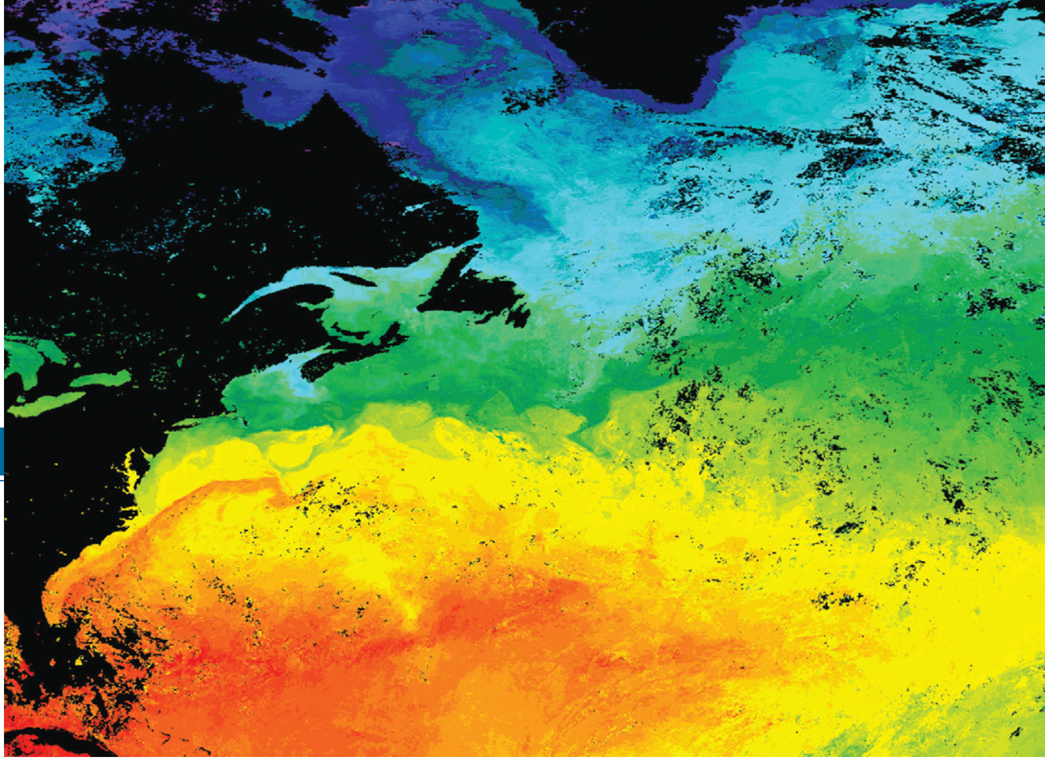


RANDOM WALK

WARM WATERS, COLD WINTERS

If you're sitting on a bench in New York City's Central Park in winter, you're probably freezing. After all, Manhattan's average January temperature is 0°C. But if you were just across the pond in Porto, Portugal, which shares New York's latitude, you'd be much warmer—the average temperature there is a balmy 9°C.

Throughout northern Europe, average winter temperatures are around 10°C warmer than at similar latitudes on the northeastern coast of the United States and the eastern coast of Canada. The same phenomenon happens over the Pacific, where winters on the northeastern coast of Asia are colder than winters in the Pacific Northwest.

Caltech researchers have now discovered an explanation for these chillier winters. The culprit? Warm water. "Warm ocean waters off a continent's eastern coast actually make it colder in the winter—it's counterintuitive," says Tapio Schneider, the Gilloon Professor of Environmental Science and Engineering. Schneider and postdoc Yohai Kaspi described their work in a paper published in the March 31 issue of the journal *Nature*.

In the Northern Hemisphere, subtropical ocean currents circulate in a clockwise direction, bringing an influx of warm water northward from the low latitudes. In the Atlantic, the Gulf Stream originates off the Florida coast and moves north along the Eastern Seaboard before turning eastward near the coast of North Carolina and heading out into the ocean.

For decades, the conventional wisdom has been that the Gulf Stream heats northern Europe by delivering warm water from the Gulf of Mexico. But in 2002, research showed that the Gulf Stream doesn't transport enough heat to be directly responsible, contributing to perhaps 10 percent of the temperature contrast between the continents.

Now Kaspi and Schneider have found that the temperature difference isn't because the Gulf Stream warms Europe, but because the Gulf Stream *cools* the eastern United States. Their computer simulations of the atmosphere show that the warm water heating the air above it leads to the formation of Rossby waves—atmospheric undulations that stretch for more than 1,000 miles. These Rossby waves are stationary—their peaks and valleys don't move, but they still transfer energy, drawing cold air down from the northern polar region to form a plume just to the west of the warm water. In our case, this dumps the frigid air right over the northeastern United States and eastern Canada.

The researchers then sped up Earth's rotation to see how this affected the dynamics. When they did, the plume of cold air got bigger—consistent with it being from a stationary Rossby wave. Most other atmospheric features would get smaller if the planet were to spin faster.

Although it's long been known that a heat source could produce Rossby waves, which can then form plumes, this is the first time anyone has shown that this can affect continental temperatures. The researchers say the cooling effect could account for 30 to 50 percent of the temperature difference across oceans.

This process also explains why the cold region is equally big in North America and Asia, despite the two continents being so different in topography and size. The Rossby wave–induced cooling depends on heating air over warm ocean water. Since the warm currents along both the Pacific and the Atlantic's western boundaries are similar, the resulting cold regions farther west would be similar as well.

The next step, Schneider says, is to build simulations that more realistically reflect what happens on Earth by incorporating such complexities as continents and clouds. —*MW* E&S

This map shows sea-surface temperatures averaged over eight days in September 2001, as measured by NASA's Terra satellite. Dark red represents warm water (32°C) and purple is cold (–2°C). The Gulf Stream can be seen as the orange strip extending from the eastern U.S. toward the Atlantic.

PICTURE CREDITS
2 — Ronald Vogel, SAIC for NASA GSFC; 3 — Genping "Roots" Liu; 4, 10 — Lance Hayashida; 5 — Charles Decker; 7 — Katie Neith; 9, 11 — Jenny Somerville

WALL OF SOUND

Over 50 members of the Caltech Jazz Bands and the Caltech-Occidental Concert Band brought the sound of music to the Great Wall of China in March. Positioned in front of a fort on a portion of the wall near Beijing, the group played a concert featuring two new pieces written specifically for the occasion. One of the world premieres was written by Caltech alumnus Leslie Deutsch (BS '76, MS '77, PhD '80), chief technologist for the Interplanetary Network Directorate at JPL; the other was written by his son, Elliot, a jazz bandleader, composer, and trumpeter. The featured vocal soloist, Kjerstin Williams (BS '00, MS '02, PhD '06), lent her voice to the jazz tunes. The group also joined fellow musicians from Tsinghua University for a joint concert in Beijing. —*KN* E&S

"Playing on and climbing the Great Wall was definitely a highlight of the trip. It will be something that I will be able to talk about for decades after I graduate from Caltech, since it will always stand out from the everyday life of a Techer," said freshman clarinetist Hima Hassenruck-Gudipati.

'MID THESE DANCING ROCKS

The following real-world paradox comes to you courtesy of Assistant Professor of Geology Michael Lamb: "Say you're out hiking, and you come to a roaring stream plunging down the side of a mountain. It's full of rocks and boulders, all precariously balanced. You come back the next year, and you find that those same rocks are still there, just where they were. In fact, year after year you come back, and they never seem to move. Why is this?"

Don't know the answer? Neither does Lamb, and he's been thinking about it for a long time. Loose rocks on the bottom of lazy, low-sloping rivers migrate slowly downstream under nature's inexorable nudging. But in very steep channels, where it would seem that the collaboration between water and gravity should produce much more dramatic results, much of the stuff on the bottom stays put. And no one knows why.

A huge flume recently installed on the Caltech campus just might provide some answers. A flume is an artificial river—in this case, a tilted rectangular chute down which water cascades. Explains Lamb, "We can load our flume with various sediments, including fair-sized rocks, tilt it at any angle up to 15 degrees, and change the rate of flow of the water. That gives us a way to simulate all kinds of rivers."

Rocks, water, slope—surely there must be more to simulating a river than that? "Surprisingly, that's complicated enough," shrugs Lamb. "Water, on its own, we understand fairly well. We know the equations that describe how it flows in a smooth channel. But as soon as we start introducing sediment, the coupling between moving sediment, immobile sediment, and water becomes quite a complicated problem. We don't even know the equations to describe it."

The flume hulks in one corner of the Central Engineering Services building's machine shop, filling virtually every cubic inch of available space. It features a main section more than 15 meters long and, bone-dry, it weighs

15 tons—simply dwarfing most of the other laboratory flumes in the world capable of such steep slopes. Lamb didn't design it this way from a bigger-is-better mentality, but because he's interested in complexities that can't be modeled on smaller scales. "Imagine a steep mountain stream where the boulders have organized themselves into steps," he explains. "There's a boulder that makes a little waterfall, with a pool at the bottom, and below that there's another boulder making another waterfall with another pool, and so on. In order to understand how the sediment organizes itself into these structures, and how the structures then feed back into the system, we'd need to create three or four step-and-pool sequences in a row. You can't do that in a small flume."

A remotely controlled cart trundles back and forth atop the length of the flume, bearing high-precision instruments that map both the surface and the bottom of the artificial river with submillimeter accuracy. Water overflows into the flume's upstream end from the headbox, which is constantly refilled at whatever rate is needed in order to simulate anything from a trickling creek to a roaring cascade. The headbox is replenished from the tailbox at the flume's downstream end by a pair of pumps. "The larger one is the size of a Volkswagen," Lamb points out. "It can move 8,000 gallons of water a minute."

"Typical flume research," Lamb continues, "uses sand or even finer sediments, which can be pumped right through the pipes along with the water. But we're looking at the much coarser objects found in mountain channels." Rocks the size of softballs or soccer balls don't normally mix well with high-speed pumps, so a system of external conveyors collects the accumulation in the tailbox and returns it back to the head.

Lamb's plans range from studying issues of local concern, such as how debris rumbles down a denuded mountainside after a wildfire, to the global connection between erosion and climate change. "When you weather silicate rocks into clays, you're sucking carbon dioxide out of the atmosphere. But once the rock is covered by a layer of clay, the weathering process shuts down unless you physically transport that material away and expose fresh bedrock to more weathering. So the highest chemical weathering rates are tied to the highest erosion rates. In the Himalayas, for example, where rocks are uplifting rapidly and the rivers are eroding rapidly, weathering may be drawing enough CO_2 out of the atmosphere to affect global climate. But if I stood in front of a mountain river with the most knowledgeable people in the world, and asked them to tell me how fast that river was cutting, or how much sediment would come out of it in a year, they wouldn't be able to tell me within a factor of ten. We just don't have the observations yet to know how these systems work.

"A lot of research has been done on low-sloping, big channels: how to engineer them, how to dam them, and so forth. That makes sense, because we live in a world full of cities built on rivers. But small, steep mountain channels play a critical role in shaping our terrain and climate over long timescales, and we know very, very little about them." *—DZ* e&s

A look into the empty flume. The flume can be tilted as much as 15 degrees, allowing water and sediments—such as rocks, pebbles, and dirt—to flow down and simulate everything from a creek to a cascade.

Laura Decker scores a hit on the Air Force Academy's Heather Nelson at the NCAA saber finals in March.

ON THE FENCE

Life is about making choices, but this one's a doozy: Laura Decker, a senior who recently changed course from chemistry to medieval history, is on the threshold of an even bigger decision—grad school or the Olympics? Yes, *those* Olympics: trying out for the U.S. fencing team for the 2016 summer games in Rio de Janeiro.

Decker has dreamed of being a scientist since the seventh grade, she says. Her plan was to get a PhD and go into research, and she got off to a flying start at Caltech—by the summer of her sophomore year she was immersed in synthetic organic chemistry as a SURF (Summer Undergraduate Research Fellowships) student in the lab of Nobel Prize–winner Robert Grubbs.

Meanwhile, she'd also signed up for fencing to fulfill her phys ed requirement. Although she'd never wielded a blade, she'd studied martial arts in high school, and before the first class ended, she found herself on the Caltech varsity squad. "My high school was probably the only one in the entire state of New Jersey that didn't have a fencing team," she says. "But that's the great thing about Caltech athletics—no experience required. If you show up and you work hard, you're on the team." Of course, natural aptitude helps. Decker got serious about saber in May of her sophomore year, and as a junior she qualified for the NCAA finals, competing in the 2010 national championships at Harvard. (Only 42 colleges nationwide have fencing teams; since it's an individual sport, there are no divisions as there are for sports like basketball.)

"I traveled a lot, fencing on the national circuit, and met a lot of people," Decker recalls. "By the end of January in my junior year, I realized that I couldn't see myself being stuck in a lab for the rest of my life." She opted for history that spring and, with the collegiate season over, competed in United States Fencing Association (USFA) tournaments, where she earned points toward qualifying for the Olympics.

But earning match points and making the team are two very different things. Training to be an Olympian isn't something you can do between problem sets, nor is it something you can do in Braun gym, as good as Caltech coach Michael D'Asaro is. Says Decker, "If I wanted to train seriously, I would need to decide to do so before entering a PhD program, as fencers tend to physically peak in their mid-twenties." But with no experience training full-time for a sport, she wondered if it was worthwhile putting academia on hold to pursue something this far-fetched. Meanwhile, applications for graduate school were coming due; if the athletic regimen proved too much after a few months, she'd have lost a full year of academics.

Fortunately, there's a grant for that: Once a year the Caltech Y hands out the Paul Studenski Memorial Award, a travel grant for up to $4,000 intended for a student at a crossroads in life who, in the words of the endowment letter, "would benefit from a period of time away from the academic community in order to obtain a better understanding of himself and his future." When Jeanette Studenski wrote that in the fall of 1974, female undergrads were just starting to appear on campus; the Studenskis' son, Paul (BS, MS '72), had been killed in an automobile accident that summer while driving to Cornell to begin graduate school, after having taken a year off to clear his head while seeing the country.

Decker was trying to figure out what to do when she "got one of those emails that goes out to everybody. I don't read them very often, but this one looked like one I might be interested in." The email invited potential Studenski applicants to an information session and dinner at Caltech Y board member Tom Mannion's house. Says Decker, "I felt like I was at a crossroads, but I wasn't sure that this was the sort of crossroads the committee was looking for. A lot of the awards in the past have been for more humanitarian kinds of things." However, her dinner companions convinced her to apply, and as you may have guessed, she is this year's winner. Says Caltech

Y board member Deborah Smith, who sat at Decker's table, "If Laura's situation wasn't a crossroads, I don't know what is."

Will fencing triumph over (or even delay) academia? It's anybody's guess. This past March at the NCAA finals at Ohio State, Decker beat Caitlin Taylor of Brown (5-4), a member of the Australian national team. That was the good news. The bad news is she lost 5-4 to Dagmara Wozniak of St. John's, who is ranked second in the United States and 18th in the world, and who brought home the bronze from Beijing as part of the 2008 Olympic team. Decker also lost 5-0 to Monica Aksamit of Penn State, ranked sixth in the country—but in January Decker had defeated Aksamit 5-2 at an Olympic-qualifying USFA event. NCAA tournaments use a round-robin format, with the top four fencers going on to the direct-elimination finals; Decker did not make the cut. "Last year was my first major tournament, and I was completely freaked out," she says. "This year I was more competitive in all my bouts."

And if the saber proves mightier than the pen, there's still one last crossroads Decker will have to face. A dual citizen of the U.S. and the U.K., she notes: "I could make the British national team, but they're not as strong as the U.S. team. To make the U.S. team, I'll really have to work." *—DS* E&S

HOUSE OF THE POWERING SUN

The house of tomorrow won't just be green—it'll be smart. At least that's how students at Caltech and the Southern California Institute of Architecture (SCI-Arc) envision it. For over a year, the joint SCI-Arc/Caltech team has been designing and building its vision: a state-of-the-art, energy-efficient house for the Solar Decathlon.

Sponsored by the Department of Energy, the biennial competition challenges 20 teams from around the world to create the most energy-efficient, affordable, and attractive house possible. The teams will be judged on 10 "events," in each of which the house has to perform certain tasks, such as heating 15 gallons of water in less than 10 minutes. The houses also have to cost less than $350,000 for the consumer. The competition will take place from September 23 to October 2 on the National Mall in Washington, D.C., providing a high-profile venue intended to inspire policymakers, industry leaders, and the public to pursue a sustainable future.

Designed for use in the urban landscape of Southern California, the SCI-Arc/Caltech house is full of energy-saving features. The exterior is covered with a soft, insulating "skin" of white architectural vinyl, making the building somewhat resemble a giant pillow. The house is entirely powered by solar panels, and plentiful windows make artificial lighting during the day unnecessary. Waste heat produced by the air-conditioning unit generates hot water and provides warmth at night. "This is a simple idea that makes a lot of sense, but hasn't yet been done in a residential setting," says Richard Wang, a senior majoring in mechanical engineering who is spearheading Caltech's side of the project. The key aspect that sets this house apart from other Decathlon entries, he says, is that the team based every design choice on rigorous theoretical and computer models of how a house works. The team is installing and testing its designs this summer.

The next challenge will be transporting the entire house to Washington, D.C. The house consists of four modules that will sit on flatbed trailers and be pulled by trucks across the country. When everything arrives on the Mall just before the competition, cranes will piece the modules together like a jigsaw puzzle. One of only two houses in the competition with two stories, the SCI-Arc/Caltech design boasts a spacious interior, despite an area of only 800 square feet. (Contest rules limit the area to between 600 and 1,000 square feet.) The four modules' open interiors become a single, roomy structure, providing comfort that turns a house into a home, says Fei Yang, also a senior majoring in mechanical engineering and another student leader. In many of the other designs, he says, the modules remain separate, looking like trailers. "I don't care how pretty your trailer is," he remarks. "It's still a trailer."

The house's brains are an off-the-shelf computer called Control4, which controls everything from appliances to heating. The computer keeps track

The full-sized mock-up of the SCI-Arc/Caltech Solar Decathlon house is partially covered in a soft, insulated "skin" of architectural vinyl.

of the house's energy balance, making the necessary adjustments to ensure net-zero energy use—that the house consumes no more power than it produces—over the course of the competition. Future residents can set the washer to have their laundry done by Sunday, and the machine will turn on when it's efficient and cheap to do so—at night after a sunny Saturday afternoon, for example. They can even use their iPad as a remote.

They will always be able to override the computer, so there's no worry of the house becoming self-aware and turning into HAL, the homicidal machine from *2001: A Space Odyssey*. "Our house is not meant to control your life, but to help you live your life," says Yang. All the fancy technology in the world won't make a greener globe unless people change how they live, he says.

Because people living in the SCI-Arc/Caltech house will be able to monitor their energy efficiency in real time, they can adjust their behavior accordingly—a phenomenon sometimes known as the Prius effect, in which drivers of the hybrid car alter their driving styles to improve mileage. The team is trying to maximize this effect by considering such notions as installing "mood lights" that change color depending on energy consumption.

The team is also working on lights that can be dimmed or switched on and off with just simple gestures. But despite the high-tech wizardry, the house of a greener future is closer to realization than you think, Wang says. "The Solar Decathlon—and our house in particular—is standing proof that affordable, beautiful net-zero houses are already here." —*MW* e&s

E/Q PHONE HOME

Pity the poor news anchor in the immediate aftermath of an earthquake. While he's waiting on the feed from the Caltech Seismo Lab, there's precious little for him to do, apart from restating the obvious ("If you've just joined us, there was an earthquake moments ago"), offering unassailable prognostications ("Aftershocks are certainly a possibility"), and taking breathless phone calls from chatty viewers ("Nah, this one was definitely stronger than Northridge, because this time *both* my cats freaked out").

The banalities and generalities will no doubt be with us forever. But that thoroughly unscientific community survey may soon change into something much more useful.

What if there were inexpensive, pocket-sized gizmos that could sense the shaking and zap that info to Seismo while the ground was still rolling? What if you could deploy a million such devices throughout Los Angeles, forming an incredibly dense sensor network?

Oh, wait—this gizmo already exists. It's your cell phone. There's an accelerometer built right into it; add a bit of software, and you've got a portable seismometer. Instead of a grainy image of a major earthquake collected from widely scattered recording stations, seismo-smart phones could give first responders a high-definition, block-by-block (or even floor-by-floor) picture of how buildings and soil are moving.

So says Ramo Professor and Professor of Computer Science K. Mani Chandy. He's helping develop the Community Seismic Network (CSN), a proposed city-scale system that would link low-cost sensors with a cloud-computing network. The CSN's detailed maps would allow emergency crews to be dispatched *where* they're most needed *when* they're most needed immediately after the quake. Says Rob Clayton, professor of geophysics, "In a quake, one building may be destroyed while the building standing next to it is not damaged at all. We saw examples of this in the Mexico City quake. The CSN enables the community to build a highly detailed shake map collaboratively, giving first responders much more accurate information." Clayton is the principal investigator on a grant from the Gordon and Betty Moore Foundation to deploy a prototype network of some 1,500 sensors throughout Pasadena.

In between earthquakes, the CSN has other uses. Tom Heaton (PhD '78), professor of engineering seismology and another PI, proposes to put dense sensor networks into high-rise buildings, with many sensors on each floor. "Being able to monitor a building's behavior over long periods of time will help civil engineers better understand its dynamics," he says. "Add to that a dense network of ground sensors, and seismologists and civil engineers can work together on unraveling the interaction between ground soil mechanics and building mechanics."

"It's a nontraditional way of doing seismology and civil engineering," acknowledges Monica Kohler (PhD '95), a senior research fellow in mechanical and civil engineering. Earlier this year, she and a group of students did a preliminary test in the nine-story Millikan Library, the tallest building on campus. The students distributed a dozen smart phones throughout the building and on the roof. A Caltech staffer videoing the event for posterity contributed a Caltech beaver-mascot bobblehead and a cup of water to the rooftop sensor array, and then the shaking machine, an off-axis rotary contraption that has long been a staple of Caltech's earthquake engineering studies, was loaded with weights and set spinning. Small ripples immediately appeared in the water.

Graduate student Ming Hei Cheng (MS '09) explains: "Although there's only about 500 pounds of weight in the shaker, the rotation makes it act as if it were 5,000 pounds. And here on the roof is where we'll feel the maximum acceleration and the maximum displacement." In fact, the entire nine-story building was moving as much as a couple of inches from side to side—easy enough for the sensors to detect. (The bobblehead remained motionless.)

The CSN is an integral part of a year-long course on distributed systems being cotaught by Chandy and Julian Bunn, a lecturer in computing and applied mathematics, along

Monica Kohler (in the yellow shirt) supervises the deployment of smart phones on the roof of Millikan Library. Also in the photo: grad student Shiyan Song (MS '09).

with grad students Michael Olson and Matthew Faulkner. Besides the Moore Foundation, the project is being supported by the National Science Foundation's Cyber-Physical Systems Initiative, and by Google, which donated 20 Android phones. The other CSN team members include project manager Richard Guy, computational scientist Leif Strand, grad student Annie Liu (MS '10), undergrads Rishi Chandy and Jonathan Krause, and Andreas Krause, assistant professor of computer science and the third PI. Says Chandy, "The project is typical of Caltech's multidisciplinary approach to research, with undergraduates, PhD students, staff, and faculty from different areas collaborating to solve real problems that impact humanity."

But the CSN won't rely solely on smart phones. The experiment on the Millikan rooftop also tested several freestanding miniature sensors, each the size of a half-dollar, that can be plugged into a desktop computer. Arming a PC with one of these devices, at a cost of about $100 each, makes it possible to record several months' worth of motion data. "Everybody's got a computer," remarks Kohler. "So we could distribute hundreds of thousands of these. And in ten years, everybody will have a smart phone."

So right after that next big temblor, when a new crack has appeared in your driveway and you've just got to tell everyone, don't be in such a hurry to grab that cell phone. It may have already beaten you to it. —*DZ* E&S

EARTHSHAKING NEWS

In the wake of the magnitude 9.0 Tohoku earthquake off the northeastern coast of Japan, reporters sought the expertise of Caltech's seismologists. Representatives from approximately 50 different media outlets—television, radio, newspapers, and online publications—descended on the Seismo Lab, where Caltech and U.S. Geological Survey (USGS) staff were on call for around-the-clock interviews. (The Pasadena USGS office is, not coincidentally, just across Wilson Avenue from the Seismo Lab.) In the weeks following the disaster, Caltech experts were a consistent source of reliable data and judicious opinions. Jean-Philippe Avouac, professor of geology and director of the Tectonics Observatory, disseminated the latest data from the quake; Hiroo Kanamori, the Smits Professor of Geophysics, Emeritus, who had been in Tokyo at the time, offered firsthand accounts of his experiences; and Mark Simons, professor of geophysics, penned an op-ed for the *Wall Street Journal* on the importance of federal funding for advanced early-warning and response technologies. Caltech faculty and staff were quoted in over 250 articles and broadcast reports. —*KN* E&S

Above: At a press conference held on March 11, just over 12 hours after the quake and resulting tsunami, USGS and Caltech seismologists fielded questions from a throng of reporters. From left: Ken Hudnut, a USGS visiting associate in geophysics; Tom Heaton (PhD '78), professor of engineering seismology; Lucy Jones, also a USGS visiting associate in geophysics; and seismologist Kate Hutton, a member of the professional staff.

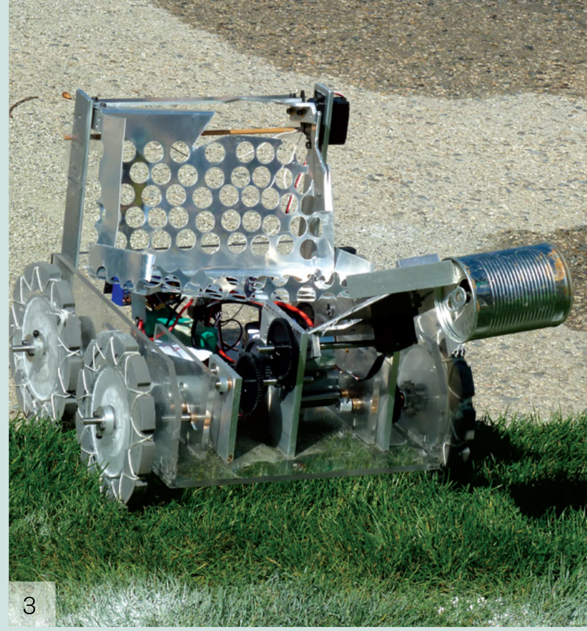
1

ROBOTS REUSE, RECYCLE

For the past 26 years, robots have invaded Caltech each spring to battle for their makers' bragging rights—sometimes to an electronic death—in the ME 72 engineering design competition. On March 8, six teams of undergrads competed in an "Extreme Recycling" challenge that pitted pairs of robotic vehicles against difficult terrain and other robots in an effort to collect plastic water bottles, aluminum cans, and steel cans. Each team built two robots designed to traverse water, sand, rocks, and wood chips to gather the recyclables and drop them into recycling bins—or prevent their opponents from doing so. The competition was the culmination of a 20-week laboratory class in which each team was given a budget of $1,200 to build the best bots possible. The final designs followed a couple of basic themes: robots with scoopers and grippers to grab the bottles and cans, and ones with baskets to haul the loot. Other design features included ramps to wedge under opponent robots and trip them up. The winning team, named BRB, consisted of juniors Chris Hallacy, Brad Saund, and Janet Chen. Team BRB bested all five other teams without dropping a heat during the double-elimination contest. —*KN* E&S

4

2



3

1 ME 72 participants check out one of the "placebos," robots designed by the teaching assistants and used to round out a bracket when there was an odd number of contestants. Placebos were not allowed to score, or to intentionally hurt another robot, but could generally mess with the competition. This placebo featured an innocent-looking, rainbow-colored pinwheel that was actually made of magnets.

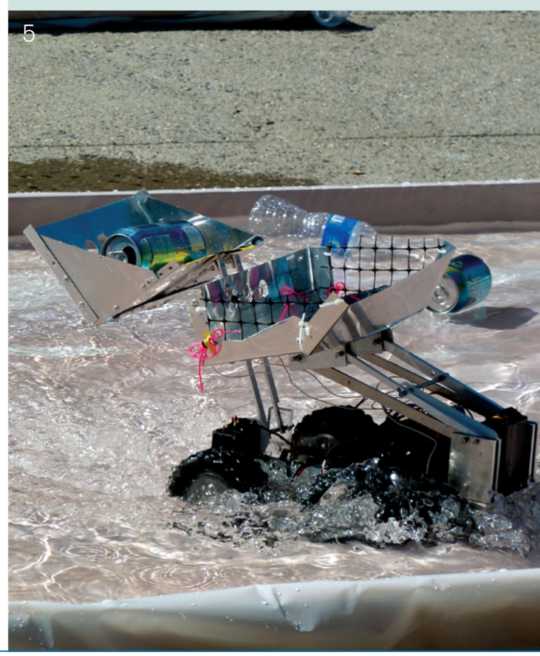
2 Pile up! Competing robots ram into each other like sumo wrestlers in an effort to neutralize the opposition.

3 A winning robot from Team BRB shows off its can-carrying skills.

4 The giant placebo robot menaces a much smaller competitor.

5 A Team Aviator robot takes a spin through the water trap, successfully picking up a can along the way.

6 This daring run threatened to damage the electronics. Juniors Sara Ahmed (left) and Jee Su Baek blow-dry the robot before its next round. (The third team member, senior Cole Hershkowitz, is not pictured.)



5

6