The Legal Implications of Space Weather Awareness and the Need for International Dissemination of Space Weather Forecasts

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Abstract

This paper will examine the legal implications of space weather awareness and the need for the international space community to develop or recognize an authority with the responsibility for developing and disseminating space weather forecasts.

Disruption of satellite services due to space weather is part of the everyday reality of the satellite world. The long term human engagement in space activities not only escalates the hazards of space weather and increases the need for awareness of space weather. Space weather encompasses events such as solar wind, coronal holes, coronal mass ejections and solar flares. It can also include geomagnetic storms and plasma clouds. The electrostatic discharge caused by coronal mass ejections, solar storms, and solar flares present external risk to satellites. Similarly, the ionized discharges and disturbances of plasma clouds and geomagnetic storms can adversely affect the operation of satellite systems and subsystems. The need for awareness of space weather is reflected by the United States enactment of 42 U.S.C. §18388.

Articles III and IV(1)(b) of the Convention on International Liability for Damages Caused By Space Objects ("Liability Convention") impose fault based liability for damage one space object causes to another space object situated in outer space. This raises the concept of fault liability being assigned to a launching state based on its space object damaging another space object due to a malfunction resulting from a forecasted space weather occurrence. Similarly, first party in-orbit insurance policies generally require the insured to exercise due diligence in avoiding injury or damage to a satellite. This duty suggests that an insured may not have exercised due diligence if the damage or injury to its space object results from a space weather occurrence. Given that space weather may not be deemed to be "force majeure" under the Liability Convention or first party insurance coverage, the international community designating an entity or entities for developing and disseminating space weather forecasts is a viable goal to assist parties in regulating and operating their space activities.

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1 Introduction

Space situational awareness necessitates owners and operators of space objects having knowledge and information concerning the operating environment of its space asset.[1] The increasing use of outer space and congestion of Earth orbits by diverse space ventures escalates the possibility and probability of more frequent space object collisions[2] as well as other adverse economic occurrences. This, in turn, elevates the importance of space situational awareness among participants in the commercial space economy.[3] Space situational awareness (SSA) generally refers to efforts to continuously monitor events in the natural space environment that affect the operation of space objects.[4] These factors include the position and orbit of one's own space object, the position and orbit of other space objects, the location of non-natural space debris, and space weather.[5]

Generally, space weather effects three separate aspects of commercial ventures in outer space. The first effect is on the space object itself. The second concerns the effects on the ground station with the third effect being on the propagation of signals between the space object and points on Earth.[6] Commercial space transportation or delivery services introduce another dimension distinct from space weather's impact on technological and mechanical operation of a space asset. Space weather's effect on the people who populate a space object as either crew or participant presents an additional need for space weather awareness in the commercial space transport industry.

In addition to space situational awareness, space weather awareness is also important for security and stability of the modern technological era. Space weather can disrupt national power grids and trigger "cascading failures affecting everything from banking and finance to agriculture, the environment, education, medical care, telecommunications, transportation, and so on."[7] This paper will explore the obligation to exercise due diligence in relation to space weather and some of the potential legal consequences for not doing so.

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1 P.J. Blount, *Renovating Space: The Future of International Space Law*, 40 Denv. J. Int'l L. & Pol'y 515, 529 (2012)

2 Collisions of space objects have occurred and will continue to occur. The primary concern is how often will collisions take place.

3 Andrew T. Park, *Incremental Steps for Achieving Space Security: The Need for A New Way of Thinking to Enhance the Legal Regime for Space*, 28 Hous. J. Int'l L. 871, 909 (2006)

4 Brian Wessel, *The Rule of Law in Outer Space: The Effects of Treaties and Nonbinding Agreements on International Space Law*, 35 Hastings Int'l & Comp. L. Rev. 289, 296 n.29(2012)

5 *Id.*

6 John Kennewell and Andrew McDonald, *IPS - Space Weather - Satellite Communications and Space Weather*, http://www.ips.gov.au/Educational/1/3/2(last accessed September 2, 2014)

7 Avi Schnurr, *Vulnerability of National Power Grids to Electromagnetic Threats: Domestic and International Perspectives*, 34 Energy L.J. 1, 19 - 20 (2013).

2 Space Weather and Situational Awareness

The emerging awareness of space weather is evident by the United States Congress enacting legislation specifically addressing the subject in the National Aeronautics and Space Administration Act of 2010.[8] The legislation acknowledges that "space weather events pose a significant threat to modern technological systems"and that "severe space weather" can adversely affect technological systems used for terrestrial and extraterrestrial activities as well as human health.[9] This congressional enactment officially recognizes that the natural space environment contains phenomena which can inflict economic and operational casualties not only on terrestrial assets but also on space assets. Space weather related losses among satellites can range from temporary transmission outages to loss of the satellite.[10] Between 1994 and 1999, one "major spacecraft insurance company estimated that over $500 Million in insurance claims were distributed for in-orbit satellite failures related to space weather.[11] Similarly, the United States Department of Defense estimates that it spends up to $500 Million annually to mitigate the adverse impact of space weather on its satellite systems.[12] Yet, the Department estimates that its satellite fleet still incurs over $100 million annually in "unmitigated effects" attributable to space weather events.[13]

The consensus definition of "space weather" refers to the "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 that can affect human life and health."[14] This definition is premised on the Sun's influence on the near Earth space environment.[15] The term "near Earth space" refers to the area including Low Earth Orbit ("LEO") and extending out to and including Geostationary

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8 42 U.S.C.A. § 18388 enacted by PL 111–267 Title VII, § 809.

9 42 U.S.C. § 18388(a)(1)&(2).

10 American Meteorological Society(AMS), Space Weather- A policy Statement of the American Meteorological Society, (Adopted by AMS Council on 5 May 2008) Bull. Amer. Meteor. Soc., 89 (June 2008), reprinted at http://www.ametsoc.org/policy/2008spaceweather_amsstatement.html

11 NOAA/Space Weather Prediction Center, *Space Weather Prediction Center Topic Paper: Satellites and Space Weather*, published at http://swpc.noaa.gov/info/Satellites.html (Last visited on September 14, 2014).

12 AMS Policy Statement, *supra* note 10 at 18.

13 *Id.*

14 European Space Agency, *Space Situational Awareness: About Space Weather*, http://swe.ssa.esa.int/web/guest/what-is-space-weather; *A Policy Statement of the American Meteorological Society* (Adopted by AMS Council on 5 May 2008) Bull. Amer. Meteor. Soc., 89 http://www.ametsoc.org/policy/2008spaceweather_amsstatement.html; Rainer Schwenn "*Space Weather: The Solar Perspective*" http://solarphysics.livingreviews.org/open?pubNo=lrsp-2006-2&page=articlese1.html

15 Arnold Hamslmeier, *The Sun and Space Weather* 1, (Springer Press 2d ed 2007).

Earth Orbit ("GEO").[16] Technically, this consensus definition is not comprehensive because while the Sun is the primary influence on near Earth space weather, it is not the exclusive force as there are some near Earth natural space phenomena for which the Sun is not a predominate factor.[17]
Meteorite showers constitute one non-solar natural space environment phenomena.[18] Meteor impacts present a risk for space assets as they are a regular space phenomenon.[19] Whenever the Earth intersects a comet's path a meteor shower of some type normally ensues.[20] Additionally, the Earth "encounters many sporadic" space particles on a daily basis which originate in the solar system's asteroid belt.[21] In addition to physical damage, meteors can cause a loss by creating an electrostatic discharge resulting from "the formation of plasma clouds due to the ionization of meteoroids colliding with a satellite."[22] The risk of meteor damage essentially depends upon the space object's orbit. Assets in GEO orbit are at a greater risk to meteor impact than those in LEO as LEO assets receive some protection from the atmosphere.[23] Damage from meteor impacts, however, are normally avoidable since meteor showers are often predictable in advance thereby giving owners and operators the opportunity to maneuver the space object away from harm.[24]
With respect to solar based space weather events, the four primary occurrences which concern owners and operators of space assets are solar wind, coronal holes, coronal mass ejections and solar flares.[25] A coronal hole is an occurrence when the sun's magnetic field lines do not completely close thereby creating a pathway for the solar wind to escape at a much greater velocity.[26] The solar wind is best described as high speed charged particles flowing from the sun which carries some of the sun's magnetic field.[27]The

16 42 U.S.C. § 38302(7)
17 *Id*. Cosmic radiation is one such phenomena. *Id.,* at 2; European Space Agency website, *supra* note 14.
18 Allen J. Gould and Orin M. Linden, *Estimating Satellite Insurance Liabilities* at 54, published at http://www.casact.org/pubs/forum/00fforum/00ff047.pdf
19 Gould and Linden, *supra* note 18 at 55-56.
20 K.L. Bedingfield et al, *Spacecraft Failures and Anomalies Attributed to the Natural Space Environment*, NASA Reference Publication 1390 at 15 (August 1996) published at http://maelabs.ucsd.edu/mae155/classes/wi_05/space%20envt_nasa%20rp1390.pdf.
21 *Id* at 15 - 16.
22 *Id* at 54.
23 *Id* at 56.
24 *See Id* at 56.
25 Tools and Resources: Space Weather, intelsat.com, http://www.intelsat.com/tools-resources/satellite-basics/solar-weather/ (last visited Sept. 13, 2014)
26 Space Weather Research Explorer, Coronal Holes, (last visited Sept. 18, 2014) http://www.exploratorium.edu/spaceweather/holes.html
27 Leon Goulb and Jay M. Passachoff, *Nearest Star: The Surprising Science of Our Sun* 264 - 275 (Cambridge University Press 2d. 2014)

Earth's magnetosphere deflects the solar wind thereby protecting the terrestrial environment.[28] Two other types of solar emissions which influence space weather are Coronal Mass Ejections ("CME") and solar flares.[29]A CME, also known as a plasma cloud, is a solar eruption which emits hotter plasma, stronger magnetic fields and higher charged energy particles than the typical solar wind.[30] While it normally takes 2 to 3 days for a CME to reach Earth,[31] the existing technology and satellite only allow for about 30 minute advance warning of an impending CME impact with the magnetic field.[32] A solar flare, on the other hand, is an explosion on the Sun which occurs upon the sudden release of energy stored in the Sun's magnetic field.[33] The science underlying these solar events and their effect on technology is complex and exceed the parameters of this paper. Nevertheless, some knowledge of the hazards associated with these solar emissions will assist in understanding the need for space weather awareness. This awareness includes being prepared for phenomena produced by CMEs, solar flares and the solar wind such as electrostatic discharge by space objects ('ESD"), geomagnetic storms,[34] and radiation exposure.[35]

A. Electrostatic Discharge

ESD is the most prevalent hazard to space assets.[36] While an ESD is normally caused by solar weather events, it can also be caused by the "formation of a plasma cloud due to the ionization of meteoroids colliding" with a space object.[37] ESD, which includes surface charging, results from interactions between the satellite surfaces and space plasma, the magnetic field, and solar

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28 *Id* at 267 - 275.

29 *Id.*, at 275 - 278.

30 Leon Goulb and Jay M. Passachoff, *supra* note 27 at 278; Dr. Tony Phillips, *Carrington-class CME Narrowly Misses Earth* at 1, spacedaily.com (May 6, 2014) http://www.spacedaily.com/reports/Carrington_class_CME_Narrowly_Misses_Earth_999.html

31 *CU-Boulder scientist: 2012 solar storm points up need for society to prepare*,colorado.edu (December 9, 2013,) http://www.colorado.edu/news/releases/2013/12/09/cu-boulder-scientist-2012-solar-storm-points-need-society-prepare

32 Brad Plumer, *Two big solar storms have hit Earth -creating stunning auroras and a few disruptions* at 9, vox.com (Sept. 14, 2015), http://www.vox.com/2014/9/12/6140209/the-earths-getting-hit-with-two-modest-solar-storms-next-time-we-may

33 European Space Center, Space Science, *What Are Solar Flares?*, (last visited Sept. 18, 2014) http://www.esa.int/Our_Activities/Space_Science/What_are_solar_flares. A CME is essentially a large solar flare.

34 *Id.* A geomagnetic storm is an ionization disturbance in the geomagnetic field. *Id.,* at 24.

35 Karen C. Fox, *Storms From the Sun*, nasa.gov (March 8, 2012), http://www.nasa.gov/mission-pages/sunearth/news/storms-on-sun.html

36 Gould and Linden, *supra* note 18 at 54.

37 *Id* at 54.

radiation.[38] This interaction causes the space object to gain a charge because of the emission and collection of charged particles both to and from the exposed external surfaces of the spacecraft.[39] Energetic electrons can penetrate the spacecraft's external surface or skin and build up a charge in the internal circuitry.[40] "If the charge builds up faster than its dissipation, this can break down the shielding and produce an electrostatic discharge."[41] The electrostatic discharge can temporary or permanently disrupt electronic components or even cause the launching of a "phantom command" which can allow a space object to engage in uncontrolled functions.[42] An ESD is said to have caused the total loss of a Telstar 401 satellite in January 1997.[43] More recently, an ESD is said to have crippled or transformed an Intelsat Galaxy 15 satellite into a "zombie" for an eight month period between April 2010 and December 2010.[44] During this temporal period, the satellite was unresponsive to command controls and began drifting from its GEO, but continued to transmit its broadcast signals without control from its ground station.[45] Although it is said there was never a threat of the satellite colliding with another space object, measures were taken to minimize the satellite's broadcasting transmission signals from interfering with other satellites.[46]

B. Geomagnetic Storms

Geomagnetic storms are a disturbance in the Earth's magnetic filed generally caused by a CME.[47] A geomagnetic storm is also referred to as an electromagnetic pulse ("EMP").[48] CME caused geomagnetic storms "essentially peel Earth's magnetic field like an onion, allowing energetic solar wind particles

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38 Major Yan Chun Wong, *Satellite Anomalies and Electrostatic Surface Discharges* 3 -4, Thesis, Naval Post Graduate School (Sept. 1991) published at http://www.nps.edu/faculty/olsen/Student_theses/Wong_Sept_1991.pdf (last visited Sept. 14, 2014)

39 *Id.*

40 Satellite Anomalies, http://www.fp7-spacecast.eu/help/bg_sa.pdf (Last visited on Sept. 14, 2-14).

41 *Id.*

42 *Id.*

43 *Id.*

44 Stephen Clark, *Build-up of static electricity turned satellite into zombie*, Spaceflight now.com, (January 14, 2011), http://spaceflightnow.com/news/n1101/14galaxy15/ (last visited on Sept. 14, 2014); Peter B. de Selding, Electrostatic Discharge Crippled Galaxy 15, Intelsat Says, SpaceNews.com (January 13, 2011) http://www.spacenews.com/article/electrostatic-discharge-crippled-galaxy-15-intelsat-says (last visited Sept. 14, 2014.)

45 *Id.*

46 Stephen Clark, *supra* note 44 at 2.

47 Arnold Hamslmeier, *supra* note 15 at 212.

48 Christopher Bosch, *Securing The Smart Grid: Protecting National Security And Privacy Through Mandatory, Enforceable Interoperability Standards*, 41 Fordham Urb. L.J. 1349, 1386 n. 200 (May 2014)

to stream down the field lines to hit the atmosphere over the poles."[49] Geomagnetic storms also increase electric currents and drive them to the Earth's surface where they can "flow through any large-scale conductive structure, including power lines, oil and gas pipelines, undersea communications cables, telephone and telegraph networks and railways."[50] Thus , the greatest concern associated with geomagnetic storms is not as much as how they effect space assets, but rather their potential to disrupt the terrestrial technological dependency. A glimpse of the power and intensity of a geomagnetic storm is best understood by its terrestrial impact when an extreme EMP penetrates the magnetosphere and reaches the Earth's surface.

In 1859, the strongest known geomagnetic storm referred to as the Carrington Event stuck the Earth.[51] The storm disrupted telegraph communications, electrified telegraph machines which caused electrical shocking of telegraph operators and telegraph paper to combust.[52] The storm also produced glowing auroras that transformed night into day allowing the northern auroras to be seen as far south as Cuba and providing enough light for people in the northern portion of the United States to read a newspaper at night.[53] Given the limited technology of the era, the harm was not as extensive as that which would occur if a Carrington style event happened today. It is estimated that a Carrington style occurrence would now inflict damage in the range of $1 to $2 trillion dollars.[54]

A storm of weaker strength than the Carrington event struck Earth in 1921. It disrupted telegraph service, burned out cables, disabled New York Central's signal system and ignited a fire that burned down the Central New England Railway station.[55] A smaller geomagnetic storm struck Earth in March 1989 and disrupted electrical power grids in North America. The event caused Canada's Hydro-Québec power utility's grid to crash leaving over 6 million people without electricity for more than 9 hours.[56] In addition to impacting power grids and

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49 *CU-Boulder scientist: 2012 solar storm points up need for society to prepare*, *supra* note 31.

50 Lori Keesey, *High-Voltage Transmission Lines To Act As Antenna in First -of-its Kind NASA Space Weather Project*, spacedaily.com (April 25, 2014), http://www.spacedaily.com/reports/High_Voltage_Transmission_Lines_to_Act_as_Antenna_in_First_of_its_Kind_NASA_Space_Weather_Project_999.html

51 Christopher Klein, *A Perfect Solar Superstorm: The 1859 Carrington Event*, history.com (March 14, 2012) http://www.history.com/news/a-perfect-solar-superstorm-the-1859-carrington-event (last visited Sept. 14, 2014)

52 *Id.*

53 *Id.*

54 *Id.*

55 Avi Schnurr, *supra* note 7 at 8.

56 Adam Hadhazy, *A Scary 13th: 20 Years Ago, Earth Was Blasted with a Massive Plume of Solar Plasma*, scientificamerican.com (March 13, 2009) http://www.scientificamerican.com/article/geomagnetic-storm-march-13-1989-extreme-space-weather/

technological devices, the terrestrial impact of geomagnetic storms can result in diverting airplanes from flying polar routes.[57]

In 2012, the Earth avoided an extraordinary CME and potential geomagnetic storm which is reported to have been equal to or greater than the strength of the Carrington Event.[58] Although the CME crossed Earth's orbital plane, Earth was fortunate in as much as the CME occurred on the far side of the sun seven days after that area was facing toward Earth.[59] This effectively means the Earth was at an orbit location different from where the CME crossed Earth's orbital path. If the area from which the sun emitted the CME was facing Earth, then the CME would have struck Earth and released an extreme geomagnetic storm. The force of the CME is further evident in that while it normally takes 2 to 3 days for a CME to reach Earth orbit, the July 2012 CME streaked across Earth's orbital path in about 18 hours.[60] If the CME had made contact with the Earth's magnetic field then it "likely would have created a technological disaster by short-circuiting satellites, power grids, ground communication equipment and even threatening the health of astronauts and aircraft crews."[61]

In the United States, geomagnetic storms are rated on a 5 level category of intensity similar to the classifications used for hurricanes or typhoons.[62] The categories are based on the potential harm to space objects as well as terrestrial power grids.[63] G1 is a minor storm which may cause minor impact on operations of the space asset and weak fluctuations in terrestrial power grids.[64] G2 is a moderate storm which may necessitate corrective orientation action to a space object by ground control, and may cause changes in "drag affect orbit predictions" and fading of high frequency radio propagation at higher latitudes.[65] Possible problems for power grids include power alarms for high latitude power systems and potential transformer damage.[66] G3 is a strong storm which may cause surface charging, increase drag on objects in LEO, may require corrective orientation action and may interfere with satellite navigation, low-frequency radio navigation and high frequency radio.[67] Potential harm to terrestrial power systems include the need for voltage correction and false alarms on some protection devices.[68] G4 is a severe storm which may cause surface

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57 Brad Plumer, *supra* note 32 at 10 - 11.
58 *CU-Boulder scientist: 2012 solar storm points up need for society to prepare*, *supra* note 31.
59 *Id.*
60 *Id.*
61 *Id.*
62 Goulb and Pasachoff, *supra* note 27 at 263.
63 NOAA/Space Weather Prediction Center, *NOAA Space Weather Scales* at 1 - 3, http://www.swpc.noaa.gov/NOAAscales/ (Lasted visited on Sept. 14, 2013).
64 *Id.*, at 3.
65 *Id.*, at 3.
66 *Id.*
67 *Id.*, at 2 - 3.
68 Id.

charging and tracking problems, may require corrective orientation action, induce pipeline currents that affect preventive measures, may cause sporadic propagation of high frequency radio propagation, degradation of satellite navigation, and disruption of low frequency radio navigation.[69] Power grid issues may consist of widespread voltage control problems with some protective systems mistakenly tripping out key assets from the grid.[70] Lastly, G5 is an extreme storm which can cause space assets to experience a host of problems such as extensive surface charging, problems with orientation, uplink/downlink communications and tracking, with pipeline currents reaching hundreds of amps, high frequency radio propagation being impossible in many areas for one to two days, and degradation of satellite navigation and low-frequency radio navigation outages.[71] Power grid implications include widespread problems with voltage control and protective systems, with some grid systems experiencing complete collapse and blackouts, and transformer damage.[72]

Geomagnetic storms create orientation issues for space assets as some space objects rely on the Earth's magnetic field to assist in orientation or as a "force to work against to dump momentum and slow down reaction wheels."[73] Problems with drag may occur as space objects in LEO may "experience periods of increased drag that causes them to slow, lose altitude and finally reenter the atmosphere."[74] This interferes with tracking of a space object as well as its lifespan. For instance, the March 1989 geomagnetic storm disrupted the ability of the North American Defense Command ("NORAD") to track thousands of space objects and it subsequently took numerous days to reacquire the objects "in their new, lower, faster orbits."[75] The space weather event also caused one LEO satellite to lose "over 30 kilometers of altitude, and hence significant lifetime."[76] Additionally, geomagnetic storms pose a hazard to space assets in GEO, which are predominately communications satellites.[77] During a geomagnetic storm, a space object in GEO can become highly charged thereby creating the possibility of an ESD.[78] The storms can also disrupt or interfere with GPS or GNSS transmission signals.[79]

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69 *Id.*, at 2.
70 *Id.*
71 *Id.*, at 2.
72 *Id.*
73 Space Weather Prediction Center Topic Paper: Satellites and Space Weather, *supra* note 11 at 5.
74 *Id.*, at 4.
75 *Id.*
76 *Id.*
77 *Space Weather: What impact do solar flares have on human activities?* at 2, nasa.gov, http://hesperia.gsfc.nasa.gov/sftheory/spaceweather.htm (Last visited Sept. 15, 2014).
78 *Id.*
79 Brad Plumer, *supra* note 32 at 3.

C. Space Radiation

Radiation is energy moving in the form of high speed particles or electromagnetic waves.[80] Radiation is ionizing or non-ionizing. Ionizing radiation contains higher energy than non-ionizing radiation and earns it name by striping electrons from other atoms and giving a charge to other matter that it comes into contact with.[81] Ionizing radiation is the type of radiation used to generate electric power, kill cancer cells, and, in the form of high-energy, charged particles, is the type of radiation generally found in the natural space environment.[82] Space radiation does not pose a significant health hazard to the Earth or people on Earth as a majority of the solar radiation is deflected by the Earth's magnetic field and most of which is not deflected is absorbed by the atmosphere. However, the level of protection Earth offers from space radiation decreases the higher a person or object travels above the terrestrial landscape.[83]

Space radiation derives from three natural sources known as a solar particle event ("SPE"), trapped radiation and cosmic radiation.[84] A SPE is also called a solar radiation storm.[85] This event occurs when eruptions on the sun release energetic radiation particles into interplanetary space.[86] Trapped radiation occurs when the solar wind interacts with the Earth's magnetic field. This interaction forms a cavity in the magnetic field known as the magnetosphere which traps the charged particles from the solar wind which are not deflected by the magnetic field.[87] These trapped particles are contained within "two doughnut-shaped magnetic rings surrounding the Earth" called the Van Allen radiation belt.[88] Additionally, the radiation in certain portions of the Van Allen belts are considered so dangerous that "manned and unmanned spacecraft avoid them."[89]

Cosmic radiation is ionized radiation which originates outside of our solar system.[90] The Earth's magnetic field generally deflects cosmic rays while the atmosphere absorbs radiation. An exception exists with respect to those

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80 Space Radiation Analysis Group, Johnson Space Center, *What is space radiation?*, nasa.gov, http://srag-nt.jsc.nasa.gov/SpaceRadiation/What/What.cfm (Last visited Sept. 16, 2014).

81 Radiation Protection, Radiation: Non-Ionizing and Ionizing, epa.gov, http://www.epa.gov/radiation/understand/ (Last visited Sept. 16, 2014).

82 *Id.*

83 *See* Aircrew Health, *Aircrew Exposure to Cosmic Radiation*, 1 - 4, aircrewhealth.com (last visited Sept. 17, 2014) http://aircrewhealth.com/Topics/hazards/radiation.htm#concerns

84 *Id.*

85 Karen C. Fox, *supra* note 35 at 2.

86 Space Radiation Analysis Group, *supra* note 81 at 2.

87 *Id.*

88 *Id.*

89 *Michael W. Taylor*, *Trashing the Solar System One Planet at A Time: Earth's Orbital Debris Problem*, 20 Geo. Int'l Envtl. L. Rev. 1, 5 (2007)

90 Space Radiation Analysis Group, *supra* note 81 at 2.

cosmic rays over the polar areas because the magnetic field has pathways which are "open to interplanetary space"[91] and the atmosphere is thinnest at the polar regions.[92] Accordingly, the polar regions are where space radiation is most prevalent terrestrially.[93]

Although space assets are manufactured to withstand space radiation, eventually over time, the constant radiation bombardment can result in radiation penetrating the assets shielding and degrade its components and performance.[94] The degradation consists of damage to the solar panels, disrupting electronics, causing short circuits, and/or adversely affecting computer memory.[95] This is particularly true for space objects traveling through or with an orbit in the Van Allen belts.[96] Moreover, the owner or operator of a space asset should monitor and track the assets exposure to radiation as high radiation exposure can shorten a space asset's life span or at least cause a reduction in the available power supply as the asset nears the end of its life.[97] Similarly, human exposure to a high dosage of space radiation can cause or contribute to biological and health concerns.[98]

Solar radiation storms are categorized by strength like geomagnetic storms. The categories are S1 through S5 and warn of the potential biological harm as well as the potential harm to satellites.[99] S1 is a minor storm which may have minor impacts on high frequency radio in the polar areas but does not pose any biological harm or harm to satellites.[100] S2 is a moderate storm which may expose aircraft crew and passengers flying at high latitudes to elevated radiation risks. As for space objects, an S2 storm may cause "infrequent single-event upsets" for satellites.[101] As for space objects, an S2 storm may have a small effect on the propagation of high frequency radio in the polar areas and possible navigation problems in the polar regions.[102] S3 is a strong storm and poses an elevated risk of radiation exposure for the crew and passengers of aircraft flying at high

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91 *Id.*

92 Aircrew Health, *supra* note 83 at 1 - 2.

93 Dr. Tony Phillips, *The Effects of Space Weather on Aviation*, (Oct. 29, 2013), http://www.spacemart.com/reports/The_Effects_of_Space_Weather_on_Aviation_999.html

94 Jennifer Chu, Space weather's effects on satellites, mit.edu (Sept. 17, 2013), http://newsoffice.mit.edu/2013/space-weather-effects-on-satellites-0917

95 *Id.*

96 *Id.*

97 Space Weather Prediction Center Topic Paper, *supra* note 11 at 4.

98 *Michael W. Taylor*, *Trashing the Solar System One Planet at A Time: Earth's Orbital Debris Problem*, 20 Geo. Int'l Envtl. L. Rev. 1, 5 (2007)

99 NOAA Space Weather Scales, *supra* note 62 at 4 - 5. The space storms ratings were developed by National Oceanic and Atmospheric Administration Space Environmental Center now known as the Space Weather Prediction Center ("SWPC").

100 *Id.*, at 5.

101 *Id.*

102 *Id.*

latitudes and suggests that astronauts avoid extra-vehicular activity.[103] An S3 storm can result in satellites experiencing single-event upsets, imaging system noise, a modest reduction of solar panel efficiency, a small effect on the propagation of high frequency radio in the polar areas and possible navigation problems in the polar regions.[104] S4 is a severe storm and poses an elevated risk of radiation exposure for crew and passengers of aircraft flying at high latitudes and warns of unavoidable radiation hazards for astronauts engaging in extra-vehicular activity.[105] The storm may cause a satellite to encounter problems with memory devices, imaging systems noise, orientation problems, solar panel degradation, blackout of high frequency radio communications through the polar regions and increased navigation errors which can last for several days.[106] Lastly, S5 is an extreme storm which poses unavoidable high radiation danger to astronauts on extra-vehicular activity and increases the possibility of harmful radiation. Exposure to passengers and crew in aircraft at high latitudes.[107] As for space objects, an S5 can render a satellite inoperable or can cause loss of control, serious noise in image data, impede star-trackers ability to locate sources or permanently damage solar panels.[108]

As seen, alerts associated with geomagnetic storms and solar radiation storms are not limited to extraterrestrial activity. A glimpse of their terrestrial use is seen by a space weather event referred to as the "Halloween Storms" which occurred in late October 2003. The Halloween Storms consisted of a turbulent solar activity which motivated the United States Federal Aviation Administration ("FAA) to issue a radiation alert for high altitude flights. This resulted in several American and European airlines rerouting and lowering of flight altitudes in an effort to mitigate potential increase of radiation dosage.[109] The basis for the alert was information and data collected by a space weather satellite known as GOES-11.[110] Following the Halloween Storms, some airlines and other aircraft operators began expressing interest in "**timely and accurate** information concerning significant increases in the radiation intensity at aviation altitudes in order to be able to mitigate potential hazardous radiation effects on humans and on avionics," by temporarily routing their aircraft at lower flight altitudes (emphasis added).[111] Some of the airlines adopted the radiation storm classification S3 as the level at which they would reroute polar flights and fly at

103 *Id*., at 4.
104 *Id.*
105 *Id*.
106 *Id.*
107 *Id*.
108 *Id*
109 M.M. Meier & D. Matthia, *A space weather index for the radiation field at aviation altitudes. J. Space Weather* Space Clim., 2014, 4, , A13 at 1.
110 *Id*.
111 *Id*.

lower altitudes.[112] Airlines also realized that timely and accurate space weather information is crucial as rerouting polar flights and flying at lower altitudes impose economic consequences in the form of higher cost and higher fuel consumption.[113] To this extent, some consider the current radiation storm classifications inefficient, at least for the altitudes used in the aviation industry, as it does not accurately take into account the atmospheric shield and thereby generates some false alerts.[114] Nevertheless, the aviation industry addressing the issue of "timely and accurate" information regarding space weather for routing purposes is an example of exercising due diligence

3 The Due Diligence Concept Under International Law

The concept of due diligence in international law is measured in accordance with an international standard rather than a domestic standard.[115] Litigation has been instrumental in developing a State's due diligence obligation with the *Corfu Channel Case*[116] being the most notable.[117] In the 21st Century, the due diligence concept manifests itself in disparate disciplines of international law mostly by treaty imposed obligations on States as well as litigation. Within the various fields of international law, international environmental law is the dominate area developing the modern due diligence concept by treaty[118] and litigation.[119] Through this proliferation of due diligence in treaties and litigation, a customary international law standard evolved which obligates a State to exercise due diligence to protect foreign nationals and their property from harm and injury.[120] The concept extends to a State's activities outside of its own territory, at least to the extent it involves the

112 *Id*.
113 *Id*.
114 *Id*., at *5*
115 International Law Association, *ILA Study Group on Due Diligence in International Law*, *First Report* at 4, (March 7, 2014) published at http://www.ila-hq.org/download.cfm/docid/8AC4DFA1-4AB6-4687-A265FF9C0137A699 (last visited Sept. 16, 2014).
116 *Corfu Channel, U.K. v. Albania, Judgment*, 1949 I.C.J. 4 (Apr. 9). *See Lac Lanoux* (Fr. v. Spain) 24 I.L.R. 101 (1957). *See also* Mark Allan Gray, *The International Crime of Ecocide*, 26 Cal. W. Int'l L.J. 215, 238 (1996).
117 Mark Allan Gray, *supra* note 116 at 238.
118 ILA Study Group *supra* note 115 at 1 - 6.
119 *See* Jessica L. Rutledge, *Wait A Second-Is That Rain or Herbicide? The ICJ's Potential Analysis in Aerial Herbicide Spraying and an Epic Choice Between the Environment and Human Rights*, 46 Wake Forest L. Rev. 1079 (2011).
120 Abdul Ghafur Hamid, *Maritime Terrorism, the Straits of Malacca, and the Issue of State Responsibility*, 15 Tul. J. Int'l & Comp. L. 155, 166-67 (2006) citing *Asian Agricultural Prod. Ltd. v. Republic of Sri Lanka*, 4 I.C.S.I.D. (W. Bank) 246, 251 (1990).

global commons.[121] For instance, UNCLOS Article 139(1) of the 1982 United Nations Convention on the Law of the Sea (UNCLOS)[122] provides as follows:

> States Parties shall have the responsibility to ensure that activities in the Area, whether carried out by States Parties, or state enterprises or natural or juridical persons which possess the nationality of States Parties or are effectively controlled by them or their nationals, shall be carried out in conformity with this Part. The same responsibility applies to international organizations for activities in the Area carried out by such organizations.

This provision is construed to mean that a State must exercise due diligence to ensure that its contractors and/or nationals comply with UNCLOS' obligation to protect the marine environment when conducting seabed mining activities.[123] "Due diligence" is not an obligation to achieve a particular result; rather it is an obligation of conduct which requires a State to engage in sufficient efforts to prevent harm or injury to another State or its nationals[124] or the global commons.[125] The breach of this duty is not limited to State action, but it also extends to the conduct of a State's nationals.[126] A breach of this due diligence standard gives rise to State responsibility.[127] Whether a State has exercised due diligence is a flexible standard which varies depending upon the factual basis and circumstance of the particular case.[128] Although due diligence is variable depending upon the circumstance, some objective criteria is used to

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121 *See* Mark Allan Gray, *supra* note 116 at 242; *The Fifty-Third Session of the International Law Commission,* 96 Am. J. Int'l L. 412, 416 (2002).

122 entered into force Nov. 16, 1994, 1833 U.N.T.S. 397, 21 ILM 1261(1982).

123 ILA Study Group *supra* note 115 at 29 citing Responsibilities and Obligations of States Sponsoring Persons and Entities with Respect to Activities in the Area, Seabed Mining Advisory Opinion at ¶ 117 (Seabed Dispute Chamber of the International Tribunal of the Law of the Sea, Case No 17 , 1 February 2011).

124 ILA Study Group *supra* note 115 at 29 citing Responsibilities and Obligations of States Sponsoring Persons and Entities with Respect to Activities in the Area, Seabed Mining Advisory Opinion at ¶ 117 (Seabed Dispute Chamber of the International Tribunal of the Law of the Sea, Case No 17 , 1 February 2011); Jan E. Messerschmidt, *Hackback: Permitting Retaliatory Hacking by Non-State Actors As Proportionate Countermeasures to Transboundary Cyberharm Shearman & Sterling Student Writing Prize in Comparative and International Law, Outstanding Note Aw*, 52 Colum. J. Transnat'l L. 275, 302 - 305 (2013). *See United States Diplomatic and Consular Staff in Tehran (U.S. v. Iran)*, 1980 I.C.J. 3, 61 - 67 (May 24).

125 *See* Mark Allan Gray, *supra* note 116 at 242; Robert Rosenstock and Margo Kaplan, *The Fifty-Third Session of the International Law Commission*, 96 Am. J. Int'l L. 412, 416 (2002)

126 Mark Allan Gray, *supra* note 116 at 243.

127 *See* Smita Narula, *The Right to Food: Holding Global Actors Accountable Under International Law*, 44 Colum. J. Transnat'l L. 691, 759 - 765 (2006).

128 ILA Study Group *supra* note 115 at 2

evaluate whether a State has satisfied its responsibility.[129] These objective factors include the degree of foreseeability or predictability of the harm, the importance of the interest needing protection,[130] and the State's capability.[131] Thus, while there is "an overall minimal level of vigilance" associated with due diligence, "a higher degree of care may be more realistically expected" from States possessing the ability and resources to provide it.[132]

State responsibility is a comprehensive aspect of international law. Traditionally, State responsibility represents the classic concept for dealing with a state's violation of international law which causes injuries to another state or to nationals of another State.[133] A State suffers a distinct and separate injury when one of its nationals is injured by another state.[134] To this extent, the act does not have to be committed directly by a State as it is sufficient if the act or conduct can be attributable to the State.[135] When a breach of international law inflicts injury on nationals of another State, the duty is to make reparations.[136]

The initial concept of state responsibility is best characterized as a violation of a primary international obligation which gives rise to a secondary obligation to make reparation for injuries to foreign nationals.[137] Over time the concept of state responsibility evolved from a regime to redress injuries suffered by foreign nationals, "into a comprehensive system of international responsibility of a State, regardless of whether aliens or individuals are involved and regardless of injuries."[138] Despite this evolution, fundamental "doctrinal disputes concerning state responsibility" exist over whether state responsibility is automatically imposed upon violation of an international obligation irrespective of fault or whether fault is a necessary ingredient to trigger a remedy under the State responsibility doctrine.[139]

A breach of an international duty properly attributable to a State triggers the secondary obligation to make reparations for the injury.[140] A breach can be

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[129] *Id.*, at 3.
[130] *Id.*
[131] Robert Rosenstock and Margo Kaplan, *supra* note 125 at 416.
[132] *Id.*; *See* ILA Study Group *supra* note 115 at 4 and 31.
[133] Sompong Sucharitkul, *State Responsibility and International Liability Under International Law,* 18 Loy. L.A. Int'l & Comp. L.J. 821, 823 (1996)
[134] *See Avena and Other Mexican Nationals (Mex. v. U.S.)*, 2004 I.C.J. 12, 36 (Mar. 31)[The court noted that could submit a claim in its own name for injuries "suffered both directly and through the violation of individual rights conferred on Mexican nationals."]
[135] Dan St. John, *The Trouble with Westphalia in Space: The State-Centric Liability Regime*, 40 Denv. J. Int'l L. & Pol'y 686, 706 (2012).
[136] Sompong Sucharitkul, *supra* note 133 at 823.
[137] *Id.,* at 825
[138] *Id.,* at 823.
[139] David K. Linnan, *Iran Air Flight 655 and Beyond: Free Passage, Mistaken Self-Defense, and State Responsibility*, 16 Yale J. Int'l L. 245, 354 (1991)
[140] Dan St. John, *supra* note 135 at 706.

attributable to a State if the State plays an active role in causing the injury,[141] omits to perform an act,[142] or having knowledge of a hazardous condition fails to warn others of the hazard.[143] Reparations are a mandatory duty which attaches to a State violating its international obligation.[144] The remedy is generally owned only to another State as individuals and other non-state entities traditionally lack standing under international law to pursue or collect reparations under State responsibility jurisprudence.[145]
The *Chorzow Factory* case[146] establishes the standard for reparations. Pursuant to *Chorzow Factory*,

> ...reparation must, so far as possible, wipe-out all the consequences of the illegal act and re-establish the situation which would, in all probability, have existed if that act had not been committed. Restitution in kind, or, if this is not possible, payment of a sum corresponding to the value which a restitution in kind would bear; the award, if need be, of damages for loss sustained which would not be covered by restitution in kind or payment in place of it—such are the principles which should serve to determine the amount of compensation due for an act contrary to international law.[147]

Chorzow Factory establishes that the first obligation of reparation is to restore the injured party to the condition that existed prior to the breach of the international obligation. If that is not possible, then a monetary payment corresponding to the value of the restitution is appropriate. If neither of these are totally sufficient, then reparations can take the form of an apology,[148] official recognition of the injury,[149] or promises or guarantees of nonrepetition of the injurious act or conduct.[150]

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141 Dr. William C.G. Burns, *A Voice for the Fish? Climate Change Litigation and Potential Causes of Action for Impacts Under the United Nations Fish Stocks Agreement*, 48 Santa Clara L. Rev. 605, 644 (2008)
142 *United States Diplomatic and Consular Staff in Tehran (U.S. v. Iran)*, 1980 I.C.J. 3 (May 24)
143 *Corfu Channel, U.K. v. Albania, Judgment*, 1949 I.C.J. 4 (Apr. 9)
144 Michael F. Blevins, J.D., M. Div., *Restorative Justice, Slavery, and the American Soul, A Policy-Oriented (Fnaa1) Intercultural Human Rights Approach to the Question of Reparations*, 31 T. Marshall L. Rev. 253, 276 (2006); Jon M. Van Dyke, *The Fundamental Human Right to Prosecution and Compensation*, 29 Denv. J. Int'l L. & Pol'y 77, 89 (2001)
145 Libby Adlera1 and Peer Zumbansen, *The Forgetfulness of Noblesse: A Critique of the German Foundation Law Compensating Slave and Forced Laborers of the Third Reich*, 39 Harv. J. on Legis. 1, 46 (2002)
146 *Factory at Chorzow (Ger. v. Pol.)*, 1928 P.C.I.J. (ser. A) No. 17, at 29 (Sept. 13).
147 *Id* at 47 (footnote added).
148 Dan St. John, *supra* note 135 at 706.
149 *Id*.
150 Daniel Bodansky, John R. Crook, et al, *Righting Wrongs: Reparations in the Articles*

The concept of international liability is a derivative of State responsibility.[151] The intricate relationship between State responsibility and international liability causes confusion at the international level and in space law, concerning the scope, meaning and consequences of liability.[152] "International liability is predicated on a set of primary rules concerning the primary obligations of States'"[153] This means that the breaching a "primary obligation under international liability inevitably sets in motion the secondary rules prescribed under State responsibility."[154] However, the parameters or implementation of secondary rights and obligations associated with international liability are generally subject to international conventions and multilateral treaties which create specialized regimes governing liability.[155]

One distinction between State responsibility and international liability is that under State liability the obligation to pay for damages can exist regardless of unlawfulness or prohibition by international law."[156] Thus, unlike State responsibility, liability concerns "who should pay compensation for damage caused by an activity."[157] In other words, State responsibility is about "answerability" for acts or omissions[158] whereas liability is about avoidance or "passing the buck" for payment.[159]

4 Due Diligence, Space Weather and the International Space Law Regime

The space law regime incorporates due diligence in the Treaty on Principles Governing the Activities of States in the Exploration and Use of Outer Space, including the Moon and Other Celestial Bodies ("Outer Space Treaty").[160] Outer Space Treaty Article VI imposes State responsibility as it reads:

> States Parties to the Treaty shall bear international responsibility for national activities in outer space, including the Moon and other celestial bodies, whether such activities are carried on by governmental agencies or by non-governmental entities, and for assuring that national activities are

on State Responsibility, 96 Am. J. Int'l L. 833, 839 (2002)

151 Dan St. John, *supra* note 135 at 707.

152 Dr. Frans G. von der Dunk, *Passing the Buck to Rogers: International Liability Issues in Private Spaceflight*, 86 Neb. L. Rev. 400, 401 (2007)

153 Sompong Sucharitkul, *supra* note 133 at 832

154 Id.

155 *Id.*

156 *Id.* at 833.

157 von der Dunk, *supra* note 152 at 401.

158 Bin Cheng, *Article VI Of The 1967 Space Treaty Revisited: "International Responsibility," "National Activities," And The Appropriate State."* 26 Journal of Space Law 7, 9 (1998)

159 von der Dunk, *supra* note 152 at 401.

160 entered into Force Oct. 10, 1967, 18 UST 2410; TIAS 6347; 610 UNTS 205; 6 ILM 386 (1967).

> carried out in conformity with the provisions set forth in the present Treaty. The activities of non-governmental entities in outer space, including the Moon and other celestial bodies, shall require authorization and continuing supervision by the appropriate State Party to the Treaty. When activities are carried on in outer space, including the Moon and other celestial bodies, by an international organization, responsibility for compliance with this Treaty shall be borne both by the international organization and by the States Parties to the Treaty participating in such organization.

Outer Space Treaty Article VII provides for international liability as it reads as follows:

> [e]ach State Party to the Treaty that launches or procures the launching of an object into outer space, including the Moon and other celestial bodies, and each State Party from whose territory or facility an object is launched, is internationally liable for damage to another State Party to the Treaty or to its natural or juridical persons by such object or its component parts on the Earth, in air space or in outer space, including the Moon and other celestial bodies.

Article VI's imposition of State responsibility and Article VII's international liability standard have distinct and overlapping obligations in the space law arena. To better appreciate the doctrine of State responsibility as applied by Article VI, it is best to first possess a working understanding of Article VII's international liability concept.

A. International Liability in Space

The Convention on International Liability for Damages Caused By Space Objects ("Liability Convention")[161] is the prodigy of Article VII of the Outer Space Treaty.[162] Although the Liability Convention is not a comprehensive agreement, it does encapsule core legal principles concerning definition of certain terms, fault allocation, and the measure of damages associated with third party liability for damage caused by a space object. The Convention limits applicability of its legal principles to damage caused by space objects anywhere on Earth, to another space object in space and people aboard such other space object, and to an airplane in flight.[163] It also restricts international liability to the space object's launching State or launching States.[164] In

[161] entered into Force Sept. 1, 1972, 24 UST 2389; TIAS 7762; 961 UNTS 187; 10 ILM 965 (1971).
[162] *Id*.
[163] Liability Convention Articles II - VII.
[164] *Id*., at Articles I - VII.

addition, the Convention contains a non exclusive dispute resolution procedure which can only be utilized by States.[165]

Liability Convention Article 1 defines the terms "launching State," "space object" and "damage." Pursuant to Article 1(c) "launching State" is a State which launches or procures the launch of the space object and the State from whose territory or facility the space object is launched. The term "space object" has a redundant definition. Article 1(d) reads as follows "[t]he term 'space object' includes component parts of a space object as well as its launch vehicle and parts thereof." Article 1(a) defines "damage" to mean "loss of life, personal injury or other impairment of health; or loss of or damage to property of States or of persons, natural or juridical, or property of international intergovernmental organizations."

Articles II through VII allocate fault and set the criteria for applying absolute or strict liability, shared liability, apportioned liability and exoneration of liability. The *loci* of the damage occurrence determines which liability scheme applies. For instance, if a space weather event causes a space object to crash to Earth, each launching state will have absolute liability for all damage it causes on the Earth's surface.[166] Exoneration from absolute liability can occur if a launching State proves that the damage resulted either, wholly or partially, from gross negligence or an intention act or omission by the claimant State or natural or juridical persons on whose behalf it has brought the claim.[167] However, such exoneration is not available if the activities of a launching State were not in conformity with international law or the space law treaty regime.[168] Absolute liability for each launching State will also exist for any and all damage and injury the space object causes to an airline in flight or people or property aboard the airplane.[169] However, it is unclear if absolute liability applies if the space object damages a space transport craft while it is transiting the atmosphere heading into outer space. It seems this will depend upon whether such a craft is deemed to be an airplane prior to crossing the boundary into outer space. Nevertheless, absolute liability is subject to the same exoneration principles as those applicable to damage a space object causes on Earth.

Lastly, if a space weather event causes a space object to collide in space with a space transport craft, an orbital space platform, or any other space object, then liability is predicated on fault.[170] Fault allocation is joint and several in event

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165 Ka Fei Wong, *Collaboration in the Exploration of Outer Space: Using Adr to Resolve Conflicts in Space*, 7 Cardozo J. Conflict Resol. 445, 452 (2006)["Although the Liability Convention sets forth ways in which to settle disputes, the Convention is not the exclusive means to seek redress."]

166 Liability Convention Article II.

167 *Id.*, Article VI(1).

168 *Id.*, Article VI(2).

169 *Id.*

170 *Id.*, Article IV(1).

there is more than one launching State.[171] This allocation between two or more launching States is apportioned in accordance with the fault of each launching State for the damage.[172] In event the percentage of fault attributable to each launching State can not be ascertained, then the allocation of fault will be "apportioned equally between them."[173] This equal apportionment does not preclude the claimant State from seeking the entire recovery from "any or all of the launching States which are jointly and severally liable."[174]

Regardless of where the damage occurs or whether the liability is absolute or fault based, the measure of damages remain the same. Liability Convention Article XII equates the measure of recovery with that articulated in *Chorzow Factory*.[175] Article XII informs that the measure of compensation is "determined in accordance with international law and the principles of justice and equity, in order to provide such reparation in respect of the damage as will restore the person, natural or juridical, State or international organization on whose behalf the claim is presented to the condition which would have existed if the damage had not occurred."

Under the Liability Convention, the due diligence exercised by a launching State and claimant State in relation to a space weather event may serve as a basis for fault liability or a defense to the imposition of absolute liability or fault liability. This is not a novel concept. For instance, in the maritime industry, the peril of the sea doctrine which includes severe weather, absorbs a carrier from liability for damage resulting from the peril.[176] Although there is not a definitive definition of "perils of the sea," the case known as *The Rosalia*[177] articulates the general working definition accepted by the American courts.[178] According to *The Rosalia,* "perils of the sea" is defined as "something so catastrophic as to triumph over those safeguards by which skillful and vigilant seamen usually bring ship and cargo to port in safety."[179] In determining whether severe weather constitutes a "peril of the sea," the United States judiciary employs "a foreseeability test." Pursuant to this test, "severe weather conditions must be unforeseeable or unexpected in order to constitute a 'peril of the sea.'"[180] What

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171 *Id*., Article IV(2).
172 Id.
173 *Id*.
174 *Id*.
175 Joseph J. MacAvoy, *Nuclear Space and the Earth Environment: The Benefits, Dangers, and Legality of Nuclear Power and Propulsion in Outer Space*, 29 Wm. & Mary Envtl. L. & Pol'y Rev. 191, 225 (2004)
176 Harry Apostolakopoulos, *Navigating In Perilous Waters: Examining The "Peril Of The Sea" Exception to Carrier's Liability Under COGSA For Cargo Loss Resulting From Severe Weather Conditions*, 41 S. Tex. L. Rev. 1439, 1442 (Fall 2000).
177 264 F. 285 (2d Cir. 1920).
178 Harry Apostolakopoulos, *supra* note 176 at 1440.
179 *The Rosalia*, 264 F. 285, 288 (2d Cir. 1920). *See* Harry Apostolakopoulos, *supra* note 176 at 1440.
180 *Id*.

constitutes forseeability is not a concrete standard but depends on the facts and circumstances of each case.[181] Based on the "foreseeability" of weather conditions being a liability factor in the maritime industry, it is not unreasonable to view forseeability of a space weather event as a factor in establishing international liability under the Liability Convention. Thus, if an ESD, geomagnetic storm, radiation exposure or some other weather event causes a space object to inflict damage by colliding with another space object in space, an airplane in flight or crashing to the Earth's surface, then liability may very well focus on the foreseeability of the event and what efforts were undertaken to mitigate the impact of the event.

B. State Responsibility

While conduct based on the knowledge or the lack of knowledge concerning space weather conditions can be a factor in determining international liability for damage caused by a space object, State responsibility may exist for injury or harm flowing from the failure to disseminate knowledge of a space weather event or condition. Outer Space Treaty Article VI imposes State responsibility for "assuring that national activities are carried out in conformity with the provisions set forth" in the Outer Space Treaty. Outer Space Treaty Article V obligates a State to inform other States or the United Nations Secretary-General of "any phenomena" discovered in outer space "which could constitute a danger to the life or health of astronauts. This dissemination responsibility[182] reasonably includes the phenomena of space weather. Of course, the breath of this responsibility depends upon the definition of "astronauts." Most importantly though, is Outer Space Treaty Article III which requires States to carry on all space activities in accordance with international law for purposes of "maintaining international peace and security and promoting international co-operation and understanding." This obligation raises the specter of the duty to warn others concerning hazardous space weather.[183]

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[181] *Thyssen, Inc. v. S/S Eurounity*, 21 F.3d 533, 536 (2d Cir. 1994). *See* Apostolakopoulos, *supra* note 49 at 1445. Canada, France, and Belgium utilize a foreseeability test similar to that employed by the Untied States judiciary. England and Austrlia, on the other hand, do not tie the "peril of the sea" to the forseeability of severe weather but decide each case based on its own circumstance. An intermediate approach is followed by other European maritime States. *See* Heidi Lee De La Rosa, *From the Journals: Insurance Law Abstracts*, 8 Conn. Ins. L.J. 565, 594-95 (2002).

[182] *See* Evan R. Seamone, *When Wishing on A Star Just Won't Do: The Legal Basis for International Cooperation in the Mitigation of Asteroid Impacts and Similar Transboundary Disasters,* 87 Iowa L. Rev. 1091, 1133 (2002).

[183] *See* Tyra Ruth Saechao, *Natural Disasters and the Responsibility to Protect: From Chaos to Clarity*, 32 Brook. J. Int'l L. 663, 682 (2007)[Recognizing a States duty to warn of an impeding natural disaster.

The duty to warn principle emerges from the *Corfu Channel Case*[184] wherein Britain sought recovery from Albania for damage and death caused by mines in a portion of Albania's territorial waters through which other States claimed a right of passage.[185] Albania's responsibility rested on whether it had knowledge of the mines and failed to warn other States of the hazard. In finding that Albania had a duty to warn and that it breached the duty, the I.C.J reasoned:

> [t]he obligations incumbent upon the Albanian authorities consisted in notifying, for the benefit of shipping in general, the existence of a minefield in Albanian territorial waters and in warning the approaching British warships of the imminent danger to which the minefield exposed them. Such obligations are based, not on the Hague Convention of 1907, No. VIII, which is applicable in time of war, but on certain general and well-recognized principles, namely: elementary considerations of humanity, even more exacting in peace than in war...[186]

Some scholars broadly interpret the *Corfu Channel* as all States having a general duty to warn other States of potential or impending harm.[187] Other commentators read the case as limiting the duty to warn to known dangers existing in its own territory.[188] Nevertheless, *Corfu* "serves as a building block for the emergence of the duty to warn concept"[189] which is considered a facet of due diligence.[190] Accordingly, Outer Space Treaty Article III can be reasonably construed as imposing a duty to disseminate space weather information and warn of space weather hazards.

This duty to disseminate or warn, however, is not limited to Article III. The duty can apparently be inferred directly under Article VI which extends State responsibility to "national activities in outer space." The Outer Space Treaty does not define the phrase "activities in outer space." The lack of a definition creates uncertainty on its scope in as much as it is unresolved if the phrase "national activities in outer space" is restricted to acts performed in space or if it includes activities in space remotely controlled from Earth. The lack of a restrictive definition suggests that Article VI's responsibility encompasses "all the concomitant activities associated with what actually occurs in outer space, both before and after."[191] Moreover, even a narrow reading of Article VI can

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184 *See supra* note 23.
185 1949 I.C.J. at 23.
186 1949 I.C.J. at 22.
187 Tyra Ruth Saechao, *Natural Disasters and the Responsibility to Protect: From Chaos to Clarity*, 32 Brook. J. Int'l L. 663, 682 (2007).
188 *Id.*
189 *Id.*
190 *See* ILA Study Group *supra* note 115 at 4 and 31.
191 Bin Cheng, *supra* note 158 at 19.

reasonably lead to the conclusion that the supervising responsibility includes "terrestrial activities directly related to concurrent activities in outer space."[192] This suggests that due diligence exists not only for conduct which actually takes place in space, but can also apply to conduct on Earth which is integrally related to acts or events which transpire in space. This analysis can potentially result in the act of collecting, analyzing and predicting space weather being construed as a "national activity in outer space" within the meaning of Outer Space Treaty Article VI. This is particularly so given that collecting information regarding space weather conditions necessitates utilizing and relying on satellites.[193] The duty to warn under Article VI, therefore, is not limited to potential harm or injury to space assets or people working on space assets. Instead, it can be viewed as including the duty to warn of potential terrestrial harm and injury posed by a space weather event such as injury to power grids and the consequential harm flowing from such an occurrence.

The duty to warn raises the question as to whether State responsibility entails more than an internet posting of space weather forecasting or sending a forecast report upon request. Given the flexibility of the "due diligence" concept, the factual circumstance surrounding a space weather event and the injury or harm it inflicts on foreign nationals or a another State will apparently determine what diligence was due. This will entail evaluating the degree of foreseeability or predictability of the event and the harm it could potentially inflict, the importance or degree of the harm or injury suffered, [194] the capability to foresee or predict the event or otherwise take measures to negate the harm or injury.[195] This suggests that space faring State's and those that possess the resources to foresee or predict space weather events may have a greater duty to warn States that do not possess such capability or have a lesser capability.

C. Distinctions Between State Responsibility and International Liability in Space Law

Article VI's State responsibility obligation is much broader in scope and application than international liability assessed pursuant to Outer Space Treaty Article VII and the Liability Convention. First, State responsibility is

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[192] Michael C. Mineiro, *Law And Regulations Governing U.S. Commercial Spaceports: Licensing, Liability, And Legal Challenges*, 73 Journal of Air Law and Commerce 759, 768 (Fall 2008)

[193] *See* Satellite instrument package to assess space weather ready for delivery by CU-Boulder, spacedaily.com (May 6, 2013), http://www.spacedaily.com/reports/Satellite_instrument_package_to_assess_space_weather_ready_for_delivery_by_CU_Boulder_999.html

[194] *Id.*

[195] Robert Rosenstock and Margo Kaplan, *supra* note 125 at 416; *See* ILA Study Group *supra* note 115 at 9 - 10.

not limited to launching States. It extends to any State with "national activities in outer space." The exact breath of this coverage is uncertain in as much as "activities in outer space" is an undefined term. Article VI imposes responsibility to supervise "space activities" on the appropriate State. As with the term "activities in outer space" the Outer Space Treaty does not define or explain how to determine what is an "appropriate State."[196] Even more so, in contrast to the Liability Convention, the Outer Space Treaty does not bar a foreign State from pursuing Article VI reparations for injury to a foreign national on the basis that the foreign national participated, worked, or was otherwise involved with the space venture which caused the harm or injury.

It is undisputed that if State responsibility exists and a State breaches its due diligence obligation, then reparations become mandatory. Although the Liability Convention incorporates the *Chorzow Factory* reparations measure as the measure of damages for State liability, the recovery for a breach of State responsibility has much greater depth than that allowed by the Liability Convention. The Liability Convention limits recovery to damage as defined in Article 1(a). There is no such limitation for reparation due for a State's violation of the international responsibility imposed by Outer Space Treaty Article VI. This means reparations for breach of Article VI can encompass economic harm and injury which is viewed as being excluded by the Liability Convention.[197] Another important distinction is that the Liability Convention limits recovery to third party damage claims arising from a space asset colliding with other space objects in space or an airplane in flight or anything on Earth.[198] Recovery for breach of the State responsibility obligation is not limited to such third party claims.[199] This may pose some consequence for the home State of commercial space transport operators and commercial operators of space platforms.

The space economy envisions space platforms or modules to be used as space hotels[200] or repair stations. Such platforms used for space hotels are

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196 Cheng, *supra* note 158 at 26 - 29.

197 See Sarah M. Mountin, *The Legality and Implications of Intentional Interference with Commercial Communication Satellite Signals*, 90 Int'l L. Stud. 101, 146 (2014).

198 von der Dunk, *supra* note 152 at 412.

199 Moreover, since Liability Convention Article XXIII indicates that it is not an exclusive remedy, if a damage occurrence can also be construed as flowing from a breach of Outer Space Treaty Article VI, a claimant State can conceivably seek reparations for breach of Article VI instead of pursuing the limited recovery allowed by the Liability Convention.

200 *See* Robin McKie, *Space hotel to give rich a thrill that's out of this world,* The Guardian.com (Aug. 27, 2011) available at http://www.guardian.co.uk/science/2011/aug/27/space-hotel-rich-thrill-world; Brendan McGarr, "*Las Vegas UFO Aficionado Bets $500 Million on Space Hotel*," bloomberg.com (Jan 27, 2013) available at http://www.bloomberg.com/news/2013-01-28/las-vegas-ufo-aficionado-bets-500-million-on-space-hotel.html

anticipated to consist of pre-fabricated modular clusters assembled in orbit with the capacity to eventually to accommodate numerous people.[201] Regardless of whether a space hotel is a "space object" as defined by the Liability Convention, operating such a venture is in all likelihood a space activity within reach of Outer Space Treaty Article VI. This means State responsibility may exist for any foreign guest or foreign hotel worker[202] who suffers an injury or death attributable to an ESD, geomagnetic storm or radiation storm or other natural space weather phenomena. The determination of whether a breach of State responsibility occurred can depend on the due diligence associated with awareness of the space weather event and the steps taken to mitigate the effects of the space weather event. Similar reasoning applies to the injury to or death of a crew member[203] or flight participant which takes place on board a commercial space transport vehicle while ferrying people to a space platform or which carries people on a short "joy ride" into space. Evaluating the objective criteria in the context of space transport and space platform use will probably involve consideration of the duty to warn. This should involve examining whether foreign crew members and foreign participants of a commercial space transport venture were adequately informed of the space weather conditions and the potential harmful biological consequences, especially the radiation exposure potential, prior to departure. A similar duty to warn may exist in connection with foreign nationals that work or otherwise spend time on a space platform.

Another divergence between the Liability Convention and Outer Space Treaty Article VI is that the Liability Convention imposes a one year limitations period for initiating a claim for damage.[204] Article VI does not contain any limitation period. The significance of this differential in a limitations period also has potential consequence for crew of commercial transport vehicles or workers on a space platform. Foreign crew or employees working on a space platform or on a commercial space transport flight, and to a much lesser extent, foreign nationals who are participants in such commercial activities will be exposed to cosmic and solar radiation. Since the adverse health conditions from exposure to above normal radiation doses may not manifest itself for decades following the occurrence, the lack of a limitations period means that the passage of time between the overexposure and the onset of may not bar a claim for reparations by the alien's home State under Outer

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201 Patrick Collins, "*The Space Tourism Industry in 2030,*" Space Future, (Feb. 2000) http://www.spacefuture.com/archive/the_space_tourism_industry_in_2030.shtml

202 It is unclear whether an space hotel employees are considered "crew."

203 While a crew member is excluded from coverage under the Liability Convention Article VII, a foreign crew member is excluded from coverage of State responsibility pursuant to Outer Space Treaty Article VI.

204 Liability Convention Article X(1). The limitations period commences on the date damages is suffered or the date of identification of the liable launching State. *Id.*

Space Treaty Article VI.[205]
At this juncture, it should be noted that the United States law requires crew members and flight participants in commercial space transport vehicles to execute a wavier and release of claims against the United States and its contractors for bodily injury, death, or property damage resulting from their participation in the licensed activity.[206] It is reasonable to assume that a similar waiver will be utilized in connection with commercial space platforms once they become economically feasible. Nevertheless, it seems to be an open question as to whether a foreign national can waive the international protection of State responsibility afforded by Outer Space Treaty Article VI. By analogy to contracts between a host State and a foreign investor, it has historically been the perspective of United State scholars that an injury to a national is a separate and distinct injury to the State and an individual cannot waive the State's right to seek redress through a contractual provision.[207] This perspective, however, is tempted by the "Calvo Clause" which emerged from State/private investor agreements in Mexico and other Latin American countries.[208] Pursuant to the "Calvo Clause doctrine" a private person executing a waiver of home State protection is valid unless the host State violates international law.[209] Nevertheless, even under the Calvo Doctrine, it is generally accepted that a State's breach of its treaty responsibility violates international law giving rise to reparations.

5 Due Diligence, Space Weather and Launch and in-Orbit Insurance

The consideration of space weather and due diligence is not confined to issues of State responsibility and international liability as they can also coincide with Launch and In-Orbit ("LIO") insurance. Generally, LIO insurance policies do not contain "Act of God" provisions which related to the outer space natural environment.[210] LIO policies do not specifically consider space

[205] It is conceivable that, at a minimum, State's with nationalized or socialized medicine may desire to pursue reparations for the cost and expense associated with the care and treatment of a national with health afflictions caused by overexposure to cosmic radiation.

[206] 14 C.F.R. § 460.19 (crew waiver) ; 14 C.F.R. § 460.49(participant waiver); 14 C.F.R. Part 440 Appendix D (crew waiver form); 14 C.F.R. Part 440 Appendix E (participant waiver form)

[207] Denise Manning-Cabrol, *The Imminent Death of the Calvo Clause and the Rebirth of the Calvo Principle: Equality of Foreign and National Investors*, 26 Law & Pol'y Int'l Bus. 1169, 1177 (1995)

[208] Christopher K. Dalrymple, *Politics and Foreign Direct Investment: The Multilateral Investment Guarantee Agency and the Calvo Clause*, 29 Cornell Int'l L.J. 161, 168 (1996).

[209] *Id.* See *North American Dredging Co. (U.S. v. Mex.)*, 4 U.N. Rep. Int'l Arb. Awards 26, 26-27 (1951)

[210] The 23rd Cycle - Satellite Insurance at 1, solarstorms.org, http://www.solarstorms.org/Sinsurance.html (Last visited on Sept. 15, 2014).

weather events as a basis for not paying a claim as the sensitivity of a satellite to space weather relates to its reliability and thereby is a factor in setting the premium for coverage.[211] Nevertheless, LIO policies normally contain an express "due diligence" provision.[212] This due diligence requirement imposes a very stringent obligation on the insured because "[w]hile many other insurance polices issued today cover the insured even for its own negligence, this is not the case with satellite launch and in-orbit insurance. The policy imposes a 'due diligence' obligation on the insured satellite company requiring it to exercise due care with respect to the insured satellite."[213] This due diligence obligation is necessary as satellites are a "high value asset" which the insurer does not have ready access to and, the insurer usually can not retrieve it for examination and repair.[214]
For example, the due diligence provision in a model LIO policy of China Pacific Insurance reads as follows:

> [t]he Insured shall use due diligence and shall do and concur in doing all things reasonable and practical to avoid or diminish any loss under this Policy and shall act at all times as if uninsured[215]

The "due diligence" obligation to take all reasonable and practicable acts and to "act at all times as if uninsured" is not a novel standard utilized only in the space insurance context. The obligation "is a familiar feature of marine P & I policies."[216] In maritime jurisprudence, this requirement is aimed at the insured "who lowers his standards simply because he thinks that he can look to the [insurers] to pick up the bill."[217] Applying this due diligence standard to the space environment, can result in space weather being a necessary consideration in connection with the type of construction materials and shielding used in manufacturing the satellite and its component parts taking into consideration the existing solar cycle and proposed orbit.[218] Indeed, it has been acknowledged that in designing satellites for space, engineers seek to

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211 *Id.*, at 1 - 2.
212 Pamela L. Meredith, *Space Insurance Law–With A Special Focus On Satellite Launch And In-Orbit Policies*, 21 No. 4 Air & Space Law. 13, 14 (2008). at 14; Stephan Tucker, *What's Happening In Space Law and Why?,* 10 WTR Air & Space Law. 1, 14 - 15 (1996).
213 *Id.*
214 *Id.*, at 14.
215 *Satellite Launch and In-Orbit Insurance Policy*, cpic.com, https://www.cpic.com.cn/cx/upload/Attach/infordisclosure/46461909.pdf (last visited Sept. 15, 2014)
216 Stephen Martin, *Marine Protection And Indemnity Insurance: Conduct, Intent, And Punitive Damages*, 28 Tul. Mar. L.J. 45, 55 (Winter 2003)
217 *Id* at 56 quoting *Compania Maritima Ean Basilio S.A. v. Oceanus Mut. Writing Ass'n (Bermuda) Ltd. (The Eurysthenes)*, [1976] 2 Lloyd's Rep. 171, 175 (C.A.).
218 Jennifer Chu, *supra* note 94 at 3.

strike a reasonable balance between sufficient design against the natural space environment and designs viewed as immensely expensive and counterproductive.[219] How these considerations are balanced can very well determine whether a satellite owner and/or manufacturer has exercised due diligence in relation to the space weather impact on its space asset. This due diligence can also concern the lack of awareness of a space weather event or the awareness of a space weather event and the measures taken to avoid loss or harm to the space asset by a space weather event.

6 Basis for International Cooperation on Space Weather Forecasts

Space weather events can cause damage and disruption to technological based industries and business activities in the extraterrestrial and terrestrial realms as well as create health hazards for people who work or travel in space or in the air. However, space weather forecasting is currently "comparable to Earth weather forecasting of about half-a-century ago."[220] Moreover, it is "impossible and uneconomic to design a spacecraft that is entirely immune to variations in the space environment."[221] These realizations establish that governments, commercial interests, and people in all segments of the space and terrestrial economies share a mutual interest in being aware of and accurately predicting space weather events. It seems that the commonality of exercising due diligence toward space weather provides fertile ground for developing an international body or designating an existing organization to shepard, harmonize and disseminate space weather forecasts and warnings. Such an arrangement would seemingly assist in alleviating potential breaches of international liability or State responsibility under the space law treaty regime due to space weather events or LIO insurance due diligence obligations.

Recognition of this shared mutual interest contributed to the World Meteorological Organization ("WMO") forming the Inter-programme Coordination Team ("IPCT") on Space Weather in May 2010.[222] IPCT's goals include (1) standardizing and enhancing space weather data exchange and delivery through the WMO information system[223] and (2) developing "standard practices among operational space weather centres around the globe including operational procedures for producing and communicating both routine and warning information."[224] It appears that the IPCT is a

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219 *Id.*

220 AMS Policy Statement, *supra* note 10 at 17.

221 Space Weather Prediction Center Topic Paper, *supra* note 11 at 5.

222 Reports on national and regional activities related to the International Space Weather Initiative at 10, United Nations General Assembly Committee on the Peaceful Uses of outer Space, Doc. No. A/AC, 105/C.1/102 (Dec. 21, 2011)

223 *Id.*, at 11.

224 *Id.*, at 12.

promising start for providing an internationally recognized hub for exercising space weather due diligence that reduces political considerations from the due diligence equation, especially with respect to the duty to warn.

7 Conclusion

Space weather events are matters of serious concern for space assets. It is also of significance for terrestrial technology such as mobile phones, devices that rely on GPS or GNSS, the "extremely accurate clocks that govern financial transactions,"[225] as well as for power generation[226] and other terrestrial commercial activities. The foreseeability of space weather events will become more crucial to the space economy as Earth orbits become more congested, as commercial space ventures develop into an active industry and, more importantly, as terrestrial needs become even more dependent on electronic technology and space based services such as telecommunications, data transmissions, broadcast transmissions, and terrestrial weather forecasting. Indeed, an extreme CME is the United States Department of Energy's biggest solar weather concern as "[i]t could create low-frequency EMP similar to a megaton-class nuclear HEMP detonation over the United States, which could disrupt or damage the power grid, undersea cables, and other critical infrastructures."[227] Similarly, an extreme space weather event is also a concern for those with space assets.[228]

This convergence of interests means exercising due diligence for space weather is and will become more of a necessary precaution to ensure a space weather occurrence does not cause or inflict injury and harm on Earth, in the air or in space which can potentially trigger State responsibility under Outer Space Treaty Article VI for failure to warn or otherwise disseminate knowledge and information regarding a space weather event. Similarly, due diligence is necessary to assist in preventing a space object from inflicting damage cognizable under the Liability Convention.

This due diligence obligation for space weather stretches across the spectrum of governments, inter-governmental organizations and natural and juridical persons. While there are not any firm parameters governing the due diligence duty in the space weather context, hopefully the international community can formulate viable and effective standards and protocols prior to the aftermath of a space weather event which demonstrates the need to do so.

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225 Karen C. Fox, Impacts of Strong Solar Flares, spacedaily.com (May 15, 2013), http://www.spacedaily.com/reports/Impacts_of_Strong_Solar_Flares_999.html

226 Avi Schnurr, *supra* note 7 at 8 - 53.

227 *Id*., at 22.

228 Space Weather Prediction Center Topic Paper, *supra* note 11 at 5.