International Journal of New Media Studies (IJNMS), ISSN: 2394-4331
Volume 9 Issue 2, July-December, 2022, Impact Factor: 7.786

Space Weather with Small Satellites: Short Review

Shreya Mane

Research Fellow, Department of Research and Development, Astroex Research Association,
Deoria-274001, India

Abstract

Small satellites (SmallSats, including CubeSats), thanks to recent developments in miniaturization and commercial availability of vital satellite subsystems and detector technology, are now a desirable, affordable prospective answer for space weather research and operational demands. We discuss the need for sophisticated space weather measurement capabilities, driven by analyses from the World Meteorological Organization (WMO), and how SmallSats can effectively fill these measurement gaps. This discussion is inspired by the first International Workshop on SmallSats for Space Weather Research and Forecasting, held in Washington, DC, on 1-4 August 2017.Small satellites can fill in the gaps in space weather measurements, which are detected. It is briefly explored how solar inputs to space weather models, space radiation management, estimates of the upper Earth's atmosphere's energy budget, and satellite drag modeling could be improved. It is advised that tiny satellites use key observables, sensors, and observational techniques. It is suggested to optimize tracking for tiny satellites.

Keywords: Space weather, Space environment, Small satellites, Space radiation control.

Introduction

Monitoring the space environment is crucial for identifying and preventing potential threats to contemporary technologies and space missions. Our daily lives are directly impacted by a variety of space weather effects on radio navigation and satellite communication technologies (like GPS). We can identify or anticipate natural risks by looking into the mechanisms of connection between atmospheric gravity waves (AGW) and travelling ionospheric disturbances (TID) (e.g., earthquakes, tsunamis, volcanic eruptions, etc.) [1].

However, a lack of reliable observation prevents us from fully understanding the coupling mechanisms between different scales of structures or occurrences in the ionosphere and magnetosphere. To explore the space environment, several conventional satellite missions deployed rather large spacecraft with expensive scientific payloads. Due to numerous benefits over a single huge satellite, the idea of small satellite constellations or formation flying has recently become a popular technology. An ideal mission design for better identifying the temporal and spatial variation of multi-scale space weather events is satellite formation flight. For instance, scalable tetrahedral configurations consisting of four satellites are used in spacecraft formation flight missions like MMS (Magnetospheric Multiscale) [2] and Cluster [3] to investigate events in the solar wind, magnetopause, magnetotail, and radiation belts.

Satellites are impacted by space radiation through anomalies such as surface and interior charging, component degradation owing to ionizing radiation dosage, and single event effects (SEE). Therefore, it's crucial to comprehend the radiation environment in order to develop satellites that can resist any potential anomalies. Galactic cosmic rays (GCR), solar energetic particle (SEP) events, high-energy particles caught in the Earth's magnetic field, and the background radiation continuously are some of the sources of space radiation. Additionally, the low-Earth orbit (LEO) zone, where the majority of satellites are located, is governed by unidentified mechanisms that give it unpredictable energy variability in the particle spectra [4-6]. When it comes to electrons, which might manifest at energies above expectations, this unpredictability is particularly poorly understood.

Depending on the mission design, era, and class, different high-energy electrons, protons, and ions have different effects on spacecraft developers. Ionizing radiation effects, as well as charging and discharging impacts on satellite surfaces, should be taken into consideration when designing the spacecraft. The accompanying life support systems and mission duration [7, 8] for manned missions need to be adjusted to take into consideration the unpredictable nature of particle populations.

Small satellites are now a practical way to achieve important space weather research goals because to recent developments in sensor and spacecraft technology. Small-satellite missions can serve as stand-alone missions with narrowly focused science and application goals, or they might supplement larger missions that are either underway or planned by completing coverage or temporal gaps. The next generation of experimental space scientists, aerospace engineers, and space weather experts would benefit greatly from such trips.

Unsurprisingly, many government organizations—military and civilian—as well as corporate/private institutions around the world have made predicting severe space weather occurrences and their repercussions a primary goal. Recently, the need for space weather readiness has started to be formally recognized in public policy. For instance, the National Space Weather Strategy and related Action Plan documents [9-11] call for "improving space-weather services through advancing understanding and forecasting" (Goal 5), specifically through "improving forecasting lead-time and accuracy" and "enhancing fundamental understanding of space weather and its drivers to develop and continually improve predictive models" (sub-goals 5.4 and 5.5, respectively).

In support of WMO projects, including space weather https://space.oscar.wmo.int/applicationareas/view/space weather), the World Meteorological Organization (WMO) establishes measurement standards for observations of physical variables. A WMO panel made up of experts who typically represent their country operational space weather centers routinely reviews and updates the standards. The Inter-Programme Team on Space Weather Information, Systems, and Services (IPT-SWeISS) was the team's previous moniker, though we should note that IPT-SWeISS has since come to an end and a new WMO space weather specialist team is currently being formed. The expert team's evaluations consistently show that current observational assets fall short of the WMO criteria, and that SmallSats constellations could successfully replace these gaps. These conditions serve as a framework for developing technology for comprehending and forecasting space weather. These needs are not entirely met by planned space missions and current technology; thus, they may be used to direct present and future space weather activities. However, it would be too expensive to implement conventional mission design to meet many of the WMO standards. There is a lot of interest in researching SmallSats as a way to meet some WMO needs at a lower cost than, or in ways not possible by, standard space missions [13] because prior CubeSat missions have already shown the viability of SmallSats for focused space weather research [12].

Solar Inputs of Space Weather Models

The dependence of forecasting models on data inputs from research-type instrumentation is one of the ongoing issues for space weather operations. The inputs are of a critical nature and include solar flare parameters (such as spectral irradiance) and CME parameters (such as occurrence, initial speed, and direction), which are the primary causes of space weather, and solar photospheric magnetic fields, which are crucial for determining the background state of the heliosphere.

Designs for solar telescopes are well-developed, and measuring criteria are clear. Numerous telescopes can easily be made smaller without losing any of their usefulness for space weather; in fact, some have already been. With the exception of the necessity for operational payloads to have an extended lifetime, MiniCOR [14], a 6U CubeSat-compatible version of the STEREO/SECCHI COR2 coronagraph, satisfies NOAA's operational requirements for a coronagraph.A miniature coronagraph and three wide-field imagers will also be part of the recently chosen PUNCH Small Explorer, all of which are on SmallSats platforms. For more accurate modeling of Earth's ionospheric responses to solar soft X-ray forcing, soft X-ray spectrometers, like those carried on MinXSS [15,16], a 3U CubeSat, can give thorough spectrum irradiance diagnostics of flares and active zones.

Space Radiation Operational Control

Satellites are seriously endangered by the impacts of space radiation, including spacecraft charging (internal and external), radiation dose, and single-event effects [17]. In order to reduce the dangers associated with space weather radiation, it is essential to continuously monitor energetic particle fluxes in geo space from solar energetic particles (SEPs), galactic cosmic rays, radiation belt (RB) particles, as well as auroral low-energy particles. After solar flares or the passage of high-speed streams, respectively, there can be 2-4 order of magnitude increases in SEP or trapped energetic electron fluxes. The best way to reduce the dangers associated with space weather is by direct flux measurements. Existing space weather services today use spacecraft in the solar wind (like ACE) or in geostationary Earth orbit to identify in situ SEP events. Small satellites in low Earth orbit (LEO) can make multisatellite surveys that will help with SEP event detection and provide data on the size of the polar area that SEPs can access. The most dynamic component of the radiation environment on Earth is known as the outer (electron) radiation belt (ORB). Electrostatic discharge, which can harm spacecraft or destroy instrumentation, is caused by internal charging and the overall ionizing dosage of relativistic and sub relativistic ORB electrons.

Existing empirical models of Earth's RBs [18, 19] are not suitable for use in operational space weather services because they are unable to simulate the considerable short-term fluctuations of the energetic electron fluxes during magnetospheric disturbances. For real-time services, numerical models like VERB [20] are not as quick.

Constraining the Energy Budget of the Earth's Upper Atmosphere

Ionosphere and upper neutral atmosphere on Earth are propelled both from above (solar wind and magnetosphere) and below (gravity) (middle and lower atmosphere). Many forecasting initiatives are built on first-principles models of the linked ionosphere-thermosphere (IT) system, which depend on precise driver specifications [21]. Due to the high sensitivity of the IT system to driving [22], considerable modeling errors in IT state [23, 24] and potentially its forecasting [25] errors are caused by uncertainties in energy inputs and energy budget. The necessity of continually available low-latency observations that are directly related to space weather is stressed in [26]. Growing observational evidence suggests that the amount of energy entering the ionosphere may be overestimated if energy transmission at several scales is not taken into account [27–31].

Improvement of Satellite Drag Models

Satellite drag estimation is another aspect of space weather that small satellites can help with. The atmospheric density is altered by variations in the exospheric temperature, the local makeup of neutral species, and their net motion, which results in a drag on satellites. Missions are significantly impacted by errors in drag modeling, notably in terms of mission lifetime and collision avoidance [32]. However, since Atmospheric Explorer and Dynamics Explorer, these metrics have scarcely been measured at all. The calibration of the models and the accuracy of forecasts are impacted by the lack of global data of the neutrals and winds [33]. The existing observations network was graded poorly for operational usage overall in a WMO analysis.

The utilization of SmallSats in LEO for space weather applications can be improved by increasing telemetry volume and lowering data delay. When deploying or selecting GSs, several improvements can be made through optimum site selection. The most important and crucial element for any given GS is the antenna elevation mask, or the "view to the sky," which is tailored for the mission's radio frequency range. The elevation mask can be precisely determined using recently developed 3-D tools and methodologies based on nearby view blockage and RF interference sources. This makes it possible to choose the best antenna location while taking into account facility limits and mission performance requirements, and it can boost satellite visibility by up to 50% in densely populated metropolitan areas [34, 35].

When the longitudinal distribution of the stations is managed to reduce overlap and enhance visibility, using a network of distributed GSs has a considerable added benefit, increasing available downlink by 5–10 times. For instance, SATNet can assist with building the required telecom infrastructure to allow CubeSat operators to share radio amateur GSs [36]. However, at very modest data rates, some modern SmallSats have used real-time satellite-to-satellite communications (such as Global Star, Iridium) to provide real-time downlink independently from GS visibility. Here [37] discuss pertinent concerns that should be taken into account for global coordination, such as frequency licensing and/or the deployment and utilization of extensive GS networks.

The LAICE CubeSat mission [38] and the QB50 project [39] are two examples of constellation formations designed using CubeSat technology advancements. Another example is the SATNet project, which uses a network of scattered GSs to explore space weather. It is necessary to investigate the viability of real-time and nonreal-time telemetry systems for SmallSats platforms. For time-sensitive observations, such as alerts for solar flares, CMEs, and SEPs, low-latency or continuous downlinking is essential. Less urgent but more detailed data can be downlinked in a conventional fashion with higher latency. A significant relevance for GS sites and design in urban contexts has arisen as a result of the demand for data volume and the requirement to support SmallSats missions, tracking and control activities. The satellite access times might be increased by tracking optimization, which would improve SmallSats platform operations and comprehension of space weather.

A New Opportunity

Small satellite measurements taken from space have the potential to significantly increase our knowledge of space weather. Small-satellite missions are becoming more affordable because to improvements in sensor technology and expanding launch options. It is feasible to fly scientific satellite missions for between $1 and $10 million (including launch costs), and these missions can close critical observational gaps. Therefore, it's crucial to keep mission expenses as low as possible to prevent falling victim to risk aversion, which increases programmatic complexity and costs.

In addition, these missions are essential for educating the upcoming class of aerospace engineers and experimental space scientists. The amount of time needed to plan and carry out significant space missions has hindered the effective training of the upcoming generation of aerospace professionals. Students can participate in a small-satellite mission that can be conceived, built, flown, and operated in three to four years, giving them the opportunity to see the mission process from beginning to conclusion. The chance to view the scientific results of their small-satellite research projects will increase the pupils' already innate passion with space exploration. Small satellites' regular access to space will keep aerospace engineering and space science innovative and creative, and it will also preserve public interest in space. Small satellites will also stimulate the creation of novel experimental techniques and technologies. This new technology will be extremely helpful to the space weather community.

Conclusion

SmallSats can fill a number of present gaps in our knowledge of space weather and our operational requirements. We suggested important observables, tools, and observational techniques that help improve space weather operations across a number of fields.

References

[1]. Komjathy, A., Galvan, D. A., Stephens, P., Butala, M. D., Akopian, V., Wilson, B., Verkhoglyadova, O., Mannucci, A. J. and Hickey, M., “Detecting ionospheric TEC perturbations caused by natural hazards using a global network of GPS receivers: The Tohoku case study”, Earth, planets and space, 64(12), 2012, pp. 1287-1294.

[2]. Curtis, S., “The magnetospheric multiscale mission... resolving fundamental processes in space plasmas”, Technical Report, 1999.

[3]. Escoubet, C. P., Schmidt, R. and Goldstein, M. L., “Cluster-Science and mission overview”, The Cluster and Phoenix Missions, Springer, Dordrecht, 1997, pp. 11-32.

[4]. Sihver, L.; Kodaira, S.; Ambrožová, I.; Uchihori, Y.; Shurshakov, V. Radiation Environment Onboard Spacecraft at LEO and in Deep Space. In Proceedings of the 2016 IEEE Aerospace Conference, Big Sky, MT, USA, 5–12 March 2016; pp. 1–9.

[5]. Suparta, W.; Gusrizal. The Variability of Space Radiation Hazards towards LEO Spacecraft. In Journal of Physics: Conference Series 539 (October 2014): 012023; IOP Publishing: Bristol, UK, 2014.

[6]. Chen, L.; Thorne, R.M.; Li, W.; Bortnik, J.; Turner, D.; Angelopoulos, V. Modulation of Plasmaspheric Hiss Intensity by Thermal Plasma Density Structure. Geophys. Res. Lett. 2012, 14, 39.

[7]. Cucinotta, F.A.; Cacao, E.; Kim, M.H.Y.; Saganti, P.B. Cancer and Circulatory Disease Risks for a Human Mission to Mars: Private Mission Considerations. Acta Astronaut.2018, 13.

[8]. Miyake, S.; Kataoka, R.; Sato, T. Cosmic Ray Modulation and Radiation Dose of Aircrews during the Solar Cycle 24/25. Space Weather 2017, 15, 589–605.

[9]. Bonadonna, M., Lanzerotti, L., & Stailey, J. (2017). The National Space Weather Program: Two decades of interagency partnership and accomplishments. Space Weather, 15(1), 14–25. https://doi.org/10.1002/2016SW001523.

[10]. National Science and Technology Council. (2015a). National space weather strategy. Executive Office of the President (EOP).Retrieved from https://www.sworm.gov/publications/2015/nsws_final_20151028.pdf.

[11]. National Science and Technology Council. (2015b). National space weather action plan. Executive Office of the President (EOP).Retrieved from https://www.sworm.gov/publications/2015/swap_final__20151028.pdf.

[12]. Spence, H. E., Caspi, A., Bahcivan, H., Nieves-Chinchilla, J., Crowley, G., Cutler, J., et al. (2022). Recent achievements and lessons learned from small satellite missions for space weather-oriented research. Space Weather submitted (this issue).

[13]. Verkhoglyadova, O. P., Bussy-Virat, C. D., Caspi, A., Jackson, D. R., Kalegaev, V., Klenzing, J., et al. (2021). Addressing gaps in space weather operations and understanding with small satellites. Space Weather, 19(3), e02566.https://doi.org/10.1029/2020SW002566.

[14]. Korendyke, C. M., Chua, D. H., Howard, R. A., Plunkett, S. P., Socker, D. G., Thernisien, A. F. R., et al. (2015). MiniCOR: A Miniature Coronagraph for Interplanetary CubeSat. Proceedings of the 29th Annual AIAA/USU Conference on Small Satellites, Science/Mission Payloads, SSC15-XII-6. Retrieved from http://digitalcommons.usu.edu/smallsat/2015/all2015/82.

[15]. Mason, J. P., Woods, T. N., Caspi, A., Chamberlin, P. C., Moore, C., Jones, A., et al. (2016). Miniature X-ray Solar Spectrometer: A science-oriented, University 3U CubeSat. Journal of Spacecraft and Rockets, 53(2), 328–339. https://doi.org/10.2514/1.A33351.

[16]. Woods, T. N., Caspi, A., Chamberlin, P. C., Jones, A., Kohnert, R., Mason, J. P., et al. (2017). New solar irradiance measurements from the miniature X-ray solar spectrometer CubeSat. The Astrophysical Journal, 835(2),

122.https://doi.org/10.3847/1538-4357/835/2/122.

[17]. Schrijver, C. J., Kauristie, K., Aylward, A. D., Denardini, C. M., Gibson, S. E., Glover, A., et al. (2015). Understanding space weather to shield society: A global road map for 2015–2025 commissioned by COSPAR and ILWS. Advances in Space Research, 55(12), 2745–2807. https://doi.org/10.1016/j.asr.2015.03.023.

[18]. Ginet, G. P., O'Brien, T. P., Huston, S. L., Johnston, W. R., Guild, T. B., Friedel, R., et al. (2013). AE9, AP9 and SPM: New models for specifying the trapped energetic particle and space plasma environment. Space Science Reviews, 179(1–4), 579–615. https://doi.org/10.1007/ s11214-013-9964-y.

[19]. Vette, J. I. (1991). The AE-8 trapped electron environment. NSSDC/WDC-A-R&S 91-24.Retrieved from https://ntrs.nasa.gov/ citations/19920014985.

[20]. Shprits, Y. Y., Subbotin, D., & Ni, B. (2009). Evolution of electron fluxes in the outer radiation belt computed with the VERB code. Journal of Geophysical Research, 114(A11), A11209.https://doi.org/10.1029/2008JA013784.

[21]. Mannucci, A. J., Hagan, M. E., Vourlidas, A., Huang, C. Y., Verkhoglyadova, O. P., & Deng, Y. (2016). Scientific challenges in thermosphere-ionosphere forecasting. Journal of Space Weather and Space Climate, 6, E01. https://doi.org/10.1051/swsc/20160.

[22]. Siscoe, G., & Solomon, S. C. (2006). Aspects of data assimilation peculiar to space weather forecasting. Space Weather, 4(4), S04002. https:// doi.org/10.1029/2005SW000205.

[23]. Deng, Y., Fuller-Rowell, T. J., Ridley, A. J., Knipp, D., & Lopez, R. E. (2013). Theoretical study: Influence of different energy sources on the cusp neutral density enhancement. Journal of Geophysical Research: Space Physics, 118(5), 2340–2349. https://doi.org/10.1002/ jgra.50197.

[24]. Verkhoglyadova, O. P., Meng, X., Mannucci, A. J., Mlynczak, M. G., Hunt, L. A., & Lu, G. (2017). Ionosphere-thermosphere energy budgets for the ICME storms of March 2013 and 2015 estimated with GITM and observational proxies. Space Weather, 15(9), 1102–1124. https://doi.org/10.1002/2017SW001650.

[25]. Verkhoglyadova, O. P., Meng, X., Mannucci, A. J., Shim, J.-S., & McGranaghan, R. (2020). Evaluation of total electron content prediction using three ionosphere-thermosphere models.Space Weather, 18(9), e2020SW002452.https://doi.org/10.1029/2020SW002452.

[26]. Mannucci, A. J., Berger, T., Bortnik, J., Cherniak, I., Gulyaeva, T., Hoeg, P., et al. (2020). Recommendations for the community. Proceedings of the Chapman Conference on Scientific Challenges Pertaining to Space Weather Forecasting Including Extremes.https://doi.org/10.5281/zenodo.3986940.

[27]. Chaston, C. C., Peticolas, L. M., Carlson, C. W., McFadden, J. P., Mozer, F., Wilber, M., et al. (2005). Energy deposition by Alfvén waves into the dayside auroral oval: Cluster and FAST observations. Journal of Geophysical Research, 110(A2), A02211. https://doi. org/10.1029/2004JA010483.

[28]. Huang, C. Y., Huang, Y., Su, Y.-J., Hairston, M. R., &Sotirelis, T. (2017). DMSP observations of high latitude Poynting flux during magnetic storms. Journal of Atmospheric and Solar-Terrestrial Physics, 164,294–307. https://doi.org/10.1016/j.jastp.2017.09.005.

[29]. Miles, D. M., Mann, I. R., Pakhotin, I. P., Burchill, J. K., Howarth, A. D., Knudsen, D. J., et al. (2018). Alfvénic dynamics and fine structuring of discrete auroral arcs: Swarm and ePOP observations. Geophysical Research Letters, 45(2), 545–555. https://doi. org/10.1002/2017GL076051.

[30]. Ozturk, D. S., Meng, X., Verkhoglyadova, O. P., Varney, R. H., Reimer, A. S., &Semeter, J. L. (2020). A new framework to incorporate high-latitude input for meso-scale electrodynamics: HIME. Journal of Geophysical Research: Space Physics, 125(1), e2019JA027562. https://doi.org/10.1029/2019JA027562.

[31]. Zhu, Q., Deng, Y., Richmond, A., &Maute, A. (2018). Small-scale and mesoscale variabilities in the electric field and particle precipitation and their impacts on Joule heating. Journal of Geophysical Research: Space Physics, 123(11), 9862–9872. https://doi. org/10.1029/2018JA025771.

[32]. Bussy-Virat, C. D., Ridley, A. J., &Getchius, J. W. (2018). Effects of uncertainties in the atmospheric density on the probability of collision between space objects. Space Weather, 16(5), 519–537. https://doi.org/10.1029/2017SW001705.

[33]. Vallado, D. A., & Finkleman, D. (2014). A critical assessment of satellite drags and atmospheric density modeling.Acta Astronautica, 95, 141–165. https://doi.org/10.1016/j.actaastro.2013.10.005.

[34]. Nieves-Chinchilla, J., Farjas, M., &Martínez, R. (2017). Measurement of the horizon elevation for satellite tracking antennas located in urban and metropolitan areas combining geographic and electromagnetic sensors. Measurement, 98, 159–166.

https://doi.org/10.1016/j. measurement.2016.11.030.

[35]. Nieves-Chinchilla, J., Martínez, R., Farjas, M., Tubio-Pardavila, R., Cruz, D., &Gallego, M. (2018). Reverse engineering techniques to optimize facility location of satellite ground stations on building roofs. Automation in Construction, 90, 156–165. https://doi.org/10.1016/j. autcon.2018.02.019.

[36]. Tubío-Pardavila, R., Diaz, J. E. E., Rohling, A. J., Ferreira, M. G. V., Dos Santos, W. A., Puig-Suari, J., & Aguado-Agelet, F. (2016). Integration of the INPE ground station into the SATNet network for supporting small satellites programs in Brazil. Proceedings of the 1st IAA Latin American Symposium on Small Satellites, IAA-BR-10-01.Retrieved from https://www.researchgate.net/publication/331045064_Integration_of_the_INPE_Ground_Station_into_the_SATNet_Network_for_Supporting_Small_Satellites_Programs_in_Brazil.

[37]. Nieves-Chinchilla, T., Robinson, R., Caspi, A., Jackson, D. R., MorettoJørgensen, T., Lol, B., & Spann, J. (2020). International coordination and support for SmallSats-enabled space weather activities. Space Weather, 18, e2020SW002568.https://doi.org/10.1029/2020SW002568.

[38]. Westerhoff, J., Earle, G., Bishop, R., Swenson, G. R., Vadas, S., Clemmons, J., et al. (2015). LAICE CubeSat mission for gravity wave studies. Advances in Space Research, 56(7), 1413–1427.

[39]. Gill, E., Sundaramoorthy, P., Bouwmeester, J., Zandbergen, B., & Reinhard, R. (2013). Formation flying within a constellation of nano-satellites: The QB50 mission. Acta Astronautica, 82(1), 110–117