On the high plateau of western Tibet, 17 July 2016 started out as a lovely day. “The air smelt particularly fresh after a heavy rainfall the night before,” says Dradül, the chief of Aru village, who like many Tibetans goes by one name. Then, Dradül got a chilling phone call. In a torrent of words, a villager described how an avalanche of ice had just “swallowed the grassland,” wiping out a rich pasture where villagers, including some of Dradül’s relatives, were tending yaks and sheep.

Dradül rushed out to Aru Co Lake, 5100 meters above sea level, to help with the rescue. The grassland had disappeared, entombed under a 30-meter-high wall of ice. Eyewitnesses said the glacier had barreled in like a fast train, dumping enough ice to fill 40,000 Olympic-size swimming pools. The surge crushed nine people, including Dradül’s sister and her four children, as well as hundreds of head of livestock.

Thousands of glaciers perch near human settlements, and in recent decades, dozens of surges have claimed lives. One of the worst calamities occurred in 2002, in the Caucasus Mountains of southern Russia, when Kolka Glacier rumbled into a valley, killing 140 people. Anecdotes, and even some preliminary tallies, suggest surges are becoming more frequent. Just 2 months after the Aru disaster, Chinese scientists were on hand when a surge from an adjacent glacier engulfed another swath of grassland. No one was injured that time. But the back-to-back surges were “simply astounding,” says Yao Tandong, a glaciologist at the Chinese Academy of Sciences’s Institute of Tibetan Plateau Research in Beijing. “It makes you wonder what’s going on.”

Most surges, broadly defined as a flow at least 10 and often hundreds of times faster than a glacier’s usual pace of advance, are quieter affairs. Many are imperceptibly slow, but others attain staggering speeds. In 1953, for example, Kutiah Glacier in Pakistan advanced 12 kilometers over 3 months. Besides overwhelming settlements, glacier surges can threaten distant communities. They can block rivers, creating lakes that can later unleash floods, and by depleting glacier mass, they can threaten the flow of meltwater that downstream towns and farms may depend on.

Now, by studying glaciers from Tibet to the Arctic islands of the Svalbard archipelago in Norway, researchers are starting to understand why some glaciers swing between extremes of stagnation and crushing flow, and how surges may be predicted. Until recently, most glaciologists believed that a glacier’s physical characteristics,
have both fascinated and perplexed scientists for decades. “If you look at the past 5 decades, nearly twice the global

Even glaciers right next to each other can have totally different personalities. Jack Kohler, a glaciologist at the Norwegian Polar Institute in Tromsø, points to a pair of adjacent, massive glaciers on Svalbard: Kongsvegen and Kronebreen. “They are like twin brothers, but one surges and the other one doesn’t,” Kohler says. “It’s a total mystery.”

To understand the deeper dynamics of surges, researchers have tried to witness them firsthand, but it hasn’t been easy. In 1980, glaciologist Garry Clarke of the University of British Columbia in Vancouver, Canada, thought the odds of catching a surge were good at Trapridge Glacier in the Yukon, which had a dramatic surge 4 decades earlier. He noted that the glacier’s upper reaches were getting steeper and crevasses were multiplying—often a sign of instability. “It looked really primed to unleash another surge,” Clarke says. His team installed instruments to monitor everything from ice temperature to water pressure and conductivity beneath the ice. “We were really hoping to capture the start of an energetic surge,” he says. “All we had to do was to wait. But that moment never came.”

On Svalbard, however, Schuler and his colleagues have had better luck. In 2004, they began monitoring Europe’s largest ice field by area: Austfonna ice cap, a monster that is 560 meters thick in spots and straddles 8500 square kilometers, roughly the area of Puerto Rico. They were not expecting a surge; their goal was to assess fluctuation in ice mass. But 3 years later, they saw crevasses forming. In the summer of 2007, they installed GPS receivers on metal stakes drilled into the glacier. Then, says Schuler, “Things got more and more interesting.”

As the researchers reported in 2015 in The Cryosphere, Austfonna’s movement accelerated each year in early July and slowed in late August. Faster speeds broadly correlated with the number of days of above-freezing air temperatures. But year after year, after the glacier slowed in August, its movement was faster than it had been before the speedup. “It got pushed to a higher level every summer,” Schuler says. At the same time, its crevasses were deepening and extending. Suddenly, in the autumn of 2012, the glacier failed spectacularly. Over the following months, it gushed 4.2 cubic kilometers of ice—enough to fill 1.7 million Olympic-size swimming pools—into the Barents Sea. “It was the surge of the century,” Schuler says.

Based on the correlation between warming and speedup, Schuler and his colleagues suspect that the trigger for the surge was meltwater that trickled down through crevasses and accumulated at the glacier’s base, summer after summer. As the infiltrating water froze, the latent heat it released warmed the surrounding ice. “This alone can change glacier dynamics quite drastically” because warm ice flows a lot faster than its subzero counterpart, Schuler says. And as more water accumulated beneath Austfonna, the increasing pressure, like a hydraulic jack, lifted the glacier from its bed.

Ultimately the cold ice anchoring Austfonna’s tongue to the ground disintegrated. “That was the critical part that held the ice back,” says Jon Ove Hagen, a UiO glaciologist. Its loss unleashed the surge.

THE AUSTFONNA STUDY was a revelation. “If water is important for triggering a surge—as we are increasingly realizing—then climate change must have an impact,” says Heidi Sevestre, a glaciologist at the University of St. Andrews in the United Kingdom, who was not involved in the study.

Analyses of the Aru surges also point to a climate link. In western Tibet, annual snowfall totals have risen steadily since the 1990s, especially at higher elevations, as strengthening westerly winds bring more precipitation. “Glaciers are accumulating mass,” Yao says. “The bank accounts are getting fatter.” Meanwhile, average air temperatures in the region rose 1.5°C over the past 5 decades, nearly twice the global average. The warming has boosted the amount of meltwater shed by the Aru glaciers by 50%, 3D computer modeling suggests. “This means that more water
A glacier unleashed

Glaciers gain mass in their upper reaches, where snowfall is heavier, and lose it at their snouts, where the ice breaks up and melts (right). Most glaciers flow steadily, but some get stuck and accumulate mass (center), then release it in a surge. A surging glacier can race down a valley or mountain, growing thinner and longer (left). Then, anywhere from days to years later, the glacier’s speed ebbs and it begins thickening again.

Surging glaciers are riddled with crevasses, especially in their lower reaches. When the surge ends, meltwater that built up under the glacier before the surge may sweep mud and debris from its snout.

Trickling down

Meltwater plays a key role in triggering surges. Pooling on the glacier’s surface, it can seep down into crevasses. There it can refreeze, releasing heat that softens the ice; it can also pool at the base of the ice.

Steady state

In a “normal” glacier, meltwater drains efficiently from its base, carrying away heat and leaving the ice anchored to its bed.

Buildup to a surge

If drainage is poor or melting accelerates, meltwater can accumulate under a glacier, warming the ice and lifting it off the ground.

Aftermath

Once the surge releases the meltwater, the glacier subsides onto its bed, and the cycle begins again.
The modeling by Gilbert’s team suggests that, like Austfonna, the Aru glaciers surged after their frozen tongues became unmoored. “You need a huge amount of water to cause the failure,” Kääb says. “But as soon as the water finds its way out, the surge stops. It’s a relief for the glacier.” Dradül and other villagers confirm that after both surges, the foothills were flooded as water gushed from the snouts of the glaciers.

Sevestre and her St. Andrews colleague Douglas Benn have incorporated the effects of meltwater and precipitation into a broader picture of why some glaciers surge, and where surges are likely to occur. “To stay out of trouble, glaciers have only one job to do: to keep in balance,” Sevestre says. This means shedding any heat they gain from the air and the ground, from water that infiltrates through cracks, and from friction generated as the ice advances.

In a 2015 *Journal of Glaciology* paper, the duo presented a modeling study showing that glaciers can most easily maintain a thermal balance at climatic extremes: in cold, dry climates, where they can shed heat to the frigid air, and in warm, humid environments, where they discharge heat in steady streams of meltwater. By contrast, glaciers in intermediate conditions can easily get out of kilter, accumulating internal heat until enough meltwater builds up at their base to trigger a surge.

That picture could help explain the geographic pattern of surging glaciers. And it suggests that a change in climate can be a tipping factor in glacier behavior, as Sevestre and Benn write in their paper: “Glaciers may change from ‘normal’ to surge-type and vice versa under cooling or warming climates.” Or, as Adrian Luckman, a glaciologist at Swansea University in the United Kingdom, puts it, glacier behavior “may be a lot more fluid than we thought.”

Climate change may already be boosting the number of surges in some regions. In a 2011 paper, for example, glaciologist Luke Copland at the University of Ottawa and his colleagues tallied twice as many surges in the Karakoram between 1990 and 2004 as in the previous 14 years. In another study, the team analyzed five surges of Lowell Glacier in the Yukon between 1948 and 2009 and found that the quiescent period between events had decreased from 20 years to 12 years. And glaciologist Lonnie Thompson of The Ohio State University in Columbus told *Science* he worries that some steep, high-elevation glaciers in the tropical Andes could become unstable as temperatures rise. “There are major cities and towns in the valleys below those ice fields,” Thompson notes.

The lessons learned from glaciers may also apply to the Greenland and Antarctic ice sheets. They are more remote than most glaciers and harder to study, and yet internal plumbing and heat balance are likely to influence their movements as well. The ice streams that flow from their interiors “can also switch from steady, slow motion to rapid flow, dumping a lot more ice into the ocean, or vice versa,” says glaciologist Hester Jiskoot at the University of Lethbridge in Canada. “It’s one of the biggest wild cards in sea-level projections.”

A textbook example is the Kamb Ice Stream in West Antarctica. Probing deep layers of the ice for clues to past movements, researchers found that it advanced at 2 meters a day, perhaps for centuries, until the mid-1800s. Then it suddenly ground to a near halt, creeping at just millimeters a day, possibly after water that had built up beneath the ice shifted to a nearby ice stream, which has since been marching ahead.

Models developed from data on smaller glaciers could help investigators forecast whether polar ice streams will become more erratic in a warming world. But Schuler cautions that the effects of warming on ice sheet movements are much harder to predict than they are for individual glaciers. “We have little idea how this will play out in a long run.”

**ON A LATE SPRING DAY** on Svalbard, Christopher Nuth guns his snowmobile through the fog, shifting his weight like an acrobat to keep the bounding machine on course. The UiO glaciologist is on his regular commute from Ny-Ålesund, an international science village, to Kongsvegen—one of two glaciers with strangely contrasting behaviors.

A bone-jarring hour later, Nuth reaches his field site. Visibility has improved, and Kongsvegen looks serene, its smooth surface sloping gently toward a fjord. “Kongsvegen’s calm appearance is deceptive,” Nuth says. “It has a history of erratic behavior.” In 1948, the glacier disgorged a massive amount of ice and debris—there are no reliable estimates—into the fjord and sideways toward its neighbor, Kronebreen. Then it slowed to become one of the world’s pokiest glaciers, creeping about 2 centimeters a day. Kronebreen, in contrast, exhibits no such vagaries, maintaining a steady pace of 3 meters a day.

Now, Kongsvegen may become unruly again. Its upper reaches, where snow accumulates, are getting steeper, and it is picking up speed. Kneeling in the snow, Nuth connects solar panels to a GPS receiver anchored into the ice. A network of sensors here and on Kronebreen will allow his team to measure the ice’s motion to millimeter accuracy.

Preliminary findings show that in warm and wet conditions, the glacier’s surface can rise as much as a third of a meter—a massive hydraulic effect from meltwater pooling under the ice, Nuth believes. “It’s quite amazing,” he says. “That’s a lot of water to lift hundreds of meters of ice.” Often, the ice flows faster when it rises—more evidence for the role of meltwater in surges. Next year, the team will install seismometers to listen in on the flow of water through and beneath the ice, and to crevasse formation.

The scientists on Svalbard hope that wiring up the neighboring glaciers will reveal why they move at wildly different rates. They also hope the findings will yield broader insights into ice flow mechanics, which could save lives and aid forecasts of sea level changes. Nuth believes Kongsvegen may be on the brink of letting loose, as it did 70 years ago. “We may even capture a glacier surge,” he says. “You never know.”

Jane Qiu is a science journalist in Beijing. Her trips to Aru, Tibet, and Ny-Ålesund on the Svalbard archipelago were supported by journalism fellowships from the International Water Management Institute and the European Geosciences Union, respectively.
Ice on the run
Jane Qiu

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