A Four-Legged **Early-Warning System**

In many parts of the world, goats are important suppliers of milk, meat and hides. However, **Martin Wikelski**, Director at the **Max Planck Institute for Ornithology** in Radolfzell, has very different plans for these modest animals: he wants to use them to predict volcanic eruptions.

TEXT **ELKE MAIER**

On July 18, 387 BCE, the residents of Rome were still lying peacefully in their beds as danger approached from the north. The Celts were marching toward the city, threatening to destroy it. Only a couple of geese, so the legend goes, were awake at the time. They lived on the Capitoline Hill, in a temple dedicated to the goddess Juno. They are said to have woken the sleeping inhabitants with their loud quacking and thus saved the Capitoline.

Today, every guide book on Rome includes the story of the vigilant geese, but this story is by no means the only example of animals prophesying impending doom. Roman naturalist Pliny the Elder, who died when Mount Vesuvius erupted in 79 CE, reported that birds become restless before earthquakes. In modern times, too, we've seen time and again animals behaving strangely before natural disasters – and such diverse species as elephants, dogs, snakes, toads, fish, bees and even ants.

In February 1975, near the Chinese metropolis of Haicheng, numerous snakes were seen that had slithered out of their hideaways in the middle of winter and frozen to death in the snow. Shortly thereafter, the city was rocked by earth tremors with a magnitude of 7.3. The residents were evacuated in time due in no small part to the reptiles' abnormal behavior. In March 2009, at San Ruffino Lake in Italy's Abruzzo region, the toads that are normally found here in great numbers suddenly disappeared in the middle of the spawning season. A few days later, an earthquake destroyed the nearby town of L'Aquila.

WATER BUFFALO AND CHICKENS MAY SAVE LIVES

Before the devastating seaquake of 2004, too, many animals exhibited different behaviors than normal. Elephants in Sri Lanka, for example, sensed the danger long before the tsunami hit the coast, and fled inland. People who instinctively followed them were saved from death. "When animals go crazy, run away from the sea and go to the highlands," advises an Indonesian children's song. It comes from Simeulue island, off the coast of Sumatra, close to the epicenter of the quake. Because the inhabitants had learned from their ancestors to correctly interpret the behavior of chickens and water buffalo, they were able to save themselves from the tsunami. Despite enormous property damage, there were only a few deaths on Simeulue.

"There are many anecdotes about animals being able to foresee disasters such as earthquakes and volcanic eruptions, but hardly any systematic studies," says Martin Wikelski, Director at the Max Planck Institute for Ornithology in Radolfzell and professor at the University of Konstanz. "But scientists in this field don't have it easy, either," he grumbles. "One can quickly be dismissed as a sort of diviner."

Wikelski, who in 2008 moved to Lake Constance from Princeton University and has since headed the venerable ornithological station in Radolfzell, doesn't let that discourage him. He would like to test whether animals can be used as biological early-warning sys-

Photo: flickr/Lorenzo Blangiardi

Modest ruminants: Goats live year-round on the slopes of Mount Etna in Sicily. The animals have a keen instinct for what's happening inside the volcano.

» Severe eruptions occur from time to time when the volcano spews ash clouds and rocks several kilometers into the atmosphere.

tems for natural disasters such as earthquakes and volcanic eruptions. He's even had his idea patented: the project, which he submitted to the European Patent Office with the support of the technology transfer company Max Planck Innovation, is called DAMN (Disaster Alert Mediation using Nature). Insurance companies have already expressed interest.

ANIMAL OBSERVATION AROUND THE CLOCK

The idea for this unusual project wasn't all that absurd for the avid behavioral scientist. Wikelski records animal migrations and behaviors around the globe. His focus isn't restricted to migratory birds, but includes a broad range of wildlife. Using radio transmitters, he tracks storks on their way from Europe to Africa, monarch butterflies on their journey from Canada to Mexico, and the wanderings of rodents that disseminate seeds in the South American rainforest.

The small tachographs the scientist uses for this can not only report the exact GPS coordinates of the wearer, but also measure acceleration in different directions. This enables the researchers to draw conclusions about the animal's behavior.

"This technology allows us to conduct our observations around the clock," says Martin Wikelski. The Max Planck Director sees in this a unique opportunity that he would like to take advantage of: "If we attach transmitters to different animals in regions prone to natural disasters and record their behavior, we can subsequently find out which animals would have predicted, for example, a volcanic eruption or an earthquake." Then the researchers could, in the future, use these candidates as an early-warning system.

FIELD RESEARCH AT THE FOOT OF THE VOLCANO

A visionary idea, but was it also practicable? To show that it was, Wikelski and his colleagues launched an unusual field trial in April 2011. "If we want to study how animals behave before a volcanic eruption or an earthquake, we can't do it in the lab," the researcher explains. "We have to actually wait for such an event to occur." That can sometimes take quite a while. The chances for the Radolfzell scientists were relatively good in Sicily.

Mount Etna, towering 3,352 meters above the island's east coast, is the most active volcano in Europe. Most eruptions affect only the immediate vicinity of the crater, posing no danger for nearby people and animals. However, severe eruptions do occur from time to time, with the volcano spewing ash clouds and rocks several kilometers into the atmosphere, and streams of lava making their way down into the valley. These so-called paroxysms are frequently accompanied by massive explosions.

Grabbing the goat by the horns: For his field trial, Martin Wikelski fitted a few animals with transmitters that he had specially produced for the study. At the front of the collar is a battery pack that supplies power for many months. The GPS logger and the electronics are located on top, where reception and transmission are strongest.

Photo: MPI for Ornithology

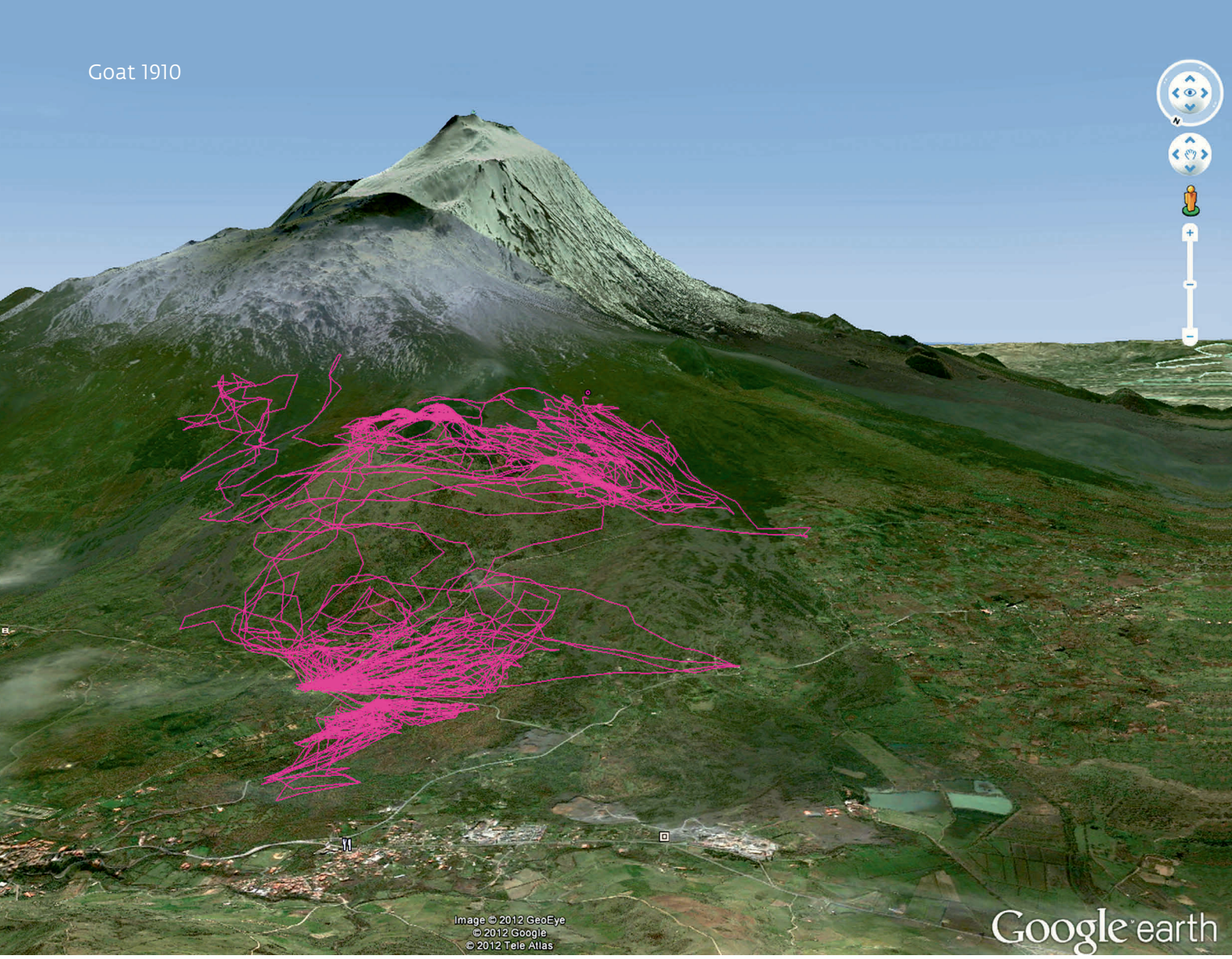


Photo: Google Earth, 2012 GeoEye, 2012 Tele Atlas (top), MPI for Ornithology (bottom)

Although Etna is one of the best-researched volcanos in the world, it has not yet been possible to reliably predict such events over the long term – especially as regards the intensity of the eruption. Martin Wikelski and his colleagues thus wanted to find out whether there are animals that can do this better.

INSPIRATION FROM HISTORICAL WRITINGS

In their search for suitable candidates, the scientists also turned to ancient myths for inspiration: "Originally, we really did consider geese," recalls Wikelski. "Then we asked locals who have been living with their animals at the foot of Mount Etna for generations. They said: Forget the geese, use goats instead!" The people in the region knew their animals extremely well and thus knew that they have a keen instinct for impending natural phenomena. "A shepherd then promptly made eight goats available to us," reports the behavioral scientist.

Most of the time, the animals live in small herds on the slopes of the volcano. They are driven into the valley only twice each year. The scientists used one such opportunity to fit the goats with transmitter collars in place of the bells they would normally get. Weighing 390 grams, the devices, which Wikelski had specially produced for the experiment, record both the exact GPS position and the acceleration on three axes and allow the data to be read via a local radio network. Back home on their computer, the researchers can access the data and, using special software, visualize the movement patterns and the behavior of the goats on the monitor.

Martin Wikelski zooms in on a map of the area around Etna. The image

By circuitous routes: The devices on the goats' collars record the GPS position at frequent intervals. Using this data, the researchers can trace on the monitor which routes an individual animal has taken (top). Most of the time the goats, being social animals, travel in groups (bottom).

shows the northern slopes of the volcano, with the little town of Randazzo at the lower left corner. "Goat 1910" is written at the top left. A jumble of pink lines indicates where the goat called "1910" has wandered to. Clicking on any line shows the date and time. "Thanks to the acceleration data, we not only know the routes the goat has covered, but we can also reconstruct what it did," explains Wikelski. Whether the animals sleep, eat, run or jump over the lava rocks – each of these behaviors produces a characteristic acceleration pattern.

SMALL EXPLOSIONS BEFORE THE BIG BLAST

"There!" Martin Wikelski points to a restless up and down of thin blue lines that runs across the entire width of the monitor. The graphic correlates to early January 2012. At one point, the lines are so long that they reach the top edge of the image, before dropping again. "Here, the goats suddenly get very active," says Wikelski, interpreting the pattern. "Something has unsettled them." Coincidence? Or perhaps a stray dog that has wandered near the animals? Wikelski ruled that out at the start: "The animals wearing the transmitters aren't traveling together in a group. When all of them nevertheless react almost simultaneously, there must really be something going on."

The data of the *Istituto Nazionale di Geofisica e Vulcanologia* revealed just what that was. The institute operates 26 automated measuring stations around Mount Etna; in addition, scientists are regularly on the premises to record the volcanic activity. Therefore, the number of eruptions, the start and duration of an eruption and its progression are well documented. The researchers at Radolfzell were thus able to establish that, on January 4, 2012 at around 10:20 p.m., a severe eruption began – about six hours after the goats had been so unusually active.

Although the seismologists had already registered smaller explosions on the morning of January 4 using infrasound detectors, they were unable to predict the intensity of the eruption. Fountains of lava were shooting out of the crater until noon of the following day, and the ash column reached more than 7 kilometers up into the atmosphere. "We would have been able to predict this event with our data," says Martin Wikelski.

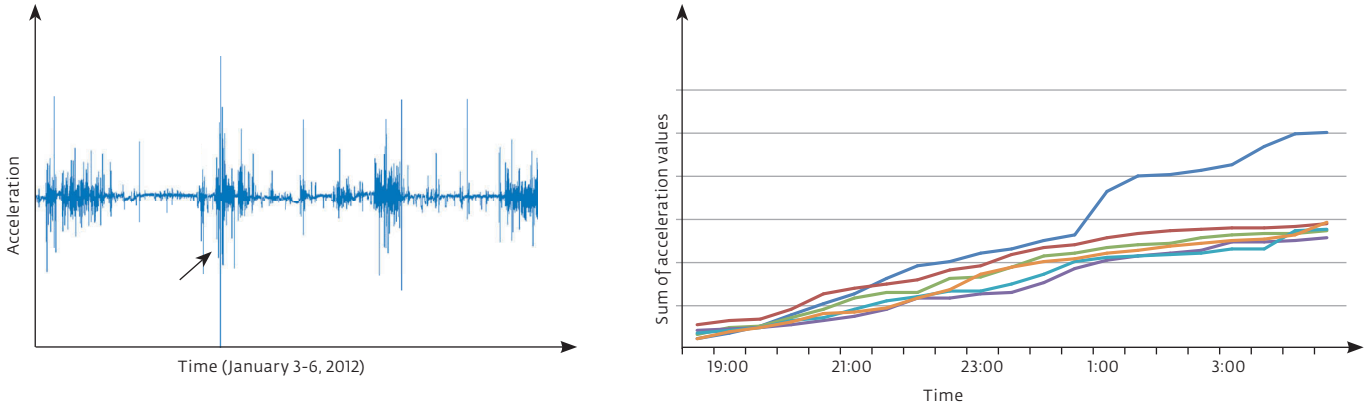
To ensure the statistical validity of their findings, the scientists continued their study for two years. During this time, they registered 27 eruptions, 7 of which were large paroxysms. Altogether, 17 goats and 4 sheep took part in the study. They confirmed that Wikelski's idea actually worked: whenever a major eruption was imminent, the animals were already perturbed hours before, running up and down or hiding under bushes and trees when they had the opportunity.

THRESHOLD VALUES FOR RECOGNIZING DANGER

By recording the animals' movements around the clock, the researchers learned how to interpret this behavior correctly. They registered how strongly the activity level varied under normal conditions and how it increased before a major eruption. Using statistical methods, they were able to quantify the variation and establish clear threshold values for the various day and night times. If the activity level exceeded such a critical value, this was a sure sign that an eruption was imminent. This would have allowed the scientists to reliably predict each of the seven major eruptions. Smaller eruptions, on the other hand, had no impact on the animals' activity.

But how do the goats notice the impending danger – do they have something like a sixth sense? "We don't yet know how they do that," says Martin Wikelski. "Perhaps they perceive the smell of rising magma leaking through

Photo: dpa Picture-Alliance



Fiery spectacle: During an eruption, streams of lava shoot out of Etna's crater (left page). As the acceleration data show – here using a goat as an example – the animals suddenly become very active before such an event (arrow in the graphic on the left). A comparison of the activity levels over the course of several nights (bottom curves in the graphic on the right) for all goats wearing transmitters shows a rapid increase in the night before a major eruption (dark blue curve).

the ground." Gases containing substances like sulfur dioxide and hydrogen sulfide seep out of the fiery molten rock.

But even if the mechanism hasn't yet been clarified, the animals do seem to be superior to the technical equipment currently available to volcanologists when it comes to early detection. The instruments register an impending eruption only shortly before it occurs, leaving little time for evacuation. Nor does this technology provide any precise information about how severe an eruption will be.

So will we have a "goat detector" for future volcanic eruptions? "Well, first we have to find out whether what works at Etna also works in other regions of the world," says Wikelski. "Another thing that is important for an effective early-warning system is to record the behavior around the clock in real time, even when the animals happen to be in an area with poor signal reception."

The ICARUS (International Cooperation for Animal Research Using Space) project, which was launched by the Radolfzell scientists, could make such global observations significantly easier – even in uninhabited regions where there is no cellular network. The objective of ICARUS is to record the movements of animals around the globe from space. The project has enjoyed the sponsorship of the German Aerospace Center (DLR) since March 2013 and is supported by the Russian Federal Space Agency, also known as Roscosmos.

RECEIVING STATION IN SPACE

Astronauts are planning to install a receiving antenna on the International Space Station (ISS) in late 2015 specifically for this project. The antenna is configured to receive the data from thousands of transmitters, which an onboard computing system will then analyze. The Max Planck Society has been financing the miniaturization of the ICARUS radio chips since December 2013, to allow the project to monitor even small animals.

However, the flight path of the ISS means that ICARUS can read the small transmitters only one to four times per day. So in its current form it isn't yet suitable as an early-warning system. In the future, additional small satellites fitted with appropriate equipment could make seamless observation possible.

With such sophisticated technology, Martin Wikelski is convinced that scientists could soon not only be tracking goats on Etna, but also following other animals around the world that can predict volcanic eruptions or earthquakes. But the Max Planck researcher doesn't expect this to happen through high-tech alone. He plans to continue to follow the lead of local traditions, which is why the chickens and water buffalo of Simeulue already top his list of promising candidates. ◂

TO THE POINT

- **Since ancient times, different animal species have been considered helpful indicators of natural phenomena such as earthquakes and volcanic eruptions.**
- **Researchers attached transmitters to goats and sheep at Mount Etna to document their behavior. This showed that the animals are indeed able to indicate when the volcano is about to erupt.**
- **The ICARUS project includes plans to install an antenna on the International Space Station (ISS) to record animal movements from space. This may make it possible one day to derive global predictions of natural disasters.**

Graphics: MPI for Ornithology