When the Earth moved Kashmir

"I call it the flash-to-bang. From the first event to the first relief there, you want to minimize the time in between."

Wiley Thompson
Oregon State University

by Laura Naranjo

Nestled in the Himalaya Mountains, Kashmir inhabits a crossroads between the Middle East and Asia. Kashmir's valleys and snow-clad peaks have historically hosted divergent cultures and housed scholarly learning centers. Its natural resources and complex heritage have attracted tourists and border disputes; the region is administered by the neighboring countries of Pakistan and India.

Kashmir also inhabits another crossroads: It lies atop a web of active faults with underground dynamics that rival the complexities above ground. On October 8, 2005, one of the faults gave way, resulting in a magnitude 7.6 earthquake. In a matter of seconds, the rugged terrain that lures travelers became a disaster zone that soon would host relief workers providing food and shelter, military rescue operations airlifting supplies, and scientists seeking to understand how the earthquake happened.

The 2005 Kashmir earthquake badly damaged the town of Balakot in northwestern Pakistan. Debris littered walkways and roads, making relief access difficult. (Photograph by Lieutenant Colonel W. Thompson, courtesy U.S. Department of Defense)

After a major earthquake, scientists have traditionally relied on ground surveys to understand the damage. But satellite imagery is producing increasingly accurate ways to spot exposed faults and map deformation caused by earthquakes, especially in remote areas like Kashmir. What scientists learn by studying earthquake geology and post-earthquake deformation can advance what we know about earthquake dynamics and provide valuable information to relief organizations.

Anatomy of an earthquake

Kashmir sits atop the boundary of two colliding tectonic plates: the small Indian plate that underlies most of India and Pakistan, including much of Kashmir; and the vast Eurasian plate that underlies Europe, China, Russia, and much of the Middle East. Jean-Philippe Avouac, a geologist and professor at the California Institute of Technology, studies Asian earthquakes and tectonics. Avouac said, "Northern India is being thrust under the Himalaya, and the mountains are being pushed up by this motion. It's a small increment of deformation, which over millions of years has built the Himalaya range." This slow-motion collision created one of the planet's most active earthquake hotspots; as the plates collide, stress builds up in the fault zones where the plates meet.

Sudden and rapid releases of seismic stress can cause large earthquakes. And sometimes, an abrupt movement along a shallow fault can rupture the surface, as happened during the 2005 Kashmir earthquake. This surface rupture extended for seventy-five kilometers (forty-seven miles) and was a first among earthquakes in the Himalaya seismic zone. Robert Yeats, a geologist at Oregon State University, traveled to Pakistan after the Kashmir earthquake and witnessed the damage caused by the rupture firsthand. Yeats said, "In the known historic and recent records, not one of the earthquakes in the Himalaya has ever produced a surface rupture, not in Nepal, or India, or anywhere. This rupture was the first one."

The Kashmir earthquake killed nearly 75,000 people, injured more than 100,000 people, and destroyed 3 million homes. Two towns that straddled the newly exposed fault suffered the most damage: Muzaffarabad and Balakot. In addition, the earthquake generated massive landslides that buried entire towns. Yeats said, "The upper side of the fault had a lot of landslides. Tens of thousands of people died because of landslides."

Mapping deformation

Yeats, an earthquake expert, has a long history of working in Pakistan. After the 2005 Kashmir earthquake, he joined a team of researchers who were the first to map the fault line on the ground. The team returned to the area several times to walk the fault and record the resulting earthquake deformation. "In that kind of terrain, seventy-five kilometers [forty-seven miles] takes a long time to cover," Yeats said. This traditional method of ground surveying can be difficult after an earthquake because the land surface has changed. Mapping ruptures typically means finding features that used to be continuous before the earthquake, like a road or fence. But in parts of Kashmir, few of these man-made features exist, meaning that the survey team had to find natural features that had been disrupted by the fault, like small crests or river gullies.

Because of the difficulties of ground surveying, researchers like Avouac are investigating how satellite imagery can aid ground surveys and rescue work by generating more immediate maps of earthquake deformation. In theory, observing earthquake deformation should be as simple as comparing two optical satellite images that show the land surface before and after the earthquake. However, correlating three-dimensional images is technically very difficult. Avouac said, "There are distortions in the images because of the topography and geometry of the terrain, the angle at which the satellite instrument is viewing the Earth's surface, and the satellite's motion." When correlating the two images, all of these distortions produced visual offsets in the resulting image that the earthquake did not cause.

The 2005 Kashmir earthquake displaced more than three million people, primarily affecting residents in the Kashmir region. Over time, the collision between the Indian and Eurasian plates formed the Himalaya Mountains, and has made the region seismically active and susceptible to earthquakes. (Courtesy L. Naranjo, based on United Nations map)

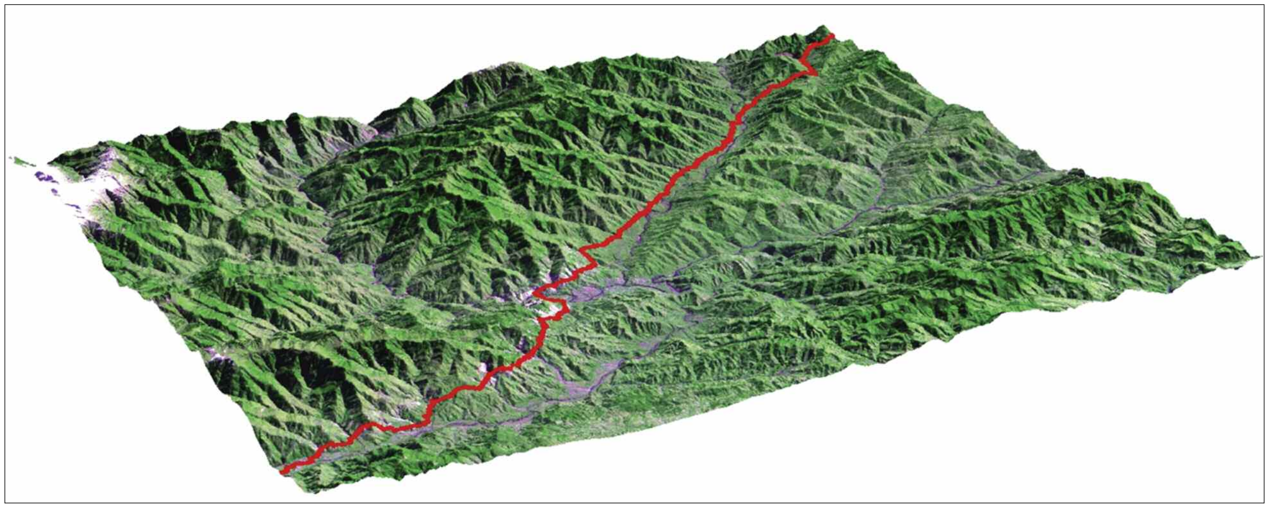
Avouac's team discovered that accurately correlating the images was not a simple process. To remove the distortions, the team needed to match geographic coordinates between the images and the ground; calculate the satellite's position and motion; drape the images onto the corresponding portion of the Earth's surface; and then compare differences between the two images. Avouac and his team refined these steps until they created a reliable technique that would accurately show the earthquake deformation without the visual distortions.

The team applied this technique using imagery of the Kashmir area from the Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) aboard the NASA Terra satellite. Although Avouac has a variety of image sources to choose from, he frequently relies on ASTER images from the NASA Land Processes Distributed Active Archive Center (LP DAAC). He said, "I've switched to using ASTER because the community of users is much larger and because of the lower cost."

Avouac chose an image taken before the earthquake and compared it to a post-earthquake image captured on October 27, 2005. The results were successful, and correlated very well with the surface rupture measured by Yeats' team. Avouac said, "We confirmed that our technique can provide information that may be very difficult to measure in the field but is critical for modeling earthquakes."

Remote answers to relief

Earthquake-stricken areas are notoriously difficult for relief workers to access because communication networks and infrastructure are damaged. Avouac hopes that the technique he and his colleagues developed can be used to hasten aid to future earthquake victims. He said, "Our technique provides detailed information that could be used by rescue teams to estimate whether a major town has been badly shaken or not."



A three-dimensional view, looking to the southeast, shows the fault that ruptured during the 2005 Kashmir earthquake. Scientists determined the deformation caused by the earthquake by correlating Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) images taken before and after the earthquake. (Image by J. Giberson, courtesy Tectonics Observatory, Caltech)

Wiley Thompson, a lieutenant colonel in the United States Army serving in Afghanistan when the quake occurred, assisted with the disaster relief efforts. Thompson said, "As a disaster response coordinator, my goal was to get relief—the right kind of relief—to the people who needed it the most at that moment."

Having access to remote sensing and field studies can help relief workers zoom in on a crisis area. Thompson said, "You need to know where to go, so you don't spend time going to places that weren't the worst hit. I call it the flash-to-bang. From the first event to the first relief there, you want to minimize the time in between." Researchers often try to deliver maps and data as soon after an earthquake as possible, but because many relief efforts evolve into long-term projects, new information can be helpful at any stage. New maps, for instance, may reveal damaged towns that were initially missed, but where relief is still badly needed. Thompson said, "Just because you don't have definitive information right after an earthquake doesn't mean it's not going to do you some good later."

Recovering from the October 2005 Kashmir earthquake will likely take several more years, putting Kashmir once again at a crossroads, this time between the old and the new. Governments are razing old concrete block buildings and replacing them with modern structures designed to better withstand earthquakes. Relief organizations are helping relocate residents of towns destroyed by the earthquake to newly erected town sites. And scientists and researchers continue to focus on Kashmir and other earthquake-prone areas, mapping ancient geological faults and identifying new ways to examine an earthquake's aftermath.

Avouac said, "By studying these ruptures, we can learn more about the characteristics of future earthquakes, like what kind of ground motion we can expect." Understanding how past earthquakes happened and how much damage they caused can help scientists estimate future seismic hazards and pinpoint areas with a high earthquake risk. They hope that this knowledge will eventually protect people living in areas with earthquakes.

To access this article online, please visit http://nasadaacs.eos.nasa.gov/articles/2008/2008_earthquakes.html.

References

Avouac, J. P., F. Ayoub, S. Leprince, O. Konca, and D. V. Helmberger. 2006. The 2005, M_W 7.6 Kashmir earthquake: Sub-pixel correlation of ASTER images and seismic waveform analysis. *Earth and Planetary Science Letters* 249: 514–528.

Parsons, T., R. S. Yeats, Y. Yagi, and A. Hussain. 2006. Static stress change from the 8 October, 2005 M = 7.6 Kashmir earthquake. *Geophysical Research Letters* 33, L06304, doi:10.1029/2005GL025429.

About the remote sensing data used

Satellite	Terra
Sensor	Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER)
Data set used	ASTER L1A Reconstructed Unprocessed Instrument Data
Resolution	15 meter (VNIR), 30 meter (SWIR), 90 meter (TIR)
Parameter	Land surface
Data center	NASA Land Processes DAAC

About the scientists

Jean-Philippe Avouac is the director of the Caltech Tectonics Observatory and a geologist and professor at the California Institute of Technology. He studies and models earthquakes and tectonics, focusing on the Himalaya region, China, Taiwan, and Sumatra. Avouac is currently developing new approaches to studying earthquakes by combining field observations, satellite imagery, and models. The National Science Foundation funded his research. (Photograph courtesy J.-P. Avouac)

Wiley C. Thompson is a lieutenant colonel in the United States Army and a professor of geography at West Point. He served in Afghanistan in 2005 and helped provide disaster relief after the 2005 Kashmir earthquake. The Department of Defense funded his 2005 earthquake relief work. (Photograph courtesy W. C. Thompson)

Robert S. Yeats is a geologist and professor emeritus at Oregon State University. He has studied earthquake hazards worldwide and has been working to understand active faults and earthquakes in Pakistan since 1978. Yeats was a member of the team that discovered the surface rupture accompanying the 2005 Kashmir earthquake. His research was funded by Earth Consultants International, an environmental consulting firm in which he is partner and senior consultant. (Photograph courtesy R. S. Yeats)

For more information

NASA Land Processes DAAC
http://lpdaac.usgs.gov

Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER)
http://asterweb.jpl.nasa.gov

Co-Registration of Optically Sensed Images and Correlation (COSI-Corr)
http://www.tectonics.caltech.edu/slip_history/spot_coseis/index.html

Jean-Philippe Avouac
http://www.gps.caltech.edu/~avouac

Wiley C. Thompson
http://www.dean.usma.edu/departments/geo/Faculty&Staff/bio-Thompson.htm

Robert S. Yeats
http://www.geo.oregonstate.edu/people/faculty/yeatsr.htm