, and any attempt to politicize or suppress science is detrimental and should be opposed.

In the recent words of Rush Holt, the current chief executive officer of the American Association for the Advancement of Science (AAAS) and a former U.S. Representative, "Science is not just for scientists" [*Gaal*, 2017]. This could not be more true of the field of space physics. In this Commentary, we discuss what space physics is, its societal relevance and its impact on U.S. policy. A number of pieces have been written about the related topic of space weather [*Baker*, 2002; *Baker and Lanzerotti*, 2016] and its societal and policy impacts [*Fry*, 2012; *Lanzerotti*, 2015; *Schrijver*, 2015; *Jonas and McCarron*, 2015; *Cassak*, 2016; *Gaunt*, 2016; *Bonadonna et al.*, 2017]; the emphasis for this Commentary is the broader field of space physics.

2. What Is Space Physics?

Space physics is the study of Earth's home in space. Space physics is a broad field with a rich history; it includes (1) the study of how the Sun works from its interior to its surface and its atmosphere (the corona), including the causes of eruptions on the Sun marking times of high solar activity, (2) the characterization of the environment between the Sun and the planets out to the interstellar medium, including the solar wind and energetic cosmic rays from outside the solar system, (3) the study of the interaction of the magnetic barriers (magnetospheres) surrounding Earth and other planets with the interplanetary environment, particularly during times of high solar activity, and (4) the study of Earth's ionized upper atmosphere (the ionosphere) and its interaction with Earth's neutral lower atmosphere.

In each of these settings, the ambient material is typically hot, tenuous, and electrically conducting; some or all of the material is ionized and therefore in the plasma state. Plasmas in space are also typically threaded by magnetic fields. In the U.S., space physics also goes by the names Heliophysics at the National Aeronautics and Space Administration (NASA) and Geospace Sciences at the National Science Foundation (NSF). Space physics is a worldwide endeavor, with many countries actively engaging in research [*Greenwald*, 2017].

The history of space physics reaches back thousands of years [e.g., *Priest*, 1982; *Kivelson and Russell*, 1995]. The auroral light display and eclipses were documented more than 2500 years ago. The solar corona was discovered over a thousand years ago during eclipses. The magnetosphere traces its roots to William Gilbert's book *De Magnete* in 1600 when it was realized that Earth is magnetized. Our understanding of space physics increased steadily but relatively slowly until the 1950s when a vast expansion occurred. Following the breakdown of international science collaboration during the early stages of the Cold War, a number of scientists called for the International Geophysical Year (IGY), an international scientific collaboration on multiple aspects of geophysics including space physics [*Sullivan*, 1961; *National Academy of Sciences*, 2005]. As part of the IGY, the launch of the first artificial satellites was planned [*Van Allen*, 1983]. The first, Sputnik 1 in 1957, emitted radio waves which provided information about the ionosphere. The United States launched Explorer I in 1958, which discovered the Van Allen radiation belts. This new arena for space study and exploration led to the creation of NASA in 1958.

Modern space physics is studied both from ground-based and space-based observatories [*Lotko*, 2017]. Solar research is performed across the electromagnetic spectrum, from radio frequencies to gamma rays. Satellites currently studying sunquakes, coronal heating, and solar activity include NASA's Solar and Heliospheric Observatory (SOHO), Solar Terrestrial Relations Observatory (STEREO), Solar Dynamics Observatory (SDO), Interface Region Imaging Spectrograph (IRIS), and Reuven Ramaty High Energy Solar Spectroscopic Imager (RHESSI) missions and the Japan Aerospace Exploration Agency (JAXA) Hinode mission; ground-based measurements are done, for example, at the Green Bank Telescope (GBT). The region between the Sun and the planets is studied with satellite monitors measuring properties of the solar wind, both between the Sun and Earth and all the way out to the interstellar medium, including NASA's Voyager, Interstellar Boundary Explorer (IBEX), Advanced Composition Explorer (ACE), and Wind missions, the National Oceanic and Atmospheric Administration (NOAA) Deep Space Climate Observatory mission, and JAXA's Geotail mission. The electromagnetic and plasma properties of Earth's magnetosphere are studied with a suite of instruments on Earth-orbiting satellites, balloons, and cubesats, and using ground-based observatories. Satellite missions studying Earth's magnetosphere include the European Space Agency (ESA) Cluster mission, NASA's Van Allen Probes, Time History of Events and Macroscale Interactions during Substorms (THEMIS) and Acceleration Reconnection Turbulence and Electrodynamics of the Moon's Interaction with the Sun (ARTEMIS), Two Wide-Angle Imaging Neutral-Atom Spectrometers (TWINS), and Magnetospheric Multiscale (MMS) missions, and NOAA's satellites monitoring the aurora (Polar Orbiting Environmental Satellites, POES) and the radiation belts (Geostationary Operational Environmental Satellites, GOES). Global position system (GPS) satellites are even used for science — they provide a measure of the density of the ionosphere. Ground-based measurement facilities including High Frequency Active Auroral Research Program (HAARP), European Incoherent Scatter (EISCAT), Super Dual Auroral Radar Network (SuperDARN), and Supermag look at the ionosphere, aurora, and changes to the near-Earth magnetic field. Radar beams are used to study the properties of the upper atmosphere, such as at the Arecibo, Jicamarca, Millstone Hill, Advanced Modular Incoherent Scatter Radar (AMISR), and Poker Flat facilities. Other planetary magnetospheres have been studied by in situ satellites including Mercury Surface, Space Environment, Geochemistry, and Ranging (MESSENGER, Mercury), Cassini (to Saturn), and Juno (to Jupiter). The constellation of satellites comprising NASA's Heliophysics System Observatory is shown in Figure 1.

There are also a number of important missions on the horizon. For example, NASA's Solar Probe Plus and the European Space Agency's Solar Orbiter will study the solar wind close to the Sun; Solar Probe Plus will go 96% of the way to the solar surface. NASA's Ionospheric Connection Explorer (ICON) will study the ionosphere to help understand what causes interference with communications and GPS signals from satellites. NASA's Global-scale Observations of the Limb and Disk (GOLD) satellite will measure the temperature and composition of Earth's upper atmosphere. A state-of-the-art large ground-based solar optical telescope, the Daniel K. Inouye Solar Telescope (DKIST), is being built in Hawaii.

Driven by, and as a complement to, these observational efforts, space physicists have developed new theories and computational techniques and tools. Magnetohydrodynamics (MHD), an extension of hydrodynamics, incorporates the effects of electric and magnetic fields [*Alfvén*, 1942]. The kinetic theory of plasmas is a

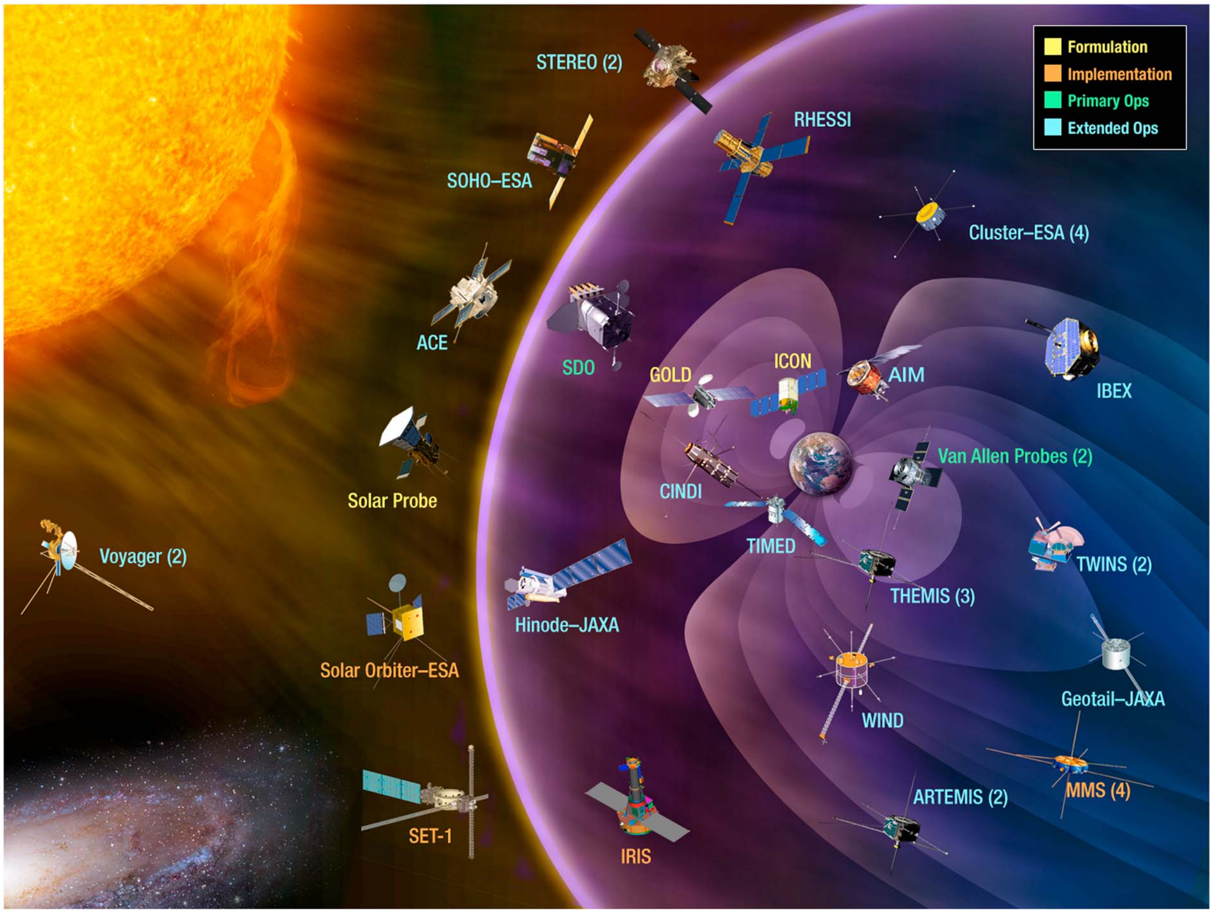

Figure 1. Artist's rendition of the Sun-Earth space environment (not to scale), with NASA's Heliophysics System Observatory overlaid. Image courtesy of NASA.

statistical description of particle behavior in a plasma [*Vlasov*, 1938; *Landau*, 1946]. For most systems of interest, the equations are too complicated to solve by hand, so high-performance computing at supercomputers is playing an important role. There is now an extensive suite of simulation tools to study virtually every area of space physics. Many computational tools have been gathered at NASA's Community Coordinated Modeling Center (CCMC) [*Chulaki*, 2017], which provides an arena for anyone to request simulations for space physics research. In summary, Earth's home in space is being studied using a diverse array of approaches.

3. How Is Space Physics Societally Important?

Even before the seemingly ubiquitous presence of technology in our day-to-day lives, space physics has been important to society. Radios, for example, invented in the late nineteenth century, exploit the reflection of electromagnetic waves from the ionosphere. However, as technology has proliferated, space physics has taken on a new and profound importance for humankind. Many modern technologies are susceptible to eruptions on the Sun. Flares and coronal mass ejections propel radiation and energetic charged particles into space. These eruptions can trigger a chain of events that cause damage to the electrical grid and widespread power outages, damage to satellites and taking them out of their orbits, life-threatening dangers to astronauts, erosion of pipelines, and communication and health problems for passengers and crew on airplanes flying polar routes [*Eastwood*, 2008; *Baker and Lanzerotti*, 2016]. Space weather is the prediction of solar eruptions and their effect on Earth. Estimates suggest that an intense space weather event could take months to recover from with significant costs [*Hapgood*, 2011]. The study of space physics is crucial for space weather prediction.

While space weather is the most commonly discussed example of a societal impact of space physics, there are countless others. For example, many technological advances have been a direct result of the development of satellite technology, which itself was motivated by space physics and the IGY. One example is solar cells, which now have efficiencies near 25% [*Green*, 2009]. Major advances in efficiency resulted from the effort to use solar power for the Vanguard satellite in 1958. Another example is the magnetometer, a device which measures magnetic fields. It is now used for military purposes, coal, mineral, and oil exploration, and even in cell phones; its performance has been greatly furthered by the demands of space physics.

The satellite program has played a key role in many modern technologies. It is difficult to overstate the importance of satellites in our modern lifestyle. There are over 1000 currently operational satellites in orbit, which are used for personal and commercial communications, military communications, and national security, in the business sector, and for scientific studies both pointing earthward and upward to outer space. All of them have relied on knowledge of the space environment provided by space physics. Anyone with a smart phone in their purse or pocket knows how useful GPS can be [*Hapgood*, 2017]. The idea for GPS followed from U.S. attempts to track the Sputnik satellite during the IGY [*Mai*, 2015]. Another example is the computer algorithms developed to make topographical maps of the moon that have been used for medical applications of computer-aided tomography and magnetic resonance imaging [*NASA*, 1999]. NASA and ESA have had thousands of spin-off patents from their satellite programs [*Lockney*, 2017; *European Space Agency*, 2017]. These are just a few examples of the huge return on investment in developing satellites for space physics research.

Space physics research has reaped extraordinary dividends in astrophysics and planetary science. The Sun is our "Rosetta Stone" for understanding the structure and behavior of other stars, including their evolution into compact objects such as neutron stars and black holes. Perspectives from Earth and its magnetosphere have provided important motivation for the study of planets in the solar system and beyond.

Theoretical efforts on space physics have also found widespread use in other settings. The MHD theory, initially developed to study the Sun [*Alfvén*, 1942], was used to pursue the production of energy through fusion, for novel approaches to spacecraft propulsion, and many engineering applications [*Davidson*, 2001].

Space physics simulations have been directly applied for space weather prediction. NASA and NOAA cooperate to transition these codes from research to operations. NOAA not only provides weather data to the public but also provides space weather data through its Space Weather Prediction Center (SWPC). Currently, SWPC has over 50,000 subscribers [*Space Weather Prediction Center (SWPC)*, 2017]. These subscribers include stakeholders in the private sector, including all the major airlines, drilling, and oil exploration companies, most satellite companies, the transportation sector, and emergency responders. The reasons discussed in this section underscore how important basic space physics research is to society.

4. How Does Space Physics Impact Policy?

Space physics has a major impact on policy both in the U.S. and worldwide. The most visible recent example in the U.S. was the executive order signed by President Obama in 2016 to coordinate many branches of the government to ensure the U.S. is prepared for a major space weather event [*Lanzerotti*, 2015]. A thrust of this effort is supporting basic research in space physics. Bipartisan bills to implement the plan are currently being discussed in both the U.S. Senate [*Peters*, 2017] and House.

In addition, many U.S. congressional committees deal with issues for which space physics is important. Examples include the following:

1. *Homeland Security, Armed Services, Intelligence.* Satellites are used for military communication. It is believed that a critical loss of communication caused by a solar disturbance during the battle of Takur Ghar (Afghanistan, 2002) led to the loss of three U.S. soldier's lives [*Kelly et al.*, 2014].
2. *Agriculture.* GPS satellites provide accurate positioning information that is crucial to farmers for precision agriculture [*Stafford*, 2000].
3. *Commerce.* The Department of Commerce manages the U.S. GPS program, including its use for space weather forecasting. Annual worldwide sales of products and services related to GPS reached $8 billion by the year 2000 [*Enge and Misra*, 2002]. The commercial space industry is undergoing unprecedented expansion, reaching over $245 billion in 2015 [*Space Foundation*, 2016]. Also, as mentioned earlier, many industries rely on space weather predictions [*SWPC*, 2017]. There is a correlation between insurance claims for business electrical equipment losses and space weather activity [*Schrijver et al.*, 2014].
4. *Transportation.* In addition to health hazards to passengers and crew from solar radiation during solar eruptions [*Knipp*, 2017], communications between air traffic control and aircraft flying polar routes can be disrupted [*Jones et al.*, 2005]. As a result, airlines cannot fly along polar routes when solar storms are active. The required rerouting of planes occurs at a significant cost and inconvenience to passengers.

5. *Energy.* One of the most visible impacts of space weather is large scale power outages, which occurred in, for example, Canada and the U.S. in 1989 and in Sweden in 2003 [*Eastwood*, 2008], so space physics informs decisions about power grid maintenance and protection.
6. *Science.* Understanding space physics is crucial for human space travel. The Apollo 16 and Apollo 17 missions in April and December of 1972, respectively, narrowly missed a significant solar eruption in August 1972 [*Eastwood*, 2008]. Astronauts on longer-duration missions will not be so lucky. Transfers from Earth to Mars take over 7 months each way. Throughout the trip, astronauts would be prone to the debilitating effects of solar eruptions. These dangers are equally present for commercial human spaceflight. Private industry is unlikely to have the capacity for, or interest in, doing basic space physics research that would inform their activities, so they rely that research being supported at the federal level.
7. *Education.* Space physics missions and the images they produce excite and inspire children and young adults [*National Research Council et al.*, 2013]. This increases the likelihood that they will pursue careers in science. Also, students trained in space physics at universities have a wide array of skills of use in the technical workforce.

5. Concluding Remarks

Space physics has a rich history. Its relevance to our "home in space" has appealed to both scientists and the public for many years. Its importance to the economic and technological infrastructure in many sectors of modern life is significant and continuing to grow. Therefore, a deep understanding of space physics is crucial to the formulation of responsible policy.

At a time when the very importance of basic science research is being questioned, scientists need to consider it part of their responsibility to ensure that their elected officials are aware of why their work is important. (Resources for doing so are available at http://sciencepolicy.agu.org, and community members are encouraged to contact any of the coauthors for assistance.) Scientists need to continue to learn about the universe according to strict scientific principles and ethics, thereby continuing to provide a strong return on the nation's investments. Scientists also need to present their knowledge in an unbiased and easily understood manner when called upon by policy makers. In return, policy makers need to reaffirm that investing in basic science research is crucial to the success of the nation. Further, policy makers need to recognize that space physics in particular, and science in general, is a crucial nonpartisan resource for making informed policy decisions.

Acknowledgments
P.A.C. thanks Earl Scime for helpful discussions about satellite technology transfer. The opinions expressed in this article are the authors' own and do not necessarily reflect the views of their institutions, the Journal of Geophysical Research, or the American Geophysical Union. This commentary did not present any new data.

References

Alfvén, H. (1942), Existence of electromagnetic-hydrodynamic waves, *Nature*, *150*, 405–406.
Baker, D. N. (2002), How to cope with space weather, *Science*, *297*, 1486–1487.
Baker, D. N., and L. J. Lanzerotti (2016), "Resource Letter" for space weather, *Space Weather*, *14*, 528–529, doi:10.1002/2016SW001485.
Bonadonna, M., L. Lanzerotti, and J. Stailey (2017), The National Space Weather Program: Two decades of interagency partnership and accomplishments, *Space Weather*, *15*, 14–25, doi:10.1002/2016SW001523.
Cassak, P. A. (2016), Inside the black box: Magnetic reconnection and the magnetospheric multiscale mission, *Space Weather*, *14*, 186–197, doi:10.1002/2015SW001313.
Chulaki, A. (2017), Community Coordinated Modeling Center. [Available from https://ccmc.gsfc.nasa.gov/, accessed 26 March 2017.]
Davidson, P. A. (2001), *An Introduction to Magnetohydrodynamics*, Cambridge Univ. Press, Cambridge, U. K.
Eastwood, J. P. (2008), The science of space weather, *Philos. Trans. R. Soc. A*, *366*, 4489–4500.
Enge, P., and P. Misra (2002), Special issue on global positioning system, *Proc. IEEE*, *87*, 3–15.
European Space Agency (2017), ESA Technology Transfer Programme. [Available from http://www.esa.int/Our_Activities/Space_Engineering_Technology/TTP2/Technology_Transfer_Network3, accessed 26 March 2017.]
Fry, E. K. (2012), The risks and impacts of space weather: Policy recommendations and initiatives, *Space Policy*, *28*, 180–184.
Gaal, R. (2017), Science is not just for scientists, *APS News*, *26*, 1.
Gaunt, C. T. (2016), Why space weather is relevant to electrical power systems, *Space Weather*, *14*, 2–9.
Green, M. A. (2009), The path to 25% silicon solar cell efficiency: History of silicon cell evolution, *Prog. Photovoltaics: Res. Appl.*, *17*, 183–189.
Greenwald, R. (2017), The importance of international collaboration in space research, *Radio Sci.*, doi:10.1002/2017RS006329, in press.
Hapgood, M. (2011), *Lloyd's 360 Risk Insight: Space Weather: Its Impacts on Earth and the Implications for Business*, Lloyd's, London.
Hapgood, M. (2017), Satellite navigation — Amazing technology but insidious risk: Why everyone needs to understand space weather, *Space Weather*, doi:10.1002/2017SW001638, in press.
Jonas, S., and E. D. McCarron (2015), Recent U.S. policy developments addressing the effects of geomagnetically induced currents, *Space Weather*, *13*, 730–733.
Jones, J. B. L., R. D. Bentley, R. Hunter, R. H. A. Iles, G. C. Taylor, and D. J. Thomas (2005), Space weather and commercial airlines, *Adv. Space Res.*, *36*, 2258–2267.
Kelly, M. A., J. M. Comberiate, E. S. Miller, and L. J. Paxton (2014), Progress toward forecasting of space weather effects on UHF SATCOM after Operation Anaconda, *Space Weather*, *12*, 601–611, doi:10.1002/2014SW001081.
Kivelson, M. G., and C. T. Russell (1995), *Introduction to Space Physics*, Cambridge Univ. Press, Cambridge, U. K.
Knipp, D. (2017), Essential science for understanding risks from radiation for airline passengers and crews, *Space Weather*, doi:10.1002/2017SW001639, in press.

Landau, L. (1946), On the vibration of the electronic plasma, *J. Phys. (USSR)*, *25*, 25–34. English translation in JETP 16, 574.
Lanzerotti, L. J. (2015), Space weather strategy and action plan: The National Program Is Rolled Out, *Space Weather*, *13*, 824–825, doi:10.1002/2015SW001334.
Lockney, D. (2017), NASA Spinoff Technology Transfer Program. [Available from https://spinoff.nasa.gov/, accessed 26 March 2017.]
Lotko, W. (2017), The unifying principle of coordinated measurements in geospace science, *Space Weather*, doi:10.1002/2017SW001634, in press.
Mai, T. (2015), Global positioning system history. [Available from https://www.nasa.gov/directorates/heo/scan/communications/policy/GPS_History.html, accessed 26 March 2017.]
Mervis, J. (2017), U.S. Senate bill aims to make sure federal scientists aren't 'muzzled'. [Available from http://www.sciencemag.org/news/2017/02/us-senate-bill-aims-make-sure-federal-scientists-aren-t-muzzled, accessed 4 April 2017.]
National Academy of Sciences (2005), The International Geophysical Year. [Available from: http://www.nas.edu/ history/igy/, accessed 26 March 2017.]
National Aeronautics and Space Administration (1999), NASA contributes research and technology to the war against cancer. [Available from https://science.nasa.gov/science-news/science-at-nasa/belleau2, accessed 30 March 2017.]
National Research Council; Division on Engineering and Physical Sciences, Space Studies Board, Aeronautics and Space Engineering Board, and Committee on a Decadal Strategy for Solar and Space Physics (Heliophysics) (2013), *Solar and Space Physics: A Science for a Technological Society*, National Academies Press, Washington, D. C.
Peters, G. C. (2017), S.141—Space Weather Research and Forecasting Act. [Available from https://www. congress.gov/bill/115th-congress/senate-bill/141, accessed 30 March 2017.]
Priest, E. R. (1982), *Solar Magnetohydrodynamics*, Springer, Dordrecht, Netherlands.
Schrijver, C. J. (2015), Socio-economic hazards and impacts of space weather: The important range between mild and extreme, *Space Weather*, *13*, 524–528, doi:10.1002/2015SW001252.
Schrijver, C. J., R. Dobbins, W. Murtagh, and S. M. Petrinec (2014), Assessing the impact of space weather on the electric power grid based on insurance claims for industrial electrical equipment, *Space Weather*, *12*, 487–498, doi:10.1002/2014SW001066.
Science News Staff (2017), A grim budget day for U.S. science: Analysis and reaction to Trump's plan. [Available from http://www.sciencemag.org/news/2017/03/trumps-first-budget-analysis-and-reaction, accessed 26 March 2017.]
Space Foundation (2016), The Space Report: 2016. [Available from https://www.spacefoundation.org/sites/default/files/downloads/The_Space_Report_2016_OVERVIEW.pdf, accessed 5 April 2017.]
Space Weather Prediction Center (SWPC) (2017), Space Weather Prediction Center subscription services. [Available from http://www.swpc.noaa.gov/content/subscription-services, accessed 30 March 2017.]
Stafford, J. V. (2000), Implementing precision agriculture in the 21st century, *J. Agric. Engng. Res.*, *76*, 267–275.
Sullivan, W. (1961), *Assault on the Unknown; The International Geophysical Year*, McGrawhyphenHill, New York.
Van Allen, J. A. (1983), *Origins of Magnetospheric Physics*, Smithsonian Institution Press, Washington, D. C.
Vlasov, A. A. (1938), *The Oscillation Properties of An Electron Gas*, US Atomic Energy Commission, AAAS, Washington, D. C.