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Large quakes in region can affect land in Singapore, study finds

Vital to factor in vertical shifts of millimetres when studying sea-level rise: Researchers

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The devastating 9.2-magnitude earthquake off the coast of Sumatra in 2004 caused land in Singapore to sink gradually in the years that followed, scientists have found.

While the shift was just up to several millimetres annually, it is important to take such measurements into account when studying sea-level rise and developing plans for adapting to climate change, they said.

Research led by Nanyang Technological University (NTU) revealed that large tremors in Sumatra have caused land to dip not just in the Republic, but also in neighbouring countries Malaysia and Thailand.

The geologists found that the ground continued to shift, even in places more than 600km away from where the earthquakes had occurred.

Without accounting for how land sinks and rises, also known as vertical land motion, coastal flood risks in low-lying areas could be underestimated, they said.

These findings, published in the scientific journal Communications Earth & Environment, were announced by the university on July 10.

"When massive earthquakes strike, they do not just shake the ground for a few minutes," said Grace Ng, the study's lead author. "They set off a slow adjustment deep within the earth that can continue for years."

Researchers linked this movement to the mantle beneath the earth's crust in an area known as the Sumatran backarc – the broad region behind Sumatra's volcanoes where Singapore, Malaysia and Thailand are located.

To understand this subterranean activity, the team analysed up to two decades of ground movement data from Global Navigation Satellite System stations across Singapore, Malaysia and Thailand. They then compared these recordings with computer models of the earth's layers.

They discovered that the movement observed could be explained only if the upper mantle beneath the backarc was weak enough to flow slowly over time. The mantle is made of hot, solid rock that flows very slowly over long periods. The weaker the mantle, the more easily it flows.

As this underground material shifts away, the earth's crust sinks in the countries on the Sumatran backarc.

Conducting such a study prior to 2004 would have been difficult, noted Ng, a research fellow at NTU's Earth Observatory of Singapore, as many of the continuous satellite positioning stations needed to measure long-term deformation were installed only after the 2004 disaster.

A previous study in 2025 looking at the causes of vertical land motion found that three of the earth's most powerful earthquakes in Sumatra caused Singapore to sink at rates of up to 2.2mm annually between December 2004 and April 2012.

Except for this period of tectonic movement, the main island was generally stable, with the sinking being close to zero, that study found.

Now that researchers have better understood the mantle viscosity beneath the region, they are modelling how much of the observed land motion is due to the long-term effects of major earthquakes.

Emma Hill, AXA-Nanyang Professor in Earth and Environmental Science and senior author of the paper, noted that most current sea-level projections focus primarily on climate factors such as ice melting and ocean warming.

"Our new study shows that post-earthquake land sinking is an important factor in regional relative sea-level change," said Hill, who is also acting director of the Earth Observatory of Singapore. "Incorporating these deep geological movements into our models will help us improve coastal planning for low-lying cities."

Noting that the cumulative sinking of Singapore is on the centimetre scale, Ng said there is still time for policymakers to act. "It's always best to incorporate these models into adaptation plans earlier rather than to incur costs by retrofitting (infrastructure) later," she added.

To date, Ng noted, incorporating tectonic land height changes into local sea-level assessments is still nascent, with countries such as New Zealand and the US among those beginning to account for these effects.

Responding to media queries, the Meteorological Service Singapore (MSS) under the National Environment Agency, which helped fund the research, said the potential influence of earthquake-induced vertical land motion on local sea levels remains an emerging area of research.

Hence, these findings were not considered in Singapore's latest sea-level rise projections published in January 2024.

"The Centre for Climate Research Singapore continues to work with the research community to improve the scientific understanding of factors that may influence local sea-level change," an MSS spokesman said.

Ng hopes the study will change how people in Singapore view the long-term impact of earthquakes in the region.

"In the past, many people thought that Singapore was too far from Sumatra to be affected by earthquakes there," she said.

"But what we are trying to raise awareness about is that even though we are so far away, we have this weak mantle that is slowly readjusting beneath us after earthquakes in Sumatra. That's why we can still experience impacts."

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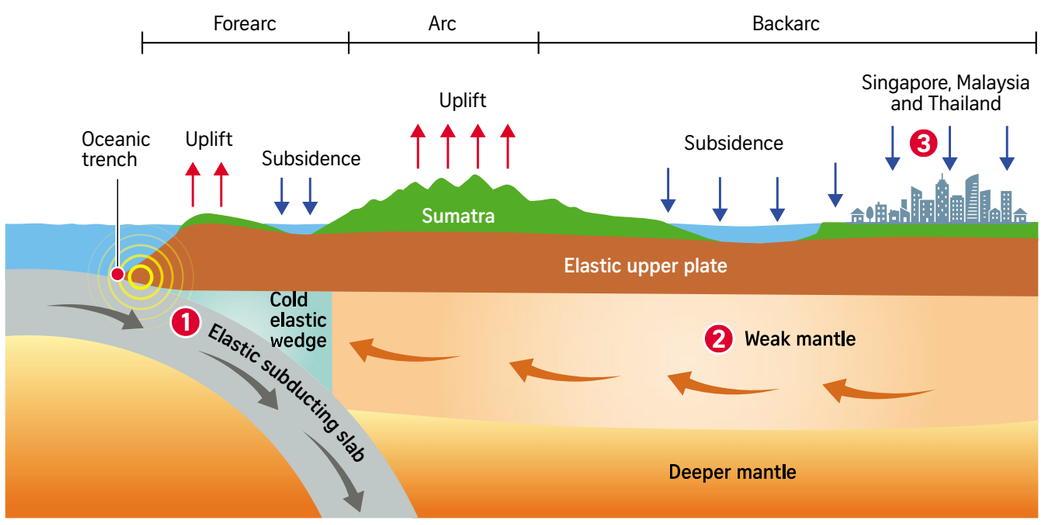
Land movements

Major quakes in the region can cause land in Singapore, Malaysia and Thailand to slowly sink by several millimetres a year. A recent study led by NTU reveals that this slight sinking is caused by a weak mantle beneath the Sumatran backarc. The mantle is made of hot, solid rock that flows very slowly over long periods. The weaker the mantle, the more easily it flows. The Straits Times explains the science behind the land movements.



PROCESS

1. As the subducting slab – a denser plate sinking into the mantle – continues to descend beneath Sumatra, stress builds up along the plate boundary until it suddenly slips, triggering a great earthquake.
2. The earthquake changes the forces deep within the earth, causing the weak mantle beneath the broad region behind Sumatra's volcanoes, known as the Sumatran backarc, to slowly flow towards the trench over years or even decades.
3. As the underground material shifts away, the land above it gradually sinks. This happens across the broad region, which includes Singapore, Malaysia and Thailand.

NOTE: This diagram is not drawn to scale.

Source: NTU STRAITS TIMES GRAPHICS