Monitoring our dynamic planet from space

Tim Wright
COMET, School of Earth and Environment, University of Leeds

COMET is the UK Natural Environment Research Council's Centre for the Observation and Modelling of Earthquakes, Volcanoes and Tectonics

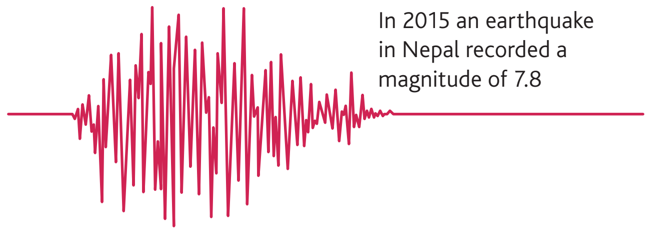
Tectonic plates move at the speed our fingernails grow

The ground beneath our feet is in constant motion. Tectonic plates – moving at the speed our fingernails grow – contort as they collide, scrape past each other or are pulled apart. Molten rock flows through complex subterranean networks. The ever-building stresses and pressures from these movements eventually have to be released – the result is earthquakes and volcanic eruptions. A new generation of satellites is allowing scientists to monitor the build-up of stresses prior to earthquakes and eruptions, providing vital information that can help communities to prepare.

The continents' crust, the upper 15km or so of the Earth's outer layer, is cold, brittle and riddled with lines of weakness, known as faults. When the upper crust is caught in a plate boundary zone it bends like a giant block of rubber, building up elastic stresses. When the stresses are higher than the frictional resistance on the faults within the crust, the faults slip and we experience earthquakes. If we want to say where earthquakes will occur, and roughly how often, we should be able to do this by simply measuring the warping of the crust. We have known this for more than 100 years, but only in the last ten years or so has this method become practical. Why has it taken so long? Because the movements are tiny. To measure the deformation around faults with sufficient accuracy to be useful for estimating future seismic hazard, we need to be able to detect movements of points separated by 100 km that are as small as 1 mm each year.

The breakthroughs in measuring our deforming planet have been by-products of navigation and imaging satellites. Two methods have been particularly important. The first of these uses Global Navigation Satellite Systems like GPS, the US-operated system that so much of our modern lives now depends on. Since the early 1990s, scientists have been using the signals sent from GPS satellites to locate the position of thousands of marker points distributed across the planet. By recording the raw signals from the satellites, the location of these marker points can be pinned down to the nearest millimetre. By tracking these markers over time, we can measure the speed and direction of movement (the velocity) of the marker points. In the latest global compilation of these GPS velocities, there are nearly 20,000 points whose positions and velocities have been measured in an extraordinary effort by the scientific community.

The second satellite method uses radar images acquired by low Earth-orbiting satellites like the new EU/ESA Sentinel-1 constellation. These acquire new images every few days by beaming radar waves from the spacecraft and measuring the reflected energy to form an image. The time it takes the signals to return depends on the distance between the satellite and every point in the radar image; we can track changes in those distances very precisely using a technique called satellite radar interferometry (InSAR). Unlike GPS, InSAR works without instruments on the ground, and we get continuous maps of ground movement with a measurements every few tens of metres or better. To obtain motion maps with the 1 mm/yr accuracy needed for seismic hazard, however, we need to remove the 'noise' that comes from the changing atmosphere – this requires using data from hundreds of radar images, acquired over several years. Systems like Sentinel-1 are now gathering the vast data sets that are allowing us to map the deforming continents in incredible detail.

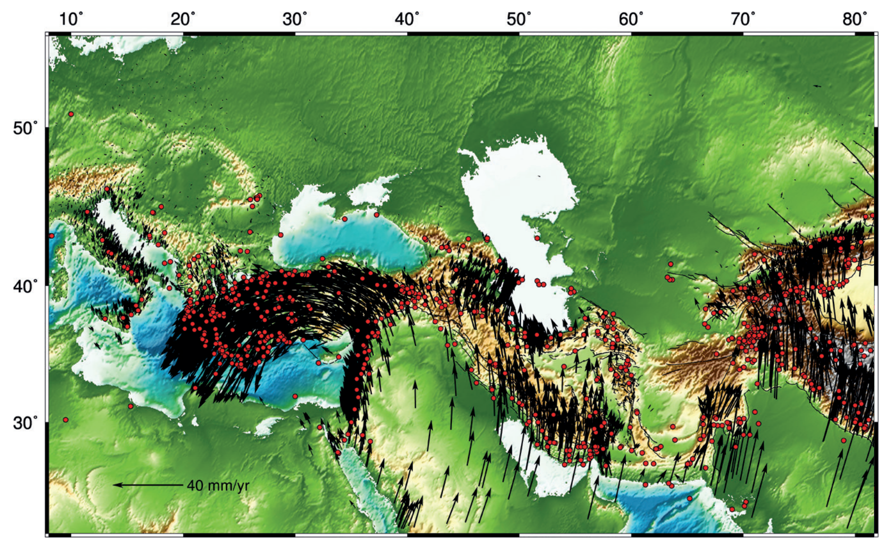


In 2015 an earthquake in Nepal recorded a magnitude of 7.8

Radar images can also have an immediate impact when an earthquake occurs – we can map how the ground moved in the earthquake and use this to work out which faults slipped and which faults remain locked and primed for future earthquakes. Just before midday (local time) on 25 April 2015, Nepal started shaking. An earthquake with a magnitude of 7.8 had occurred on the fault that lies underneath the entire country. Around 9,000 people lost their lives in this earthquake when buildings collapsed and landslides buried towns. Scientists obtained a blurry picture of what had happened using seismic waves emanating from the earthquake and recorded across the planet. But after Sentinel-1 had imaged the area with radar, four days after the quake, we were able to see precisely what had happened at depth. Surprisingly, the earthquake had not ruptured the entire fault – half of it remains unbroken. The data shows that the risk of earthquakes remains high – at some point in the future the rest of the fault plane will fail. The government, NGOs and local communities are working hard to prepare.

The ground also moves at volcanoes as molten rock moves in the subsurface prior to and during eruptions. Ground deformation at a volcano does not always mean an eruption is inevitable, however. On 18 March 2017, scientists at the Instituto Geofisico Escuela Politécnica National (IGEPN) in Quito, Ecuador, noticed increased seismic activity at Cerro Azul volcano in the Galapagos. Based on these small earthquakes, which often accompany magma movement, they issued a warning for a possible imminent eruption. Sentinel-1 acquired data before the start of the seismic activity on 7 and 8 March and again after the earthquakes had begun on 19 and 20 March. The results showed that magma was moving sideways within the crust, rather than approaching the surface. The data helped IGEPN reduce the hazard level.

We are now entering an era where deformation data is readily available for scientists and decision-makers. The organisation that I run, COMET, is now providing InSAR data from Sentinel-1 for large regions – within the next 12 months we expect to be monitoring all of the planet's tectonic belts and volcanoes. We expect the results to have a major impact on our understanding of our hazardous planet and to help communities and decision-makers prevent future earthquakes and eruptions from becoming disasters.



Earthquakes across the Earth

Each circle is a large earthquake and the arrows show the motion of points relative to the Eurasian plate, as measured with GPS. The collision of Africa, Arabia and India with Eurasia has created a wide deforming zone of thickened crust, high seismicity and high strain rates that stretches for up to 2,000km from the foothills of the Himalayas to the distant steppes of Mongolia.