by hydroxyl. Because of this, scientists can use the trend in its abundance to infer the trend of the radical, says David Etheridge, an atmospheric chemist at the Commonwealth Scientific and Industrial Research Organisation (CSIRO) in Aspendale, Australia, and a co-leader of the drilling project.

RISKY BUSINESS

But measuring levels of carbon monoxide that contain carbon-14 is tricky, because there are only a few kilograms of it in the atmosphere, says Etheridge. "And we're trying to measure a bit of that over the last 150 years in the Antarctic ice."

There is also a risk that the ice cores will become contaminated with external sources of carbon-14 from cosmic rays. This high-energy radiation cannot penetrate the ice, but the moment the cores are removed, they are at risk of exposure. This would interfere with the signal the team is trying to measure, says co-leader Vasilii Petrenko, an ice-core scientist at the University of Rochester in New York. To avoid that risk, the researchers will melt the ice and extract the air on site.

Organizing the equipment to do this and transporting it to a remote ice sheet has been a huge logistical challenge, says team member Peter Neff, an ice-core scientist at the University of Washington in Seattle.

Tractors pulled giant sleds loaded with equipment to the Law Dome drilling site, more than 130 kilometres from the nearest research station. And it will take the team 36 days to melt the ice they need to get enough air samples. "It's a marathon, not a sprint," says Neff.

The project is co-funded by the Australian Antarctic Division and the US National Science Foundation.

Once the researchers return from Antarctica, to assess the levels of carbon-14 in carbon monoxide, the team will convert the gas into carbon dioxide and then into graphite, from which the isotope can be measured. The scientists can then use the information to infer how hydroxyl levels in the Southern Hemisphere have changed over time.

Up to now, information on historical trends in hydroxyl levels has come solely from atmospheric models; these simulations suggest that concentrations remained fairly stable from 1850 until the 1970s, when they started to rise (A. Voulgarakis *et al. Atmos. Chem. Phys.* **13**, 2563–2587; 2013). The increase was mainly because of a boost in atmospheric warming at the time, says Voulgarakis.

The data collected from Law Dome will help to determine whether the atmospheric models have captured this trend correctly, says Matt Woodhouse, a climate modeller at CSIRO, who will use the information to improve Australia's global chemistry-climate model, called ACCESS. "Our ability to resolve hydroxyl won't revolutionize climate models, but it'll increase our confidence in them."

And accurate pictures of hydroxyl's historical and current atmospheric concentrations are essential for developing better projections of its future levels, says Voulgarakis. This will then enable more-accurate projections of the future abundance of gases that affect climate — such as methane, ozone in the lowest layer of the atmosphere, and aerosols — that hydroxyl scrubs from the sky, he says. This would make it easier to determine the gases' potential contribution to global warming. ■

GEOLOGY

Volcano algorithm predicts Etna's eruptions

System tracks low-frequency waves to determine when volcano is about to erupt.

BY SHANNON HALL

Smoke filled the cabin as the Boeing 747 plunged towards snow-covered mountains in southern Alaska. All four engines had shut down, and it took the pilots eight long minutes to regain control of the aircraft. No one on board was hurt — but they had had a very close call with an erupting volcano. The jet had flown through an ash cloud.

Incidents such as this near miss from 1989 show why geologists have long sought to forecast volcanic eruptions: to protect people, whether in the air or on the ground. Now scientists are one step closer to this goal.

Maurizio Ripepe, a geophysicist at the University of Florence in Italy and his colleagues have created the world's first automated volcano early-warning system, which alerts authorities near Mount Etna in Sicily about one hour before an eruption. The team described the system in a study published last month (M. Ripepe *et al. J. Geophys. Res. Solid Earth* http://doi.org/cw6w; 2018).

The approach relies on the fact that volcanoes are noisy. Their rumblings and explosions can sound like a jet engine or even a high-pitched whistle, but they also produce low-frequency infrasound waves that people cannot hear. Unlike seismic waves, infrasound waves can travel for thousands of kilometres, allowing scientists to spot volcanic eruptions from afar. When Krakatoa, in Indonesia, erupted in 1883, its infrasound signal travelled around the globe twice.

> ***"If there is an ash cloud that has suddenly popped up, then the pilots need to know that information."***

With that in mind, Ripepe and his colleagues turned to Mount Etna, Europe's largest active volcano. At first, they wanted to create a simple system that could detect an eruption using data from an existing array of infrasound sensors, and automatically alert authorities. But their ambitions grew when they discovered that the volcano often produces infrasound waves before it erupts, making prediction possible.

Although the finding was a surprise, the scientists say that it makes sense, given that Mount Etna is an 'open-vent' volcano with exposed magma. As gas rises out of the magma before an eruption, it causes air in the volcano's crater to slosh back and forth — creating sound waves like those in a woodwind instrument. And just as the sound of a musical instrument depends on its shape, the geometry of a crater also affects the sounds it can produce.

The team created its early-warning system in early 2010 and tracked its performance during 59 eruptions over the next 8 years. The system — an algorithm that analyses infrasound signals from the sensor array — predicted 57 of those events and sent messages to the scientists about 1 hour before an eruption took place. In 2015, the scientists programmed the system to send automatic alerts to the Italian Civil Protection Department.

An automated alert system can broadcast warnings faster than can predictions that require experts to vet information beforehand, says John Lyons, a geophysicist at the Alaska Volcano Observatory in Anchorage. And time is of the essence for communities near

Mount Etna in Sicily is one of the world's most active volcanoes.

SANDRO SANTIOLI/ FOCUS/EYEVINE

volcanoes, or passengers in a jetliner that can fly faster than 800 kilometres per hour. "You're covering a lot of ground really fast, so if there is an ash cloud that has suddenly popped up, then the pilots need to know that information as soon as possible," he says. "Every minute counts."

Although Lyons worries about the potential for false alarms, he says that the system is a pivotal step forward — not only for Etna, but also perhaps for similar volcanoes around the globe.

These could include Kilauea, an open-vent volcano on Hawaii's Big Island whose months-long eruption this summer destroyed whole neighbourhoods, says David Fee, a geophysicist at the Alaska Volcano Observatory. But he says that Kilauea differs from Etna in some key ways. Eruptions at Kilauea can originate from the volcano's summit and from an area on its flank called the East Rift Zone. Etna erupts only from its summit.

Because of this, Lyons says, Mount Pavlof in Alaska, one of the most active US volcanoes, could be a better test for an early-warning system. Pavlof, whose structure resembles Etna's, has shown increased infrasound activity before the most energetic phase of its eruptions. Its frequent activity could also give researchers a large data set with which to tune their algorithm for predicting eruptions.

Ripepe and his colleagues are beginning to test their early-warning system in Iceland. Working with the Icelandic Meteorological Office in Reykjavik, the scientists have installed five sensor arrays across the island to monitor infrasound waves from multiple volcanoes. Among them is the infamous Eyjafjallajökull, whose last eruption, in 2010, shut down air traffic across northwestern Europe for weeks. ■