“This train was delayed because of bad weather in space”

Professor Jim Wild, a space physicist from Lancaster University, explains how solar storms can disrupt railway signalling, and calls on the sector to start taking the risk of ‘space weather’ seriously.

It is a fact of life that railway operations can be impacted by bad weather.

High winds, fallen trees, flooding, landslides and cold weather are well-known natural hazards that can have a significant impact on the network, but there are some less familiar natural phenomena that we should also pay attention.

It may sound like science fiction but heightened solar activity (known as ‘space weather’) can affect human technologies not just in space, but also in the air and on the ground.

This includes railway infrastructure: recent research with which I’ve been involved shows that big changes in space weather can disrupt railway signals, even turning signals from green to red.

So, what is space weather and how big a risk does it pose to our railways?

As well as the heat and light that nourishes our planet, the Sun emits a continuous stream of material into space, with the amount of material varying over time.

More commonly known as the solar wind, this magnetised stream of sub-atomic particles constantly interacts with the Earth’s magnetic field and atmosphere. A common and beautiful side effect of high solar activity is the aurora borealis: the northern lights that dance across Arctic skies.

Solar disturbances are nothing new. Life on Earth has developed over billions of years, largely unaffected by the solar storms that wash over our planet from time to time. But in the last 200 years, humans have become increasingly reliant on technologies that are vulnerable to these geomagnetic events.

One of the earliest (and biggest) space weather events on record occurred in September 1859, when a massive solar eruption crashed into the Earth triggering a geomagnetic storm that lasted for days.

It was named “the Carrington event” after the English astronomer who observed it, the scientific instruments of the day recorded rapid fluctuations in the Earth’s magnetic field as powerful electrical currents flowed through the upper atmosphere. Ships’ logs noted observations of the northern lights as far south as the Caribbean, and telegraph systems across the world were disrupted as electrical currents were induced in the copper lines. Several telegraph operators received electric shocks and some telegraph stations even caught fire.

So, there’s no doubt that space weather can be highly disruptive to our infrastructure. But how badly, and how frequently, might it disrupt our railway system?

To address this question, we need to understand the vulnerabilities of different sorts of technologies.

It’s unsurprising that spacecraft and satellites feel the effects of space weather: blizzards of high energy particles can damage sensitive electronics and harm astronauts aboard crewed missions.

But down on the Earth’s surface, a different hazard can develop.

Solar storms drive currents of millions of amps through the electrically conductive upper layer of our atmosphere known as the ionosphere. These currents, which can fluctuate rapidly, drive powerful magnetic disturbances at the Earth’s surface that in turn induce electrical currents in the planet’s crust.

These geomagnetically induced currents (GICs) can become a hazard when they flow through conducting infrastructure, usually entering and exiting networks where equipment is grounded to Earth.

GICs are known to be an issue in electricity transmission and distribution grids. While GICs tend to fluctuate during a space weather event, they can be considered to be direct current (DC) compared to the 50-60 Hz alternating current (AC) within an electricity grid.

Superimposed on the AC signal current, GICs can cause imbalances in the large transformers embedded within the power grid, potentially damaging or disabling the critical infrastructure required to keep the grid operational and the lights on.

There have been several examples of space weather impacting power grids in the last few decades, notably blackouts caused by GICs in Canada in 1989 and Sweden in 2003.

There have also been historic examples of space weather interfering with the telegraph-like technology used for railway signalling control systems.

An article in an 1871 issue of *Nature* reported on a space weather event in 1841: “In some cases these magnetic storms were so severe as to impede the working of the railway signals. On the 18th of October, 1841, a very intense magnetic disturbance was recorded, and amongst other curious facts mentioned is that of the detention of the 10:05pm express train at Exeter sixteen minutes, as from the magnetic disturbance affecting the needles so powerfully, it was impossible to ascertain if the line was clear at Starcross. The superintendent at Exeter reported the next morning that someone was playing tricks with the instruments, and would not let them work.”

Space weather has clearly caused disruption in the rail system in the past. But what about now?

Our 21st century railways have largely moved away from this telegraph-like mode of signalling, but signalling track circuits are common in the UK network.

This technology relies upon electrically isolated sections of track, known as blocks, in which the signal is controlled by an electrical circuit between the rails. The signal controlling the block is held at green by a relay, but if a train enters the block, the train axles divert power from the relay, causing the signal to switch to red and preventing another train entering the occupied block. It is estimated that there are more than 50,000 track circuits in the UK.

We know that space weather can drive GICs through long electrically grounded infrastructure like railway tracks. Electrified railways work on AC current, like the grid. So we wanted to know if today’s signalling system can be disrupted by space weather.

Working with PhD researcher Cameron Patterson at Lancaster University, and with Dr David Boteler of Natural Resources Canada, we have modelled how GICs flow through the track circuits of AC electrified lines.

In these lines, the trains are powered via overhead cables. One rail (known as the traction rail) is not broken into sections as it provides the return path for the current. The traction rail therefore presents a long, electrically continuous path for GICs to flow through.

In research published in the journal *Space* Weather, the team focused on the Glasgow to Edinburgh (via Falkirk) Line and a section of the West Coast Main Line from Preston to Lancaster.

By building a computer model of the signalling track circuits using realistic specifications for the various components of the system, we found that space weather events capable of triggering faults in these track circuits are expected in the UK every few decades.

So, although space weather isn't expected to be an everyday issue for British railways, less frequent but more severe space weather looks like it will impact railway signalling, causing delays and disruption.

Crucially, our research suggests that space weather is able to flip a signal in either direction, turning a red signal green or a green signal red. The former is obviously much more significant from a safety perspective.

We also assessed the impact of a solar storm of the size of the 1859 Carrington event, predicting that it would cause widespread problems with signalling on both of the lines studied.

This UK-focussed research is especially timely. Severe space weather has been included in the UK Government's National Risk Register for Civil Emergencies since 2012. The latest version of the register was released in August 2023, and elevated the risk posed to the UK's economy and society by severe space weather to "significant", placing it alongside a handful of other natural hazards including heat waves, flooding, low temperatures and snow.

Although we don't expect space weather to be a daily hazard, a rare and powerful space weather storm could significantly impact railway UK signalling, with implications for safety-critical systems.

We can't totally prevent the impacts on current technologies, but it is possible to be prepared, just as one might for the more familiar extreme weather events such as snowfall and flooding.

At present, the UK Met Office issues space weather forecasts twice daily. While this forecasting is still in its infancy, these forecasts give a warning of what's in store in the coming days.

But it is not clear how the rail industry would respond to an alert that a 1-in-100 year solar storm was expected to impact the Earth in two days' time.

Our research suggests that many signals could misoperate during the storm, but at present we can't say precisely which signals are going to be affected or when the faults would occur. Every solar storm is different and more research is needed to fully understand the vulnerability.

But it’s still worth thinking now about how to minimise the risks. For example, can the existing procedures and communication strategies that would be deployed to deal with the forecast of a 1-in-100 year blizzard impacting the UK rail network be adapted for extreme space weather events? Are key decision-makers and personnel familiar with this natural hazard?

Other industries such as aviation, electricity generation and transmission, and the space sector are considering the risks to their operations, and exploring how these might be mitigated, but the rail sector is lagging behind.

Our research shows that space weather poses a serious, if relatively rare, risk to the rail signalling system, which could cause delays or even have more critical, safety implications.

The rail sector needs to start taking this seriously. By their nature, high-impact, low-frequency events are hard to plan for, but ignoring them is rarely the best way forward.

You can read our scientific papers on space weather and rail signalling here.

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