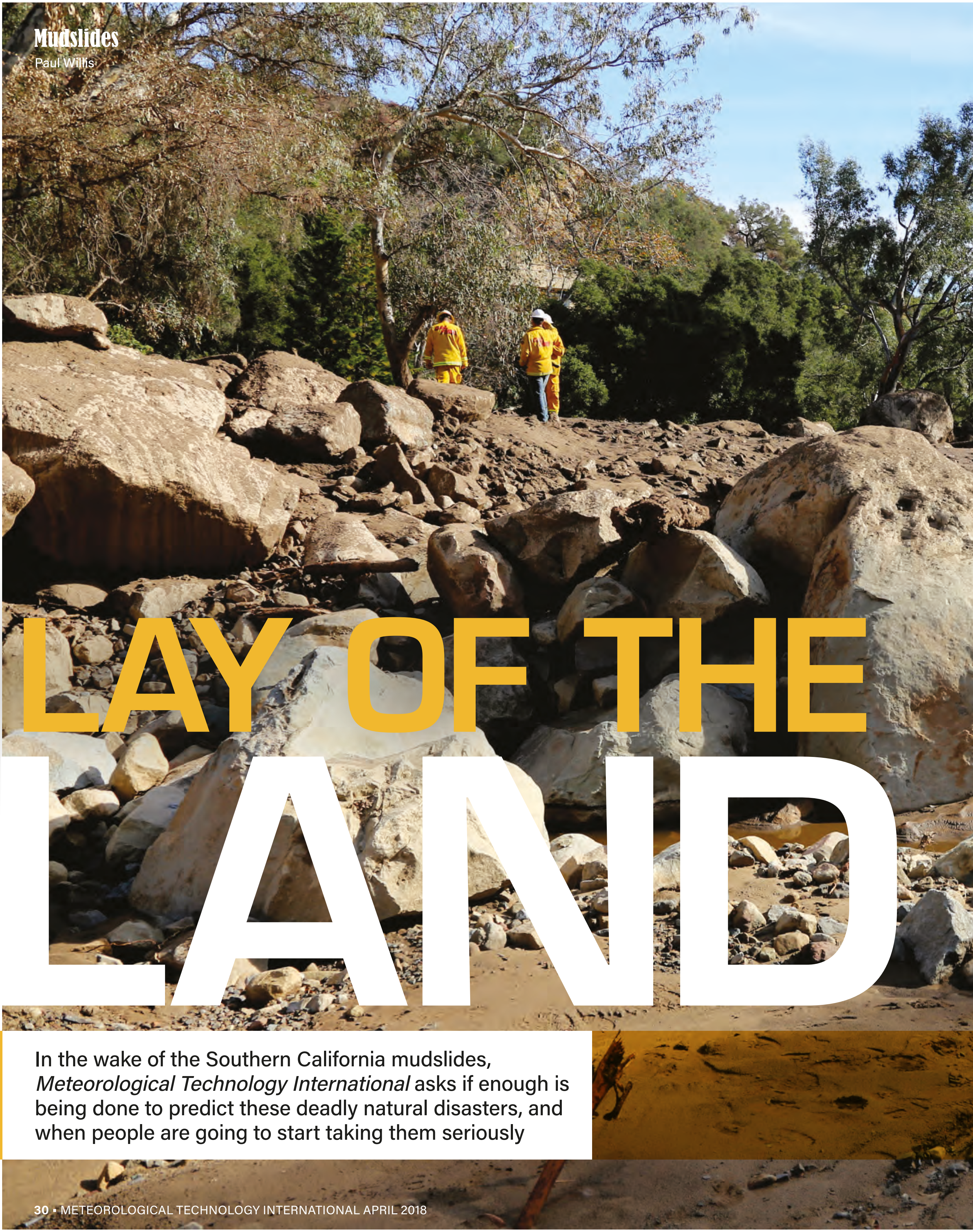
Paul Willis



LAY OF THE LAND

In the wake of the Southern California mudslides, *Meteorological Technology International* asks if enough is being done to predict these deadly natural disasters, and when people are going to start taking them seriously

Debris flow from the Montecito mudslide in January 2018

On a bleak Tuesday in January this year, Dennis Staley, a research physical scientist at the US Geological Survey's (USGS) Landslide Hazards program, boarded a flight from his home state of Colorado to the California city of Santa Barbara.

Hours earlier a horrific mudslide had laid waste to the Californian coastal town of Montecito in Santa Barbara County. Staley was visiting the town to gauge the mudslides' impact. In one of the worst mudslides in the state's history, scores of homes were destroyed and dozens of people went missing. The final death toll reached 21.

"It's hard to describe the level of devastation," says Staley. "It's the biggest debris flow I've ever seen in the built environment. It certainly makes you aware of the significance of the work you do and reinforces the need to do it the best you can."

Though Staley and his team were in Montecito to monitor the mudslide's aftermath, the ultimate purpose of their work there was to improve prediction of debris flows. "We were out mapping the impact area and trying to get a sense of the mechanics and dynamics of the flow," he says, "so that we could potentially improve our modeling."

Debris flows are predominantly a problem of the weather, according to Jim Hambleton, assistant professor of civil and environmental engineering at Illinois' Northwestern University. "It's a common pattern of causation, especially in hilly areas," he says. "Wildfires are followed by heavy rain, leading to mudslides."

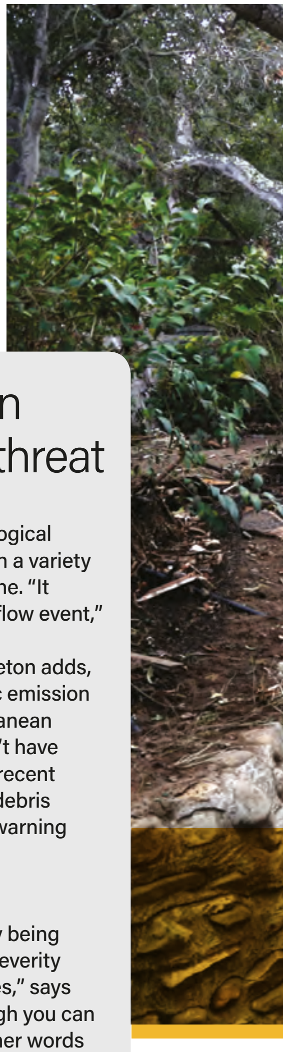
Even in regions where wildfires are scarce there are predictable patterns of causation. "The US Pacific Northwest definitely has problems with debris flows – China too," says Hambleton. "In these cases the cycle is one of drought followed by rain."

In the USA, in California in particular, wildfires followed by heavy rainfall is the most common reason for debris flows and is what caused the Montecito mudslide. Staley believes that the reason this mix of fire and rain is so potent is that slopes denuded of trees cannot absorb water well. In heavy rain the excess surface run-off picks up sediment as it flows downhill, eventually collecting enough to turn into a debris flow.

PREDICTING MUDSLIDES

Staley, who specializes in post-fire debris flows, and his team use various models to try to zero in on where post-fire flows might occur and to estimate how big the flow could be in terms of volume of material. The models are fed by two broad categories of data: the first, research data; and the second, geospatial data, much of it sourced from satellite imagery.

The research data includes data collected in the field, both at the scene of major debris flows like the one in Montecito and at two permanent field sites the USGS maintains in California. It also includes historical information on debris flows and weather events. "For example, we zero in on short,



Using technology to map out the impact area after a mudslide helps scientists to understand the mechanics and dynamics of the flow to improve modeling

How technology can solve the mudslide threat

Acoustic emission

At its field sites in California, the US Geological Survey (USGS) monitors debris flows with a variety of instrumentation, including the geophone. "It measures the seismic impact of a debris flow event," explains USGS's Dennis Staley.

Northwestern University's Jim Hambleton adds, "The phone works by measuring acoustic emission – the soundwaves produced by a subterranean seismic event. Acoustic emission wouldn't have helped with spontaneous events like the recent devastating Montecito mudslide, but for debris flows caused by a landslide it can give a warning that things are about to go."

Drone mapping

"The same radar imagery that is currently being leveraged on satellites to measure burn severity in at-risk areas can also be fitted to drones," says Staley. "If the image quality is good enough you can do change detection of the surface. In other words you can take pre- and post-fire images and measure the erosion and deposition. But the accuracy depends on how well the drone is being operated and that can vary widely."

Autonomous robots

One of the key shortcomings in measuring current debris flow risk is a lack of on-the-ground data in at-risk areas, according to Hambleton. He sees a case for autonomous robots, which he says could be deployed to map these areas: "One technique that's really effective for determining soil moisture is measuring electrical resistivity. You put an anode and cathode into the soil and pass current through it. Geotechnical engineers have been doing this for a long time. It's not far-fetched that you could have a robot do that."

Artificial slopes

Researchers at Queen's University in Ontario, Canada, have been using an artificial slope to carry out debris flow experiments. A large-scale flume is fitted with various instrumentation, such as piezometers that measure the pressure of groundwater. "You put the devices in there, induce a debris flow and see what the trigger point was," Hambleton explains.

Jim Hambleton, assistant professor of civil and environmental engineering at Northwestern University in Illinois

high-intensity rainfall events to see how often they produced debris flows," says Staley.

The models also use geospatial data on topographical steepness, soil properties and the severity of wildfires. To measure wildfire severity, Staley's team uses satellite imagery, focusing on two main bands on the color spectrum – bands four and seven. These are, respectively, the green band and the near-infrared band. "Typically we use a pre-fire and post-fire image," he comments. "Comparing bands in the image helps us understand how severe the fire was."

The comparison results in a measurement known as the difference normalized burn ratio (DNBR). "The DNBR image is combined with remote sensing and fieldwork information from teams that go out on the ground immediately after the fire to give an overall ratio of soil burn severity," Staley adds.

All these data sets are woven together to produce hazard assessments published on the USGS's website. US federal agencies use them to help compile risk estimates for the affected regions.

WILDFIRES ARE FOLLOWED BY HEAVY RAIN, LEADING TO MUDSLIDES

"The US Pacific Northwest definitely has problems with debris flow – China too"

Jim Hambleton, assistant professor of civil and environmental engineering, Northwestern University

"We are not involved in the decision process that leads to public officials ordering evacuations," explains Staley. "Our information is given to post-fire federal teams on the ground, to determine post-fire risk. Those teams typically work with municipalities to interpret our maps. But ultimately it's left to municipalities to determine which areas should be subject to evacuation orders."

In deciding whether to evacuate, municipalities also rely on weather forecasting from the US National Weather Service (NWS). To help it predict debris flows, the USGS provide the NWS with rainfall intensity thresholds for areas where heavy rain poses a particular threat. On the basis of these thresholds, the NWS issues debris flow watches in the run-up to heavy rain. In the hours before the storm it might also issue a specific warning for a particular location.

EVACUATION WARNINGS

In the case of Montecito, the NWS warned of the risk of debris flows at a weather briefing held four days prior to the disaster. For some time before the mudslide, the area had also been flagged up on the USGS's website as vulnerable to debris flows.

With these early warnings in place, the obvious question is how 21 people died. Some have blamed the death toll on the decision by Santa Barbara County's Sheriff's Office to issue two types of evacuation order: mandatory and voluntary. Since most of those that died lived in areas subject to voluntary evacuations, critics say the use of the word 'voluntary' underplayed the danger in the public's mind.

The Sheriff's Office has since promised to change its designation. The word 'voluntary' will be replaced by new

Is the mudslide threat taken seriously enough?

One of the most shocking statistics about the recent Montecito mudslide, besides the death toll, was the high proportion of residents who ignored a mandatory evacuation order telling them to flee their homes – around 85%, according to the Santa Barbara Sheriff's Office.

The reasons why so few chose to follow the advice and get out of the danger zone are unclear. Some blamed it on confused messaging from the Sheriff's Office – social media alerts ahead of the mudslide gave contradictory information about the area covered by the evacuation zone. Others said earlier evacuations for wildfires in the region, which had proved unnecessary, had left them skeptical about the reality of the risk.

US Geological Survey research scientist Dennis Staley says that in alerting the public to debris flow threats, authorities must strike a careful balance: "You have to be as accurate as you possibly can. If you issue false alarms all the time you'll find that the public begin to disengage. But under-warning is an even more dangerous situation," he warns.

The other problem is that debris flows are so rare that public perception of the dangers they pose remains low, according to Northwestern University engineering professor Jim Hambleton. He believes the proof of this is seen in the fact that people continue to move into at-risk areas. "If you look at some of the places hit by the Montecito mudslide, the reality is that people shouldn't be living there," says Hambleton. "But the views are so great and human beings like life on the edge."

Hambleton thinks there is a group behavioral element that gives rise to a false sense of security. "If you move into the area you know the risk, but the hazard is everywhere. In other words, all the houses surrounding you face the same risk. You should worry about debris flows, but so should the whole community. At that point a sort of weird logic intrudes and you think that if other people are doing it, so can you."

evacuation terminology, such as 'pre-evacuation advisory', 'recommended evacuation warning' and 'mandatory evacuation order' during future mudslides and wildfires.

Some residents blamed their decision to stay put on their experiences during the December wildfires that created the conditions for the mudslide. At that time, many followed evacuation orders that ultimately proved unnecessary. "It's a tricky issue about how aggressively you go about sounding the alarms, because if nothing happens you run the risk of not being taken seriously next time," says Hambleton.

And this is a particular risk with mudslides, because while it's relatively easy to determine an area's overall vulnerability, pinning down exactly where and when the debris flow will hit is much harder, according to Staley. "Among the strongest factors in debris flows are short bursts of high-intensity rainfall," he says. "But this kind of weather event is very hard to predict."

For this reason, Staley believes that ground-based devices that monitor rainfall can be useful predictive tools. At his team's two California field sites they use rain gauges and disdrometers.

They also instrument the hillsides with devices that measure soil moisture content and infiltration. However, as a caveat he notes: "We haven't found any clear correlation between soil moisture levels and likelihood of debris flows."

> "Most landslides move gradually over time but they can sometimes collapse catastrophically"
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> **Eric Fielding, research scientist at NASA's Jet Propulsion Laboratory**

Hambleton thinks that some of the rainfall technology could be adopted by residents in at-risk areas to help them "take ownership of what's in their backyard. If you live there you ought to have a rain gauge sitting on your deck that's connected to your smartphone and pings you with an alarm when rain levels reach a critical level. For me this kind of citizen science is the solution to the problem."

> **DEBRIS FLOWS USUALLY HAPPEN WITHIN MINUTES**

SLOW MOVING LANDSLIDES

But even with ground monitoring sensors it is still all but impossible to predict a mudslide in enough time to evacuate, since debris flows usually happen within minutes of the rainfall that provokes them.

"Most landslides move gradually over time but they can sometimes collapse catastrophically," says Eric Fielding, a research scientist who monitors slow-moving landslides at NASA's Jet Propulsion Laboratory in Pasadena. "As with mudslides, these collapses are usually caused by heavy rain but whereas mudslides tend to fail immediately, with landslides there's a lag."

He gives the example of a landslide that collapsed onto Northern California's iconic Big Sur coastal road in May 2017. "The heavy rains that most likely precipitated it occurred at least two months earlier," he says.

After the Big Sur event, Fielding and his team examined satellite imagery going back several years. They used data from the European Space Agency's (ESA) Sentinel satellites, part of the ESA's Copernicus program. The satellites are fitted with synthetic aperture radar (SAR), which enables resolutions high enough to detect ground motion on the order of a few inches. "We found that the landslide was moving for six years before it collapsed," says Fielding.

Fielding and his team are monitoring hundreds of landslides, most of them in California, for signs of imminent collapse. One might imagine that a strong indicator would be the landslide starting to accelerate, but this can sometimes turn out to be a false alarm, according to Fielding. "There are some landslides that move faster in years when there is heavy rain but then slow down again in years of drought," he explains. "We've observed this in landslides we're monitoring in Berkeley that have houses built on them. They are going so slowly that even in the fast-moving years they move barely a centimeter."

To help monitor landslide movements better, NASA is sponsoring a new radar satellite, launching in 2021, that will photograph Earth's entire land mass every 12 days. For even closer monitoring, ground-based radar systems now exist. "These new systems can take a measurement every five minutes," Fielding says. "There are quite a few deployed in mines to alert them if the mine wall is in danger of collapsing." ∎