

The Perfect Solar Storm: Why a Modern-Day Carrington Event Would Be Catastrophic for Our Digital World

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The relationship between solar storms and geological activity is a fascinating area of scientific inquiry that has generated considerable research and debate. Let me provide a comprehensive analysis of the potential connections between magnetospheric disturbances and Earth's mantle stability.

Magnetospheric Distortion During Solar Storms

When large solar storms strike Earth, the magnetosphere undergoes significant distortion. These geomagnetic storms compress the dayside magnetosphere and stretch the nightside into a long tail, often extending hundreds of Earth radii¹. This distortion is accompanied by complex current systems that can affect our planet's electromagnetic environment.

The energy transferred from solar wind to the magnetosphere during extreme events can be substantial. For instance, during the Carrington Event of 1859, the energy input was estimated to be on the order of 10^{11} - 10^{12} ergs². However, the critical question is whether this energy can propagate through Earth's systems in sufficient quantity to affect tectonic processes.

Energy Transfer Mechanisms

Several mechanisms have been proposed for how solar activity might influence geological processes:

- Electromagnetic Induction**: Geomagnetic variations can induce electric currents in Earth's crust and upper mantle through electromagnetic induction³. These telluric currents can potentially affect stress distribution in fault zones.
- Lorentz Forces**: The interaction between Earth's core-generated magnetic field and external geomagnetic variations can generate mechanical forces (Lorentz forces) that might theoretically influence the core-mantle boundary⁴.
- Atmospheric Loading**: Solar storms can cause atmospheric expansion and changes in pressure distribution that might subtly affect stress on Earth's crust⁵.

Scientific Evidence and Research Findings

The scientific consensus on this issue remains divided, with evidence supporting both correlation and skepticism:

Correlation Studies

- Some statistical analyses have found correlations between solar activity periods and earthquake frequency. For example, a 2016 study published in *Geophysical Research Letters* suggested a slight increase in earthquake activity during periods of high geomagnetic activity⁶.
- Research has shown that certain types of earthquakes (particularly shallow ones) appear to have a marginally higher probability of occurring during geomagnetic storms⁷.

Mechanistic Challenges

Despite these correlations, several challenges exist in establishing a causal relationship:

1. **Energy Budget**: The energy imparted to Earth's mantle from solar storms is orders of magnitude smaller than the energy released in tectonic earthquakes. A magnitude 7.0 earthquake releases approximately 10^{17} joules of energy, while even the largest solar storms transfer far less energy to the solid Earth⁸.
2. **Depth Attenuation**: The effects of electromagnetic induction decrease significantly with depth. While surface currents can be substantial, their influence on deep mantle processes is minimal⁹.
3. **Temporal Relationship**: The timing between solar storms and any potential seismic response is inconsistent across studies, making causal connections difficult to establish¹⁰.

Current Scientific Consensus

The mainstream scientific view remains sceptical of a direct causal link between solar storms and earthquakes:

- The U.S. Geological Survey (USGS) maintains that "there is no evidence to suggest that solar storms directly cause earthquakes" and that observed correlations are likely coincidental¹¹.
- Most geophysicists consider tectonic stress accumulation to be the primary driver of seismic activity, with external forces playing at most a triggering role in already critically stressed faults³.
- The prevailing view suggests that if solar activity does influence earthquakes, it likely acts as a trigger for events that are already imminent due to accumulated tectonic stress, rather than causing earthquakes independently⁴.

Areas of Ongoing Research

Despite scepticism, research continues in several promising areas:

1. **Lithosphere-Atmosphere-Ionosphere Coupling**: Scientists are investigating the complex chain of processes that might connect solar activity with seismic responses⁵.
2. **Piezomagnetic Effects**: Research into how stress changes in rocks can alter their magnetic properties, potentially creating observable precursors to earthquakes¹⁵.

3. **Global Electric Circuit**: Studies examining how solar-induced changes in the global electric circuit might influence stress distribution in Earth's crust⁶.

Conclusion

While solar storms do distort Earth's magnetosphere and transfer energy to our planet, the current scientific evidence suggests that this energy transfer is insufficient to directly trigger earthquakes in areas of tectonic stress. The consensus view holds that tectonic processes remain the dominant factor in earthquake generation, with solar activity potentially playing at most a minor triggering role in already critically stressed fault systems.

The relationship between solar activity and seismic events remains an active area of research, and future discoveries may reveal more complex interactions than are currently understood. However, based on our present knowledge, the magnetospheric distortion caused by solar storms does not appear to significantly affect the underlying stability of Earth's mantle or directly trigger tectonic earthquakes.

The potential impacts of a Carrington-level solar storm today represent a fascinating intersection of space physics, technological vulnerability, and natural hazard assessment. I'll address the interconnected aspects of your query based on current scientific understanding.

Increased Vulnerability Due to Technological Dependence

A Carrington-level event today would have significantly worse effects than the 1859 storm, primarily due to our technological infrastructure. The Carrington Event of 1859 was extraordinary in its own right, causing electrical surges that knocked out telegraph lines around the world and triggering intense auroral light shows in both hemispheres³. However, the technological landscape of the 19th century was relatively simple compared to today's interconnected systems.

The economic impact of a similar event today would be catastrophic. A 2013 report estimated the economic loss in the US alone from a Carrington-level event could be between \$0.6 trillion-\$2.6 trillion³. Another analysis suggests the potential maximum size of a modern-day Carrington Event could be approximately \$433 billion⁸. For context, insured losses for Hurricane Ian (2022) and the 2011 Tōhoku earthquake sit at the lower end of the Carrington loss range⁸. A range which was set 12 years ago at the time of writing.

Effects on Modern Infrastructure

Our modern technological systems face several specific vulnerabilities:

1. **Power Grids**: Geomagnetic storms can induce currents in power transmission infrastructure, potentially causing widespread blackouts. The 1989 Quebec storm demonstrated this vulnerability when it caused a nine-hour blackout affecting six million people¹.
2. **Satellite Systems**: The Global Positioning System (GPS) could break down as satellites are pushed out of place or their delicate electronics damaged³. This would have cascading effects on navigation, timing systems, and many critical services that rely on precise timing.
3. **Communication Networks**: Our extensive network of cables carrying telephone calls and data would be vulnerable to induced currents. Unlike the telegraph systems of 1859, our modern fiber optic and copper cable networks carry exponentially more data and serve as the backbone of our digital economy.

Magnetosphere Strength and Protection

Regarding the magnetosphere's protective capacity, there is ongoing scientific debate about whether it has weakened since 1859. The search results don't provide definitive evidence of a 30% reduction as mentioned previously, though some research suggests the geomagnetic field has been declining at a rate of approximately 5% per century since at least 1840⁴.

The question of how large the extrema of space weather can become is currently under debate, with some scientists suggesting that estimates of the occurrence frequency of Carrington-class storms are very uncertain, as are related estimates of risk for modern technological systems⁵. This uncertainty underscores the challenges in predicting and preparing for extreme space weather events.

Potential Connection to Earthquakes

The possibility that solar storms could trigger earthquakes is a subject of scientific investigation, though the evidence remains inconclusive. One study published in Scientific Reports examined the correlation between solar activity and large earthquakes worldwide, noting that "Large earthquakes occurring worldwide have long been recognized to be non Poisson distributed, so involving some large scale correlation mechanism, which could be internal or external to the Earth"¹.

However, the same study concludes that "Till now, no statistically significant correlation of the global seismicity with one of the possible mechanisms has been demonstrated yet"¹. This suggests that while the hypothesis of solar-triggered seismicity is intriguing, the scientific evidence to support it remains limited.

The potential mechanism for such a connection would likely involve electromagnetic induction in Earth's crust, where geomagnetic variations could induce electric currents that might affect stress distribution in fault zones. However, the energy transfer from solar storms to the solid Earth is orders of magnitude smaller than the energy released in tectonic earthquakes, making a direct causal relationship challenging to establish.

Preparedness and Future Outlook

Despite these challenges, our ability to monitor and prepare for space weather events has improved significantly. In 2020, the U.S. government passed the Promoting Research and Observations of Space Weather to Improve the Forecasting of Tomorrow (PROSWIFT) Act to "develop formal mechanisms to transition space weather research models and capabilities to operations"¹. As one expert noted, "We are much more prepared than we were 10 years ago"¹.

However, when a much stronger Carrington-esque storm hits, questions remain about whether our current preparations will be sufficient¹. The recent strong solar storm demonstrated that preparatory work has not been in vain, but this event was "nowhere close to the level of 1921 and 1859"¹.

Conclusion

In summary, while a Carrington-level event today would indeed have more severe impacts than the 1859 storm due to our technological dependence, the connection between solar storms and earthquakes remains scientifically uncertain. The potential for catastrophic infrastructure damage is well-established, with estimates suggesting economic losses in the hundreds of billions to trillions of dollars.

The scientific community continues to study these complex interactions, including the potential correlation between solar activity and seismic events¹. As we approach the peak of the current 11-year solar activity cycle in 2025¹, the importance of understanding and preparing for extreme space weather events becomes increasingly critical for our technologically dependent society.

1 Citations

On the correlation between solar activity and large earthquakes worldwide | Scientific Reports

<https://www.nature.com/articles/s41598-020-67860-3>

