Earthquake Season in the Himalayan Front

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Scientists have long searched for what triggers earthquakes, even suggesting that tides or weather play a role. Recent research spearheaded by Jean-Philippe Avouac, professor of geology and director of the Tectonics Observatory at the California Institute of Technology, shows that in the Himalayan mountains, at least, there is indeed an earthquake season. It's winter.

For decades, geologists studying earthquakes in the Himalayan range of Nepal had noted that there were far more quakes in the winter than in the summer, but it was difficult to assign a cause. "The seasonal variation in seismicity had been noticed years ago," says Avouac. Now, over a decade of data from GPS receivers and satellite measurements of land-water storage make it possible to connect the monsoon season with the frequency of earthquakes along the Himalaya front. The analysis also provides key insight into the timescale of earthquake nucleation in the region.

Avouac will present the results of the study on December 12 at the annual meeting of the American Geophysical Union (AGU) in San Francisco. They are also available online through the journal Earth and Planetary Science Letters, and will appear in print early next year.

The world's tallest mountain range, the Himalaya continues to rise as plate tectonic activity drives India into Eurasia. The compression from this collision results in intense seismic activity along the front of the range. Stress builds continually along faults in the region, until it is released through earthquakes.

Avouac and two collaborators from France and Nepal--Laurent Bollinger and Sudhir Rajaure--began their earthquake seasonality investigation by analyzing a catalog of around 10,000 earthquakes in the Himalaya. They saw that, at all magnitudes above this detection limit, there were twice as many earthquakes during the winter months--December through February--as during the summer. That is, in winter there are up to 150 earthquakes of magnitude three per month, and in summer, around 75. For magnitude four, the winter average is 16 per month, while in summer the rate falls to eight per month. They ran the numbers through a statistical calculation and ruled out the possibility that the seasonal signal was due merely to chance.

"The signal in the seismicity is real; there is no discussion," Avouac says. "We see this seasonal cycle," he adds. "We didn't know where it came from but it is really strong. We're looking at something that is changing on a yearly basis-the timescale over which stress changes in this region is one year."

Earlier studies suggested that seasonal variations in atmospheric pressure set off earthquakes, and this had been proposed for seasonal seismicity following the 1992 Landers, California, quake.

The scientists turned to satellite measurements of water levels in the region. Using altimetry data from TOPEX/Poseidon, a satellite launched in 1992 by NASA and the French space agency CNES (Centre National d'Etudes Spatiales), they evaluated the water level in major rivers of the Ganges basin to within a few tens of centimeters. They found that the water level over the whole basin begins its four-meter rise at the onset of the monsoon season in mid-May, reaching a maximum in September, followed by a slow decrease until the next monsoon season.

They combined river level measurements with data from NASA's GRACE--Gravity Recovery and Climate Experiment--mission, which studies, among other things, groundwater storage on landmasses. The data revealed a strong signal of seasonal variation of water in the basin. Paired with the altimetry data, these measurements paint a complete picture of the hydrologic cycle in the region.

In the Himalaya, monsoon rains swell the rivers of the Ganges basin, increasing the pressure bearing down on the region. As the rains stop, the river water soaks through the ground and the built-up load eases outward, toward the front of the range. This outward redistribution of stress after the rains end leads to horizontal compression in the mountain range later in the year, triggering the wintertime earthquakes.

The final piece connecting winter earthquake frequency to season, and lending insight into the process by which earthquakes nucleate, lay in GPS data. Installation of GPS instruments across the Himalayan front began in 1994, and now they provide a decade's worth of measurements showing land movement across the region. Instead of looking at vertical motions, which are widely believed to be sensitive to weather and the same forces that cause tides on Earth, the scientists concentrated on horizontal displacements. The lengthy records, analyzed by Pierre Bettinelli during his graduate work at Caltech, show that horizontal motion is continuous in the range front. Stress constantly builds in the region. But just as water levels near their lowest in the adjacent Ganges basin and earthquakes begin their doubletime, horizontal motion reaches its maximum speed.

"We had been staring at [the seasonal signal] for years, and then the satellite data came in and we deployed the GPS network and suddenly it became crystal clear," says Avouac. "It's like something you dream of."

While many scientists have suggested that changing water levels can influence the earthquake cycle, a definitive mechanism had yet to be pinpointed. "There are two main avenues by which people have tried to understand the physics of earthquakes: Earth tides and aftershocks," says Avouac. With the water level data, he could show that the rate at which stress builds along the rangefront, rather than the absolute level of stress, triggers earthquakes.

Although Earth tides induce stress levels similar to what builds up during seasonal water storage, they only vary over a 12-hour period. The Himalayan signal shows that it is more likely that earthquakes are triggered after stress builds for weeks to months, which matches the timescale of seasonal stress variation in that region.

About other earthquake-prone regions Avouac says, "seasonal variation has been reported in other places, but I don't know any other place where it is so strong or where the cause of the signal is so obvious."

Other authors on the paper are Pierre Bettinelli, Mireille Flouzat, and Laurent Bollinger of the Commissariat a l'Énergie Atomique, France; Guillaume Ramillien of the Laboratoire d'Etudes en Géophysique et Océanographie Spatiales, France; and Sudhir Rajaure and Som Sapkota of the National Seismological Centre in Nepal.

Source: Caltech