Science as Final form Ideas vs Science as Practice —Teaching High School Physics in Space Weather Studies

Ronald H. Freeman, PhD

Chair, Space Operations &Support, Technical Committee, AIAA

Contents

Standards documents (NGSS Lead States, 2013)	Scientists	Teacher	Student
To apply, explore, and learn science concepts as they participate in science practices such as developing models, analyzing data and constructing explanations.	Low Earth Orbital satellites produce data from sensors, camera and imaging per telemetry communications from which scientists decipher and evaluate for sensemaking and pattern interpretations: "The Evidence".	Teachers often present science as disconnected facts, algorithms and definitions (Roth & Garnier, 2006).	Students learn by interpreting their observations not through reception of authoritative facts (e.g., Edelson, 2001; Kolodner et al., 2003; Scardamalia & Bereiter, 1991).
These reform efforts focus on students developing and revising science ideas themselves.	Important to improve conceptual understanding.	In direct learning, teachers give an explanation about the material, followed by examples of exercises, and end with students working on exercises.	Students rather than memorizing the ideas of others (Sandoval, et al., 2014)—have students directly challenge the perception that science is made up of *final form* ideas.
Performance expectations in the United States, use the term "evidence" frequently but with a variety of meanings (Kasten, 2015).	Research is data-driven from which data may be visualized per graphing, imaging, and through correlational analysis an eventual model.	Memorizing the ideas of others (Sandoval, et al., 2014)—they directly challenge the perception that science is made up of *final form* ideas.	Reform efforts focus on students developing and revising science ideas themselves.
Science as *not* being made up of *final form* ideas (NRC, 2012).	Scientists continuously refine and revise explanations of the natural world		Student work aligns with the work of scientists who are continuously refining and revising explanations of the natural world

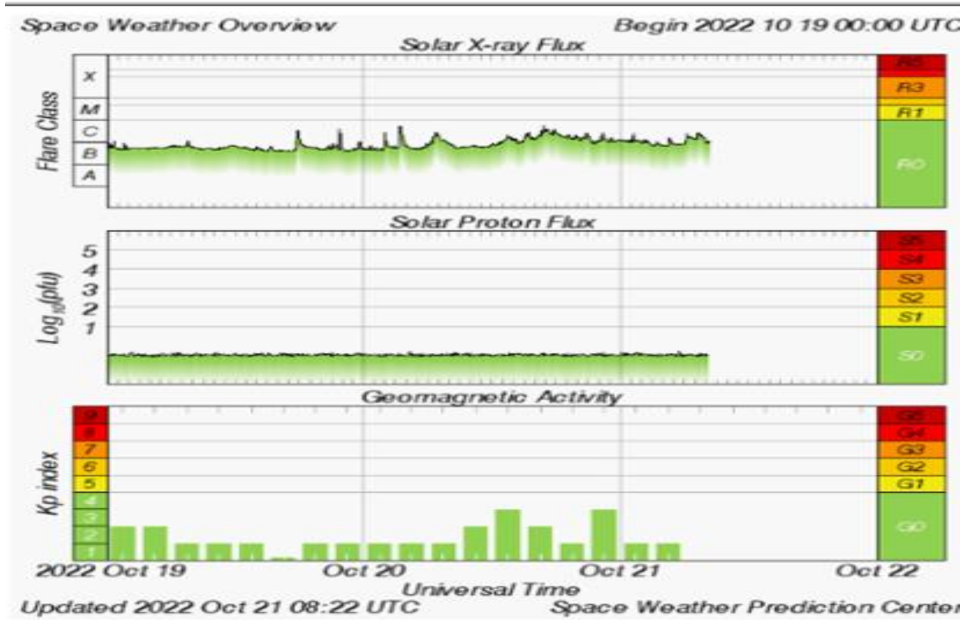
STEAM---Teaching Space Weather Studies" demonstrated a hybrid visual-kinesthetic learning style in showcasing presence of subatomic particles and their impact on Low Earth Orbit satellite operations that might cause disruptions to GPS services on Earth:

Case Demonstration--- Global Positioning System (GPS).

Final Form Idea Learning

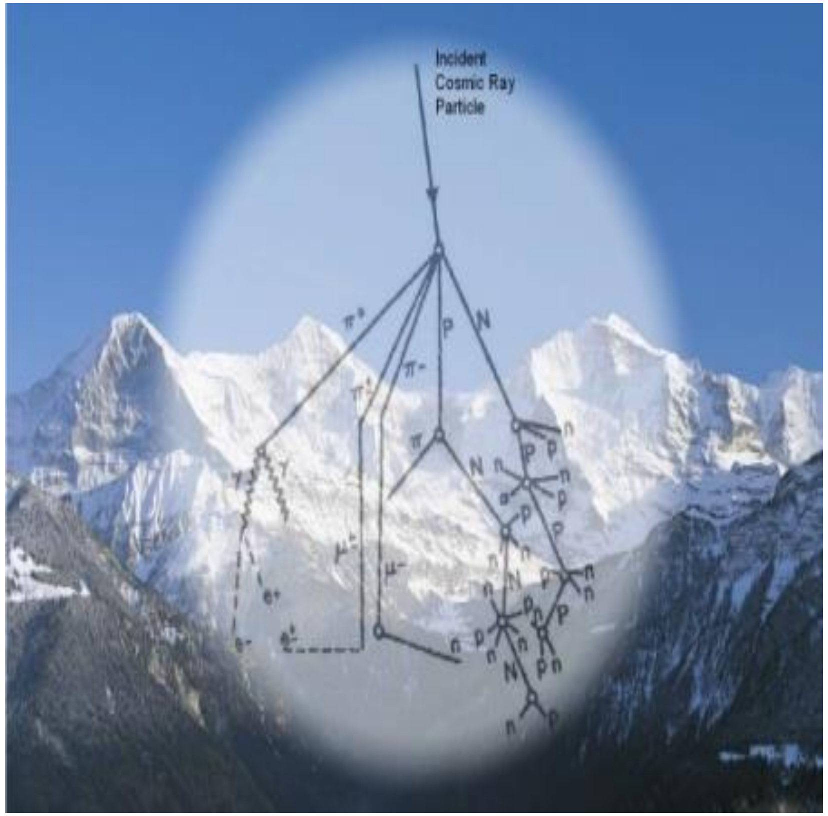
When space weather hits and interacts with the Earth, **geomagnetic storms** occur. Geomagnetic storms caused by the Sun heat Earth's upper atmosphere, causing it to expand. The heated air rises and its density increases at the orbit of satellites. This overpowers the satellites' engines causing them to fall back down to Earth and eventually burn up. This happened in 1979 with Skylab, in 1989 with U.S. Navy's satellites, and again this past February with 40 0f 49 Space X satellites of Starlink Communications, costing about $50 M in losses.. Electrons penetrate shielding and accumulate within the spacecraft's electrons to disrupt telecommunications or GPS operations.

Revisionist Learning



Space Weather Prediction Center (NOAA) produces forecast expectations, and their respective measurements. Forecasting is the prediction of future events, based on analysis and modeling of the past and present conditions of the space weather environment.

Narrations Matching (to Pictorials)



As the incident cosmic ray particle collides with an atom or a molecule of the air, it produces lots of secondary particles. If it is a heavy ion, it will be broken into lighter nuclei, protons, or neutrons. This generates a **cosmic ray cascade**. The primary cosmic ray after reacting with air atoms and molecules must have a minimum energy of about 450 MeV to produce a significant number of secondaries that can reach sea level. One has to go to high mountains or use airplanes, balloons or spacecraft to detect traces of primary cosmic rays of lower energies. The secondaries rarely reach the ground.

Narrations Matching to Scalar Tables

Solar Radiation Storms

Scale	Description	Effect	Physical measure (Flux level of >= 10 MeV particles)	Average Frequency (1 cycle = 11 years)
S 5	Extreme	**Biological:** Unavoidable high radiation hazard to astronauts on EVA (extra-vehicular activity); passengers and crew in high-flying aircraft at high latitudes may be exposed to radiation risk. **Satellite operations:** Satellites may be rendered useless, memory impacts can cause loss of control, may cause serious noise in image data, star-trackers may be unable to locate sources; permanent damage to solar panels possible. **Other systems:** Complete blackout of HF (high frequency) communications possible through the polar regions, and position errors make navigation operations extremely difficult.	10^5	Fewer than 1 per cycle
S 4	Severe	**Biological:** Unavoidable radiation hazard to astronauts on EVA; passengers and crew in high-flying aircraft at high latitudes may be exposed to radiation risk. **Satellite operations:** May experience memory device problems and noise on imaging systems; star-tracker problems may cause orientation problems, and solar panel efficiency can be degraded. **Other systems:** Blackout of HF radio communications through the polar regions and increased navigation errors over several days are likely.	10^4	3 per cycle
S 3	Strong	**Biological:** Radiation hazard avoidance recommended for astronauts on EVA; passengers and crew in high-flying aircraft at high latitudes may be exposed to radiation risk. **Satellite operations:** Single-event upsets, noise in imaging systems, and slight reduction of efficiency in solar panel are likely. **Other systems:** Degraded HF radio propagation through the polar regions and navigation position errors likely.	10^3	10 per cycle
S 2	Moderate	**Biological:** Passengers and crew in high-flying aircraft at high latitudes may be exposed to elevated radiation risk. **Satellite operations:** Infrequent single-event upsets possible. **Other systems:** Small effects on HF propagation through the polar regions and navigation at polar cap locations possibly affected.	10^2	25 per cycle
S 1	Minor	**Biological:** None. **Satellite operations:** None. **Other systems:** Minor impacts on HF radio in the polar regions.	10	50 per cycle

GPS radio signals travel from the satellite to the receiver on the ground, passing through the Earth's ionosphere. The charged plasma of the ionosphere bends the path of the GPS radio signal. In calm conditions, single frequency GPS systems can provide position information with an accuracy of a meter or less. During a severe space weather storm, these errors can increase to tens of meters or more. But when the ionosphere is disturbed by a space weather event, the models are no longer accurate and the receivers are unable to calculate an accurate position based on the satellites overhead.

Geomagnetic storms create large disturbances in the ionosphere. The currents and energy introduced by a geomagnetic storm enhance the ionosphere and increase the total height-integrated number of ionospheric electrons, or the Total Electron Count (TEC). GPS systems cannot correctly model this dynamic enhancement and errors are introduced into the position calculations. This usually occurs at high latitudes, though major storms can produce large TEC enhancements at mid-latitudes as well.

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Scale levels).
The greatest expected 3 hr Kp for Oct 20-Oct 22 2023 is 4.67 (NOAA Scale
G1).

NOAA Kp index breakdown Oct 20-Oct 22 2023
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	Oct 20	Oct 21	Oct 22
00-03UT	1.33	3.67	3.33
03-06UT	2.33	3.33	3.33
06-09UT	2.33	2.33	2.67
09-12UT	2.67	4.00	2.33
12-15UT	2.33	2.67	2.67
15-18UT	3.00	2.00	2.00
18-21UT	3.00	2.00	2.00
21-00UT	4.67 (G1)	2.67	2.33

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Rationale: No G1 (Minor) or greater geomagnetic storms are expected.  No
significant transient or recurrent solar wind features are forecast.
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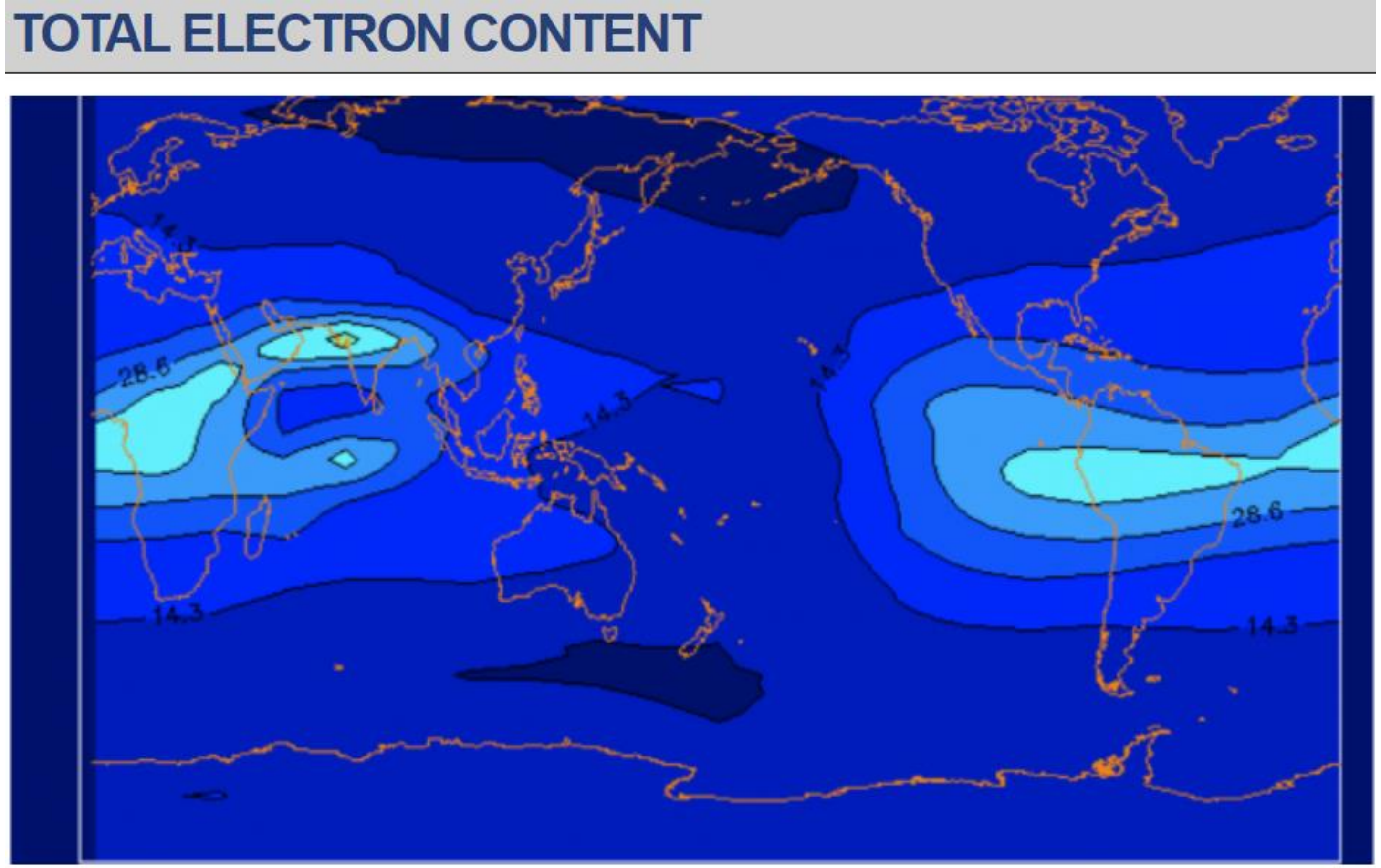
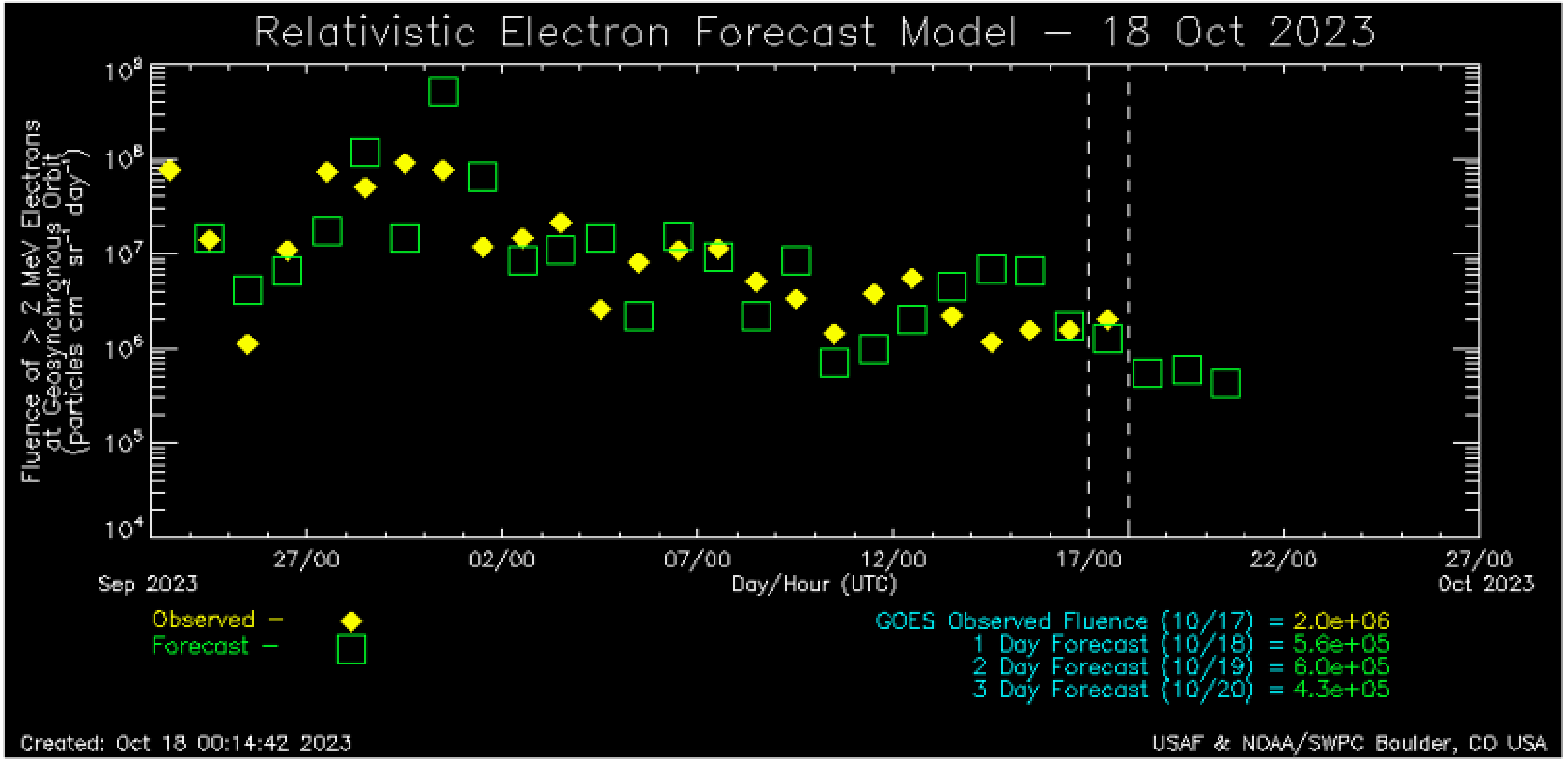
The Total Electron Content (TEC) is the total number of electrons present along a path between a radio transmitter and receiver. Radio waves are affected by the presence of electrons. The more electrons in the path of the radio wave, the more the radio signal will be affected. For ground to satellite communication and satellite navigation, TEC is a good parameter to monitor for possible space weather impacts. TEC is measured in electrons per square meter. By convention, 1 TEC Unit TECU = 10^^{16} electrons/m^2. Vertical TEC values in Earth’s ionosphere can range from a few to several hundred TECU. The TEC in the ionosphere is modified by changing solar Extreme Ultra-Violet radiation, geomagnetic storms, and the atmospheric waves that propagate up from the lower atmosphere. The TEC will therefore depend on local time, latitude, longitude, season, geomagnetic conditions, solar cycle and activity, and troposphere conditions. The propagation of radio waves is affected by the ionosphere.



The Relativistic Electron Forecast Model (REFM) predicts the >2 MeV 24-hour electron fluence at geo-synchronous orbit. It is based on a linear prediction filter (Baker, 1990) that uses average solar wind speed as its input. An offset is employed to help account for additional physical processes that can dramatically affect the electron fluence (the fluence can drop 2-3 orders of magnitude in 24 hours without a corresponding change in solar wind speed). When the 72-hour fluence exceeds 10^9 (cm^2 s sr)$^{-1}$, a warning message is displayed. Red lines (solid for observed and dashed for forecast) appear at the top of the plot, corresponding to the applicable days. A warning message also appears in the legend.



CURRENT SPACE WEATHER CONDITIONS on NOAA Scales

1. 

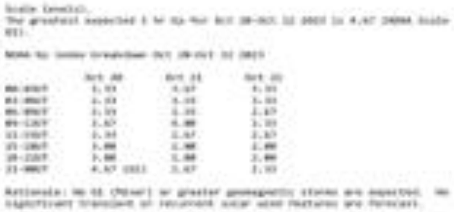
A. When space weather hits and interacts with the earth, geomagnetic storms, free electrons are created to penetrate satellite shielding and accumulate within the spacecraft's electrons to disrupt GPS operations.

2. 

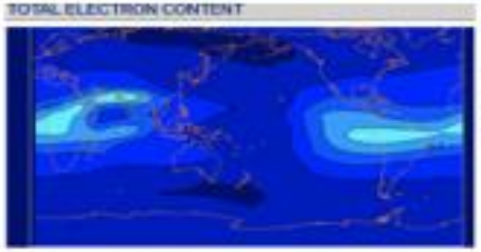
B. As the incident cosmic ray particle collides with an atom or a molecule of the air, it produces lots of secondary particles with a minimum energy of about 450 MeV to produce a significant number of secondaries that can reach sea level.

3. 

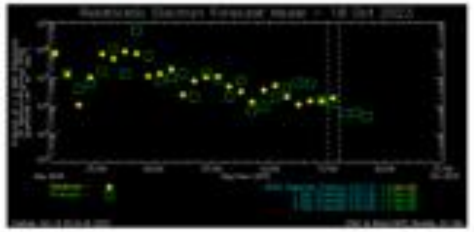
C. In calm conditions, single frequency GPS systems can provide position information with an accuracy of a meter or less. During a severe space weather storm, these errors can increase to tens of meters or more.

4. 

D. The currents and energy introduced by a geomagnetic storm enhance the ionosphere and increase the total height-integrated number of ionospheric electrons, or the Total Electron Count (TEC).

5. 

E. The Total Electron Content (TEC) is the total number of electrons present along a path between a radio transmitter and receiver. Radio waves are affected by the presence of electrons. The more electrons in the path of the radio wave, the more the radio signal will be affected. 1 TEC Unit TECU = 10^{15} electrons/m². Vertical TEC values in Earth's ionosphere can range from a few to several hundred TECU.

6. 

F. The Relativistic Electron Forecast Model (REFM) predicts the >2 MeV 24-hour electron fluence at geo-synchronous orbit. When the 72-hour fluence exceeds 10^8 (cm² s sr)⁻¹, a warning message is displayed.

CURRENT SPACE WEATHER CONDITIONS on NOAA Scales

When space weather hits and interacts with the Earth, geomagnetic storms create free electrons which then penetrate satellite shielding and accumulate within spacecraft to disrupt GPS. Cosmic ray particles with a minimum energy of 450 MeV collide with air molecules and produce secondaries that reach sea level. Under calm conditions, single GPS systems provide position information within 1 meter accuracy. But, under severe space weather storms, errors can increase to more than 10 meters. Geomagnetic storms increase the number of ionospheric electrons imaged as Total Electron Count. TEC is the total number of electrons along a path between a radio transmitter and receiver. The Relativistic Electron Model predicts the >2 MeV 24-hour electron flux and issues a warning when TEC exceeds 10^5 particles of >2 MeV.

True or False. Does the following slide show a correlation? Discuss.

7.

Scale	Description	Effect	Physical measure (Flux level of >= 10 MeV particles)	Average Frequency (1 cycle = 11 years)
S5	Extreme	**Biological:** Unavoidable high radiation hazard to astronauts on EVA (extra-vehicular activity); passengers and crew in high-flying aircraft at high latitudes may be exposed to radiation risk. **Satellite operations:** Satellites may be rendered useless, memory impacts can cause loss of control, may cause serious noise in image data, star-trackers may be unable to locate sources; permanent damage to solar panels possible. **Other systems:** Complete blackout of HF (high frequency) communications possible through the polar regions, and position errors make navigation operations extremely difficult.	10^5	Fewer than 1 per cycle

G. The Relativistic Electron Forecast Model (REFM) predicts the >2 MeV 24-hour electron fluence at geo-synchronous orbit. When the 72-hour fluence exceeds 10^9 $(cm^2\ s\ sr)^{-1}$, a warning message is displayed.