



HEATQUAKES

Climate change isn't just warming
the planet, it's shaking
Earth's foundations

by PROF BILL MCGUIRE

ALAMY

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stonishingly, earthquakes shake the US state of California almost 9,000 times a year, on average – that's about once every hour. California's official nickname is the Golden State, harking back to the mid-19th-century gold rush that saw its population explode in just

four years, from 14,000 to a quarter of a million. But if you've ever been lucky enough to visit and felt the ground move beneath your feet, you'll probably agree that 'the Earthquake State' is a far better fit.

None of this should be a surprise given that it hosts the San Andreas Fault, where two of the world's great tectonic plates – the North American plate to the east and the Pacific plate to the west – meet.

California has attracted the world's attention in recent years, not for its earthquakes, but more for its wildfires and flash floods – all super-charged by global heating and its disruption of our once-stable climate. The news, then, that such extreme weather could also promote earthquake activity is far from welcome in one of the planet's biggest seismic hotspots.

GEOLOGICAL CONSEQUENCES

When we think about climate change, it's usually in terms of how the atmosphere and oceans are heating up. The idea that it can also affect the ground beneath our feet seems almost laughable. Nonetheless, it's true.

For decades, I've been researching how the climate can drive deadly geological phenomena, like earthquakes, tsunamis and volcanic eruptions, and the evidence is absolutely clear. The latest piece of research by the Swiss Seismological Service, published this summer, links swarms of small tremors beneath Mont Blanc in the European Alps to rapid thawing of ice and snow during a heatwave in 2015.

Percolating downwards, the extra water eventually found its way into a major fault zone that slices through the 12km-long (7-mile) Mont Blanc Road Tunnel, lubricating it and causing it to shift sufficiently to trigger a burst of low-level seismic activity. The occurrence of small tremors has since remained elevated, substantially hiking the risk of bigger quakes in the future.

As global heating continues to drive longer and more intense heatwaves, meltwater sourced by accelerated glacier melting and the thawing of permafrost can be expected to increase seismic activity across the world's high mountain ranges, and the great tracts of permafrost in Canada and Siberia.

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As well as raising concerns among those who live in the Mont Blanc region, the Swiss research also holds lessons for any town or city on geological faults that have spawned big quakes in the past; think Tokyo in Japan, and San Francisco and Los Angeles in California. None of these are mountainous and so meltwater isn't an issue, but there are other ways a changing climate can increase the rate of water infiltration into the faults that threaten these cities.

Tokyo, for example, is under growing threat from typhoons that climate change is making slower and wetter. As a consequence, storms now dump more rainfall along their path, increasing the amount available for percolating into the ground and into active fault zones.

The chance of a serious earthquake hitting the Japanese capital in the next 30 years or so is thought to be as high as 70 per cent, so anything that can increase this probability is a big deal. The big worry isn't, as in the Alps, that water will trigger swarms of little quakes, but that the infiltration of water into a fault that's teetering on the edge of rupturing will set off the 'big one'.

A seismologist colleague of mine is fond of warning that all that's needed to trigger a major earthquake at a fault that's 'locked and loaded' is

the pressure of a handshake. The tiny force exerted by the percolation of water into a fault zone may just be enough.

California is awaiting the next 'big one' too – both in the north, in the San Francisco Bay area and further south near Los Angeles. The US Geological Survey reckons there's a more than 70-per-cent chance that a quake of magnitude 6.7 or bigger, capable of causing widespread damage, will strike the Bay Area in the next 18 years.

Southern California has an even greater level of earthquake risk – the highest in the entire country, in fact – and more than 300 faults in the region have the potential to trigger serious quakes. Here, the San Andreas itself presents the greatest threat, with the likelihood of a magnitude 7.5 quake in the next three decades estimated at more than 1 in 3. Whenever it happens, such an event is predicted to take around 2,000 lives and cost a colossal \$200 billion in damages.

RIVERS IN THE SKY

Given that a number of faults in the state are pretty much primed and ready to go, the concern is that climate change might provide the extra impetus

“The tiny force exerted by the percolation of water into a fault zone may just be enough”

LEFT The San Andreas fault, one of the planet's most active fault lines, runs beneath California, the most populous state in America

ABOVE Seismic activity beneath Mont Blanc is believed to be linked to meltwater percolating down from the mountain above

RIGHT The earthquake that struck Haiti in 2010 came after a series of very wet hurricanes had hit the Caribbean island in the preceding years



that advances the timing of the next big quake. In recent years, California has taken a hammering from what are known as atmospheric rivers.

Sometimes called 'rivers in the sky', these are weather phenomena thousands of kilometres long and a few hundred kilometres wide, which carry prodigious volumes of water vapour – up to 15 times the flow of the mouth of the Mississippi River. Atmospheric rivers are not uncommon across California, including the so-called Pineapple Express that draws moisture all the way from Hawaii, but in recent years they've grown, dumping enormous amounts of rain and snow across the state. Climate change is making such rivers bigger and wetter, while the strongest – known as category fives – are becoming more common.

In February 2024, an atmospheric river brought 48 hours of continuous rainfall to Southern California. It caused landslides and mudflows, knocked out power to almost a million people, and caused flash flooding across Los Angeles. This February, too, saw a barrage from more atmospheric rivers across the region, bringing flooding and loss of life.

A mix of rainstorms and active faults on the edge of rupture isn't exactly a recipe for seismic

calamity, but together they certainly have the potential to elicit a major earthquake by lubricating faults. Furthermore, there's now convincing evidence – from the other side of the world – linking rainfall and big seismic shocks. Like California, Taiwan is no stranger to earthquakes, so the magnitude 7.6 Chi-Chi quake that struck central parts of the country in September 1999 was hardly a surprise.

The event was both devastating and lethal, destroying more than 50,000 buildings and taking almost 2,500 lives. It also happened just three years after Super Typhoon Herb dropped a couple of metres of rain across the region. On its own, this could simply be a coincidence, but at least four other big Taiwan quakes in the last half-century came in the wake of especially wet storms.

On top of this, it seems that earthquakes of magnitude 6 or higher that have affected the country, are five times more likely to happen within four years of a major storm than otherwise.

LIGHTENING THE LOAD

There is, however, a twist to this story. Because of the big time lag between storms and quakes, it's unlikely that rainwater quickly percolating

ABOVE Downpours, due to atmospheric rivers carrying ever-greater volumes of water, are leading to increasingly frequent floods in California – the state that straddles the San Andreas fault

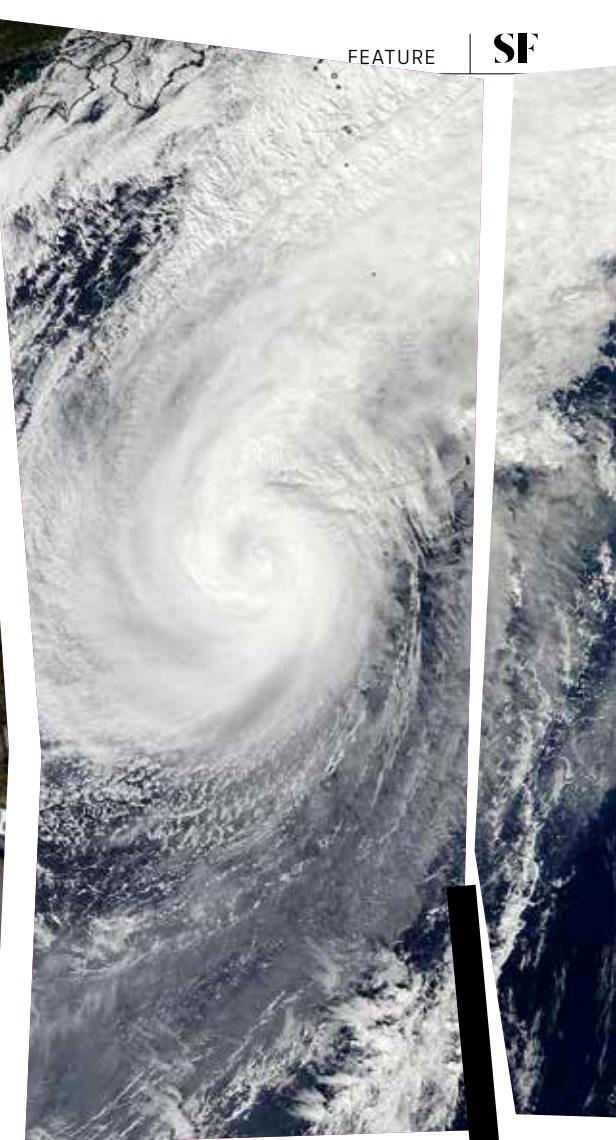


through the ground and lubricating faults is the link. Instead, it has to be something slower acting.

One proposal is that the triggering of thousands of landslides by the torrential rainfall, and the removal of the debris by erosion, reduces the weight bearing down on faults, allowing them to slip more easily. The weight unloaded is tiny, but it's all about that 'pressure of a handshake' thing again.

A similar connection between an earthquake and rainstorms is recognised on the Caribbean

ABOVE RIGHT Climate change is making the typhoons that hit Tokyo slower and wetter, increasing the volume of water falling on Japan and percolating into the fault zones beneath it



“There’s now convincing evidence linking rainfall and big seismic shocks”

island of Haiti, where a devastating earthquake in 2010, which took at least 160,000 lives, followed a succession of four very wet hurricanes a couple of years earlier.

California is in a similar situation too, with the torrential rains brought by a procession of atmospheric rivers promoting landslides and mudflows across the state. The situation is aggravated by the huge areas of bare ground exposed by the catastrophic wildfires of recent years, which are also driven by global heating.

As such, any fault that's ready to rupture faces a double whammy of percolating rainwater and unloading due to landslides and erosion, either or both of which could set it off. The problem is, however, when the next big one does occur – either beneath the Bay Area or Los Angeles – we'll likely never know whether percolating rainwater or unloading was a contributing cause; whether climate change played a role; or whether the timing of the quake was entirely down to geological processes.

And this raises an important point about the general influence of a changing climate on seismic activity. Broadly speaking, it doesn't have the capacity to cause additional quakes, just the potential

“There are some parts of the world where the seismic response of the ground to our rapidly changing climate is clear”

– via that extra little nudge – to bring forward the timing of an event that was going to happen at some point anyway.

So, don't expect to see a massive increase in the number of big earthquakes, or even any increase that can be distinguished from the normal background.

MELTDOWN

That said, there are some parts of the world where the seismic response of the ground to our rapidly changing climate is clear and present – it's in the spots where major ice masses are undergoing wholesale melting. Alaska, for example.

In the largest of state of America, an increase in seismic activity has followed the loss, in places, of a vertical kilometre (over half a mile) of ice in the last century or so. The unloading of this enormous weight from the crust is allowing faults below to slip more easily.

Looking ahead, Greenland is by far the biggest concern in this regard. Seismically speaking, the planet's biggest island is ominously quiet; not because there are no faults there, but because the huge weight of the ice above is stopping them from slipping. But this is unlikely to last as the 3km-thick (1.8 miles) Greenland Ice Sheet (GIS), which holds sufficient water to raise global sea level by 7m (23ft), melts ever faster.

Since the early 1990s, the GIS has lost an astonishing six trillion tonnes of ice, generating so much meltwater that it would cover the entire United States to a depth of half a metre (1.6ft). As melting continues, it causes the load on the faults below to diminish, so it would be no surprise at all if the island started shaking. Any faults beneath the ice would have been accumulating strain and winding themselves up for thousands of years, so we're talking about the possibility of some serious earthquakes on the horizon.

A little less than 11,000 years ago, the loss of Greenland ice mass at the end of the last ice age triggered an earthquake as big as magnitude 8.3 off the southern tip of the island. Simulations suggest it generated a major tsunami that sent waves up to 7m (23ft) high crashing into the coastlines of Canada and the UK.

Something similar happened a little over 8,000 years ago, when a massive earthquake in Norway, triggered by the melting of the Scandinavian Ice Sheet, promoted one of the world's biggest submarine landslides, which, in turn, sent a huge tsunami into the North Atlantic, this time with waves more than 20m (65ft) high.

Atlantic tsunamis on the scale of those we see today within the Pacific Ring of Fire is a shocking and unlooked-for consequence of global heating. The reality, however, is that the all-pervasive nature of resulting climate breakdown means that nothing and nowhere is immune, and that includes the ground beneath our feet. **SF**

BELOW California's wildfires, intensified by climate change, have made vast tracts of land more prone to landslide, reducing the weight pressing on any faults that lie below



by **PROF BILL MCGUIRE**

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