L.A.'s netizens who checked out the ShakeMap quickly learned that the epicenter was waaay out in the Mojave Desert, under the Marine Corps training center at Twentynine Palms, so life could go on; as their adrenaline rushes subsided, thousands of them did something totally unprecedented—they reported their own experiences to a computerized seismologist.

Did You Feel It?

by Douglas L. Smith

The Hector Mine earthquake, epicentered in a desert-warfare training grounds, bounced tanks like peas on a snare drum, but did no damage. The tank tracks came in handy for measuring displacements (above), and potentially live ammo made mapping the fault trace more interesting (below).

At 2:46 in the morning on Saturday, October 16, the magnitude 7.1 Hector Mine earthquake rolled several hundred thousand Angelenos out of bed and straight to their PCs, making this what the *Los Angeles Times* has dubbed the world's first-ever cyberquake. They logged in to http://pasadena.wr.usgs.gov, where real-time seismology data were appearing as fast as the computers could spit them out. It was the biggest workout yet for TriNet, a collaborative effort of Caltech, the United States Geological Survey, and the California Division of Mines and Geology. This system of digital, computer-linked seismometers provides preliminary location and magnitude estimates within minutes—90 seconds for Hector. Within another few minutes (four, in this case), TriNet generates a large-format, printable map, naturally called a ShakeMap, of how strongly the ground shook all over Southern California. This information, which is primarily for the benefit of emergency personnel, is posted on the Web for all to see.

Strong shaking equals severe damage, and the epicentral area isn't necessarily where the jolt was worst. For example, downtown Santa Cruz got trashed in the 1989 Loma Prieta quake, but since that sleepy city lies over the mountains from the major media center of San Francisco, nobody but the Santa Cruzans knew it for several hours. The same fate befell Fillmore, and to some degree Santa Monica, in the Northridge quake. ShakeMap eliminates the guesswork in dispatching rescue and repair crews, and TriNet automatically fires copies off to computers at the state Office of Emergency Services, the Federal Emergency Management Agency, and some utilities. This list will soon be expanded to include the railroads, Caltrans, and the media.

Creating a ShakeMap is no small feat. A seismometer tells you the ground's acceleration and velocity, but not what a human at that location would have actually felt or what damage might have occurred. Software developed by a team led by David Wald (PhD '93), a research geophysicist in the USGS's Pasadena office and a visiting associate in geophysics at Caltech, converts the recorded ground motions into shaking intensity, a measurement people can relate to. Then, by applying a set of corrections for soil type and other local geologic factors specific to each widely scattered and irregularly spaced seismometer, the software extrapolates the data to a grid of 45,000 points spaced 2.8 kilometers apart. The same set of corrections are applied to these points, which are combined with the corrected readings from the real seismometers to produce the maps. TriNet and ShakeMap debuted with a handful of sensors on March 18, 1997, during a magnitude 5.4 Landers aftershock (see *E&S* 1997, No. 2). The system now includes 120 Caltech-USGS real-time broadband seismographic stations and nearly 200 Mines and Geology dial-up strong-motion sensors. When completed in 2002, it will include over 600 instruments.

L.A.'s netizens who checked out the ShakeMap quickly learned that the epicenter was waaay out in the Mojave Desert, on the Marine Corps training center at Twentynine Palms, so life could go on; as their adrenaline rushes subsided, thousands of them did something totally unprecedented—they reported their own experiences to a computerized seismologist. By clicking on a link called "Did You Feel It?" they reached the Community Internet Intensity (CII) site, an experiment in collecting human observations over the 'net. CII, the brainchild of Wald and Vincent Quitoriano (BS '99), now a graduate student in geophysics at Stanford, allows users to fill in an electronic questionnaire from a menu of standardized choices. Example: "Did pictures on the walls move or get knocked askew? __No. __Yes, but did not fall. __Yes, and some fell." Each choice has a point value, explains Wald, so that "when you submit the form, we compute, based on your responses alone, what your intensity was. We also calculate the average intensity for your ZIP code—maybe you were a little too nervous, or a little too blasé, compared to your neighbors. We display those two numbers, and then right away you see a color-coded map, by ZIP code, of all the accumulated responses." The map is updated every five minutes.

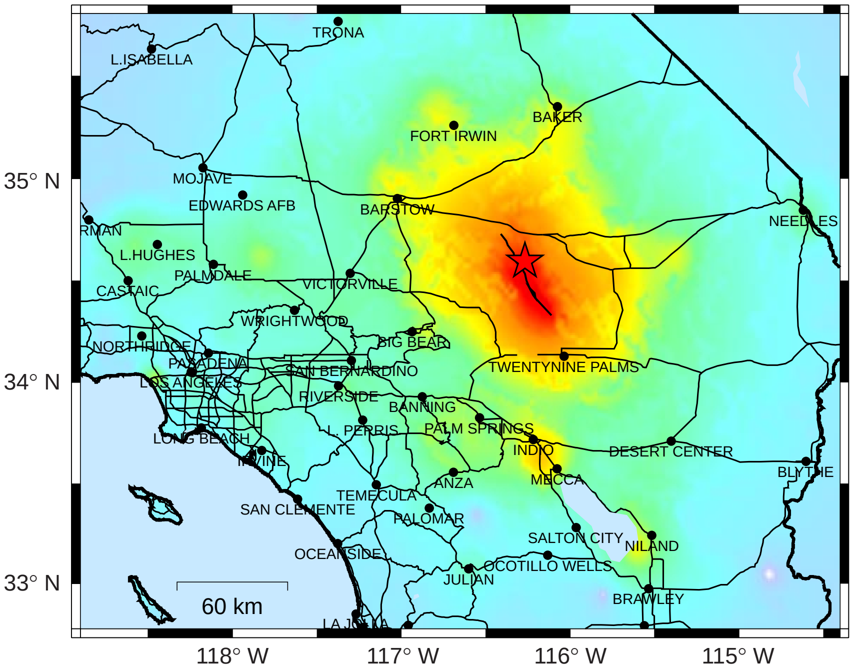
Like ShakeMap, the CII site is completely automated. If TriNet records an earthquake greater than magnitude 3.5, it triggers the CII site to create a Web page for that event, labeled with the time, epicenter, and magnitude. "If everything works perfectly," says Wald, "I don't have to deal with it at all. But if, for instance, the magnitude changes, I have to reflect that in the map. And once you see where the quake is, you might want to make the map bigger or smaller, or if it happened on the coast you might want to shift the map to show more land and less ocean."

Wald chose the ZIP code as the CII's geographic unit because "it's a simple, natural reference frame. People don't know their latitude and longitude, but everybody knows their ZIP code. And it's nonspecific enough that people don't mind giving it out, although we do ask for a street address as an optional piece of information, and typically they give it." (A future version will convert street addresses to latitude and longitude, but the process remains wobbly—it doesn't cope with sloppy typing very well.) ZIP codes, although a practical solution, are far from ideal. For one thing, a chunk of sparsely populated desert with a tiny hamlet down in one corner will be colored according to the responses of the townsfolk, even though the shaking out in the boonies where the aqueduct runs may have been quite different. And you need a minimum of five responses per ZIP code to get a nice, stable average. With fewer, each fresh contribution makes the average as skittish as a cat during an aftershock, and one hypersensitive person can really skew it. Furthermore, says Wald, "people caught on the road can't identify their ZIP code very well. And people who are at work tend to forget that they're at work, and they enter the wrong ZIP code. But it all gets washed out in the numbers if enough people respond. If we have 150 people in one ZIP code, like we have for Hector, a few radical deviations from the norm just don't show up."

These data contain a wealth of detail the ShakeMap misses. Says Wald, "I have a seismic instrument in my garage as part of the National Strong Motion Program. Now if we have an earthquake, and I call home, I'm not going to ask, 'What was the ground motion like?' I'm going to say, 'What happened to the house?' And that's exactly the difference between these two maps. However, if Lisa [his wife, who works for the USGS, too] were to go out to the garage and tell me that it was half a *g*, I'd have a pretty good idea that the place shook like crazy, it was scary, and that there was going to be some damage. But I wouldn't know whether the chimney fell or not… it probably should have." On the other hand, the ShakeMap, which doesn't depend on humans (nor their PCs, Internet service providers, and phone lines) in any way, is the much more reliable tool for directing the emergency response teams.

Detailed intensity maps have traditionally been drawn by combining data from field surveys, reports of damage from emergency agencies and the press, and a questionnaire mailed to the postmaster of each ZIP code in the affected area. The process takes months, and, says Wald, "you have to have one person looking at things, in order to be consistent. Jim Dewey, of the National Earthquake Information Center in Boulder, Colorado, is the one official government representative who does intensities for the whole country. He's been working with us, and he's been a lot of help in making our adaptation consistent with the original questionnaire." Intensity data, including ShakeMaps, are reported on the Modified Mercalli scale, which uses Roman numerals so as not to be confused (at least in print!) with magnitudes, and which runs from I (not felt, no damage) to X+ (very heavy damage). A Northridge-type earthquake will max out in the VIII–IX range.

Wald and Quitoriano's other collaborator is Lori Dengler at Humboldt State University. "She realized, after doing a phone survey of several thousand people after Northridge, that it would be easier to assign numerical values to answers than to try to interpret them subjectively," says Wald. "I read about that, and thought it would be a really good thing to apply to the Internet, and it evolved naturally from there." The collaboration launched the CII in 1988 with a questionnaire for the Northridge quake. Explains Wald, "I put up Northridge, because I figured everyone would remember it. If you were in an area that shook hard, it's a life-changing experience. And even though the fish may get bigger every time you



PERCEIVED SHAKING	Not felt	Weak	Light	Moderate	Strong	Very strong	Severe	Violent	Extreme
POTENTIAL DAMAGE	none	none	none	Very light	Light	Moderate	Moderate/Heavy	Heavy	Very Heavy
PEAK ACC.(%g)	***<.17***	***.17-1.4***	***1.4-3.9***	***3.9-9.2***	***9.2-18***	18-34	34-65	65-124	>124
PEAK VEL.(cm/s)	<0.1	0.1-1.1	1.1-3.4	3.4-8.1	8.1-16	***16-31***	***31-60***	***60-116***	***>116***
INSTRUMENTAL INTENSITY	**I**	**II-III**	**IV**	**V**	**VI**	**VII**	**VIII**	**IX**	**X+**

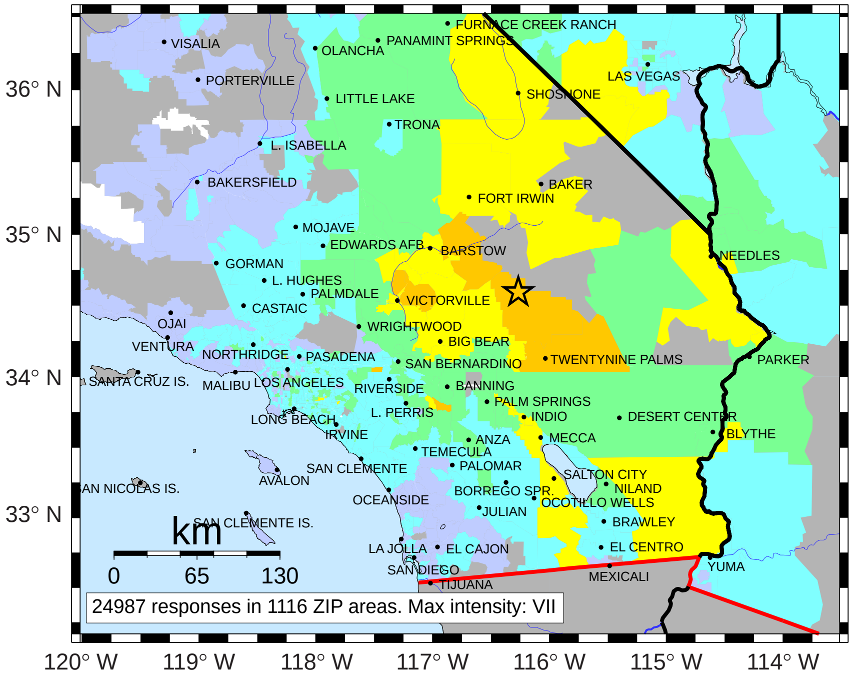
Above: TriNet's ShakeMap for the Hector Mine earthquake. The open star marks the epicenter, which ruptured segments of the Bullion and Lavic Lake faults, shown as the black diagonal line under the star. The other lines are major roads. The circles are sesismic stations. Intensities are mapped using the Modified Mercalli scale (described in the box on the opposite page). The computer uses peak accelerations, to which people are sensitive, to calculate intensities I–VI, which are keyed to human perceptions. Intensities VII and above reflect structural damage, which is related to peak velocity.

tell the story, our questions are very specific: Did your chimney come down or not? So the answers remain pretty accurate, and thus the solution is fairly robust." They garnered about 800 responses—enough to do a statistically meaningful calibration against the USGS's traditionally acquired Mercalli maps and to publish a brace of papers. "Northridge gave us a numerical connection between what people respond to and the official Modified Mercalli intensity. And once you can do that, it's automated. You don't have to interpret people's responses. That's a major step forward. A couple of other places have put questionnaires on line, but they don't do anything with the answers. Somebody might look at them at some point, but it's not automated, so it's a big chore." Dengler, Wald adds, "had a lot of good advice on how to ask the questions, because there are subtleties involved. For instance, there's a big difference between solicited and unsolicited responses. If you ask people what they felt, on average you get a different answer than if they volunteer the information." Volunteers are usually a bit more, shall we say, enthusiastic about their subject, and their intensities tend to be a bit higher. "It turns out that this bias is fairly systematic, so we can correct for it, but you have be aware that it's there."

The site, which had not been advertised and had very few links to it, nonetheless got 25,000 responses after Hector—8,000 in the first eight hours!—and has developed a faithful following. "A couple of weeks ago, we had a 3.9 in Orange County, and there were over 1,600 responses. That's not a big earthquake. We even get people who respond when they didn't feel an earthquake. Now, *that's* dedication—to have regulars who hear about an earthquake on the news, and come in and say, 'I didn't feel it,' means they feel that they can contribute to science. And that's what we want. We'd like to be able to define where it wasn't felt, as well."

The CII home page has a running index of all the quakes that have questionnaires, and visitors are encouraged to fill out as many as they can. It worked—when people did Hector, some took a whack at Northridge too, doubling the number of forms previously submitted. Now Wald is reaching back even farther, he says. "Somebody asked me, 'I was here in 1971—why don't you put Sylmar on?' So I did. Then somebody else said, 'What about Kern County in 1952?' So I added that one, and I just got a request to put Long Beach on. That was 1933! Now, I'm not putting 1906 on there, but *Long Beach?!* But I figure this is something for the people by the people, and if they want Long Beach, I'll put it up and see what comes in."

The questionnaire ends with a catchall box for additional comments, which has become a gold mine of first-person tales—people seem to find telling their stories very therapeutic. The Northridge compendium, says Wald, "is a huge data set for people involved in emergency response, in terms of how people react psychologically to disasters. We've already had requests for that data. I'm not an expert in sociology, so it's hard for me to gauge what its value is, but other people have told me what an amazing data set it is." And describing what you were doing when a big quake hits provides a pretty good snapshot of what we, as a population, are up to. "At any given time, in Southern California, somebody is doing every



Right: The Community Internet Intensity map for Hector. In a Java-equipped Web browser, moving the cursor across the map reveals the ZIP code, number of responses, and average intensity for the point beneath the cursor. Gray areas are ZIP codes from which no responses have been received. Although clarity considerations prevent each individual ZIP code from being outlined as on the Web version, and thus ZIP codes of the same intensity run together, the size disparity between ZIP codes in urban L.A. and out in the desert is still apparent.

INTENSITY	I	II-III	IV	V	VI	VII	VIII	IX	X+
SHAKING	Not felt	Weak	Light	Moderate	Strong	Very strong	Severe	Violent	Extreme
DAMAGE	none	none	none	Very light	Light	Moderate	Moderate/Heavy	Heavy	Very Heavy

possible thing you can conceive of. I'd love to put together a Top Ten for Hector. There was a police officer on top of a six-foot cinder-block wall with a flashlight, trying to trap a burglar. He was directing other units toward the burglar, and then the earthquake hit, and he got knocked off the wall. Landed on the ground, collected his thoughts, looked up, and tried to get the operation back in gear, and the end of his form says, 'Thief got away due to divine intervention.'"

About one percent of the respondents follow up with an e-mailed question or comment. The latter range from rehashing their story to reporting an error (usually in the ZIP code they gave) to suggesting improvements to the graphic interface. "We've actually had people send HTML code," Wald says in amazement. "There's a huge resource of technical expertise out there, and some of it is very impressive. I get occasional screwballs, but that's the Internet."

The collaboration's next step is for Dewey to map Hector's intensity the old-fashioned way and compare the results to the CII map. Some tweaking of the formulas used to calculate the intensities will probably result, and it may take a few more decent-sized data sets (i.e., widely felt earthquakes) to get things just perfect—an advantage to developing the system in Southern California, where earthquakes are an inexhaustible natural resource.

But it's already clear that the CII maps match ShakeMaps remarkably well. Shaking normally dies off with distance, for example, but a basin filled with soft soil or alluvium will amplify seismic waves and cause people there to feel a tremor more strongly than people on bedrock closer to the source. "After a magnitude 5 near the San Andreas fault, we got observations from people who happened to be near one of our instruments near San Bernardino. The instrument validated their report of a higher intensity than people closer to the epicenter. This implies that

The Modified Mercalli Scale

I. No one feels it. Doors may swing slowly.

II. A few people indoors, especially on the upper floors, notice it.

III. Many people indoors feel a vibration like that of a light truck passing. Hanging objects may sway slightly.

IV. Most people indoors feel a vibration like a passing heavy truck, or a jolt like a heavy ball hitting the wall. Hanging objects swing. Dishes, windows, and doors rattle. A few people outdoors feel it. Parked cars rock.

V. Almost everyone feels it. Sleepers awakened. Doors swing open or closed. Some dishes break. Pictures on walls move. Small objects move or fall over. Trees and bushes may shake.

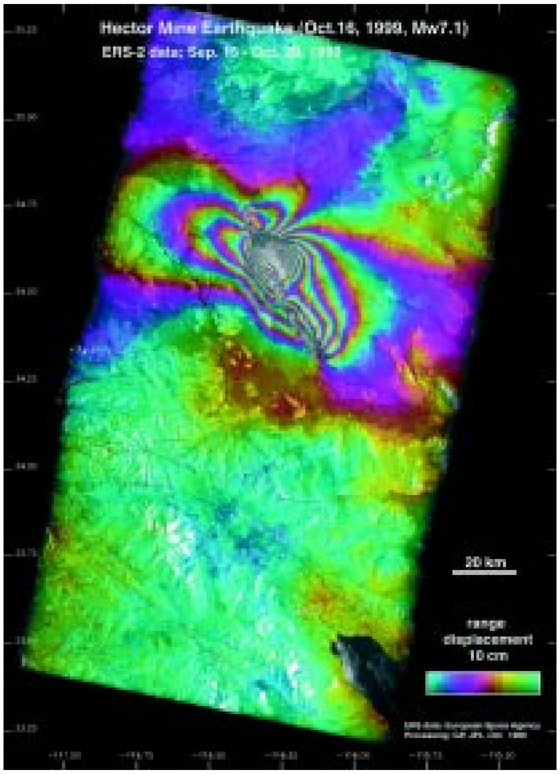
VI. Everyone feels it. It's hard to walk. Objects fall from shelves; pictures from walls. Furniture moves. Plaster walls may crack. Trees shake, small church bells ring. Slight damage to poorly built buildings.

VII. It's hard to stand. Drivers feel their cars shaking. Some furniture breaks. Loose bricks fall from buildings. Large bells ring. Negligable damage to buildings designed for quake resistance; slight to moderate damage to ordinary well-built buildings; considerable to poorly built ones.

VIII. It's hard to steer. Houses not bolted to their foundations may shift on them. Some chimneys, water towers, other tall structures fall. Quake-resistant buildings slightly damaged; ordinary buildings considerably, with partial collapse; poorly built ones severely. Wet ground and steep slopes crack open. Tree branches break. Well water levels, temperatures change.

IX. Quake-resistant buildings considerably damaged. Unbolted houses move off their foundations. Some underground pipes break. The ground cracks. Reservoirs seriously damaged.

X+. Most buildings and their foundations destroyed. Dams seriously damaged. Large landslides occur. Water thrown onto the banks of canals, rivers, lakes. Paving cracks or buckles. Railroad tracks bend.



Another map available on the Web site is this interferometric one, made from radar data taken by the European Space Agency ERS-2 satellite on September 15 and October 20, 1999 and processed by Frédéric Crampé, Gilles Peltzer, and Paul Rosen of Caltech's Jet Propulsion Lab, and Assistant Professor of Geophysics Mark Simons of Caltech. Ground displacements that occurred along the radar's line of sight between the "before" and "after" scans show up as colored bands. One full color cycle represents 10 centimeters of displacement. Dotted lines are previously mapped faults, and the thick, solid lines mark the Landers (1992) surface rupture. The thin, solid lines within the zone of dense fringes are surface breaks inferred from the radar data.

PICTURE CREDITS: 34 — Aron Meltzner; 36, 37 — Dave Wald; 38 — Sally McGill

we can sample our data very densely to map out these variations in detail. We'd have to go beyond the ZIP code boundaries, but we archive all the questionnaires, so as soon as we have the time to figure out how to do that efficiently, we will."

The USGS has been impressed enough to give Wald the okay to go nationwide. "I might live to regret this, but we've decided to run everything from here. Otherwise, every time we changed the software, we'd have to redistribute it to every regional seismic network in the country. I don't have the ZIP codes for Guam—they're hard to get—but I have the ZIP codes for Puerto Rico and every other American territory. I'm the only person doing the community map right now, so I have a pager, and every time there's an earthquake anywhere in the U.S. I know about it. It's a lot to keep up with, but I've got work-study money, and I'm hoping to find an undergrad to help part time." The National Earthquake Information Center in Colorado, whose pager it is, collects information from digital seismometers scattered across the country—around the world, actually—and automatically triggers Wald's computer in Pasadena to generate the maps. The Northern California, Nevada, and New England regional networks are interested in taking a more active role, so as the system gets more sophisticated, the plan is to have the CII interface carry the logo of the appropriate network, which will then create local links to it. Then, when the next earthquake hits that area, the local net can unveil the site to the public through the Web and the media. The northern California site is already pretty well

Among the geologists doing the field mapping was Caltech senior Aron Meltzner, who checks out a fissure with Jill Dahlman, a student at Cal State San Bernardino. Here the ground moved up and down as well as sideways.

developed—the list of automatically generated questionnaires begins on August 17, 1999, and the "historical" list reaches back to the Parkfield earthquake of 1966. At the moment, the entire rest of the country is lumped in a third site, which at this writing contains three Alaskan earthquakes and nothing else. Sometimes you have to wait for nature to take its course…

The Canadian and Mexican governments are also interested, which may be a foreshock, as it were. The e-questionnaire, appropriately translated and modified to reflect local building practices (the nature of the damage in, say, Guatemala would be quite different than it is here) could eventually find use around the globe. The jungle isn't wired yet, but there are more laptops with satellite links or wireless modems out there than you might think, and any town with telephone lines is bound to have at least one computer.

The rest of the country is years behind TriNet, and the low-risk areas may never catch up. But no part of the nation is immune to the earth's occasional hiccup, and it seems that everybody and their dog has Internet access these days. So the CII offers a way of getting good observations without an elaborate and expensive digital seismic network. But unlike the ShakeMap, the CII is not a disaster tool. For one thing, when your house has collapsed in flaming ruins around you, even the hardest-bitten Internet junkie will be out in the middle of the street in his jammies, just like everyone else. And less catastrophic quakes bring power failures, downed phone lines, and busy signals. So the CII information will eventually come in, and much faster than it would through the post office, but it won't be as timely as the ShakeMap. Meanwhile, the USGS, in a report to Congress on the state of the nation's seismic networks, is touting TriNet and ShakeMap as a model for what should be done across the rest of the nation. □