news feature

The bolt catchers

Every summer, Florida plays host to researchers who fire rockets at the sky to create lightning. And having captured the bolts, the group has found something shocking, as Mark Schrope finds out.

The early Greeks saw it as a weapon of the gods, and throughout history lightning has been viewed almost universally as something best avoided. But at a desolate patch of sand and grass in northern Florida, a handful of researchers gather each summer to call down lightning from the sky in the name of science.

Lightning strikes are unpredictable, and the research is turning out that way too. Amid studies to find fresh ways to protect homes and businesses from the wrath of storms, scientists examining the basic properties of lightning were struck by a bolt from the blue. For decades, it would seem, physicists have been working with incomplete models of these electrical discharges.

Key to the success of the studies is a high natural occurrence of thunderstorms — and a rocket launcher. In the 1960s, researchers showed that lightning can be generated in a controlled fashion by firing a rocket, trailing a grounded wire, at a thundercloud.

"Even though lightning is something you don't want to mess around with, the advantage of triggered-lightning studies is that you can actually capture lightning to measure its currents," says Paul Krehbiel, a lightning researcher at the New Mexico Institute of Mining and Technology — known as New Mexico Tech — in Socorro.

Scientists at flash points around the globe now use the rocket-and-wire technique to create and study lightning. Florida boasts some of the highest strike rates for natural lightning on the planet, and at the International Center for Lightning Research and Testing at Camp Blanding military base, scientists have triggered lightning during each thunderstorm season for the past 11 summers.

At the heart of the 40-hectare facility, operated by the University of Florida in Gainesville, is a 12-metre wooden tower topped by eight rocket launchers. Scattered around the tower are detectors that measure when the surrounding electric field is high enough for lightning strikes. As the facility's co-director Martin Uman explains, the electric field he and his team look for before launching a rocket just exceeds that which halts rocket and shuttle launches by NASA.

When conditions are right, a technician in a nearby trailer packed with monitors triggers the launch of a one-metre rocket trailing 700 metres of Kevlar-coated copper wire grounded to cables on the tower. The system succeeds about half the time with the wire literally burning up in a blaze of lightning glory.

Much of the physics involved is still poorly understood, but in basic terms lightning begins when excess negative charge builds up in a cloud and creates a downwardly moving spark invisible to human eyes. Called a step leader, this spark can reach the ground in about 20 thousandths of a second. The large negative charge in the spark induces positive charge on the ground as it approaches, creating sparks that move upwards. Once a step leader meets an upward spark, a continuous path between cloud and ground is formed along which charge from the cloud is dumped to create the luminous display we know as lightning.

The conductive wire carried by the rockets essentially reverse this process — as do skyscrapers at times — by initiating an upwardly moving spark that reaches a charged zone above. Once a channel is formed, the wire disintegrates under the blistering temperatures (between 8,000 °C and 33,000 °C) of the discharge, and the lightning itself is essentially the same as a natural bolt.

This summer, Uman's team is studying systems for protecting buildings and power lines from lightning. The group directs the electricity from triggered lightning through cables to a lightning rod attached to a newly built house just a few metres from the tower and to a full-size power-line system.

J. DWYER/UNIV. FLORIDA LIGHTNING RESEARCH GROUP

M. UMAN/LIGHTNING RESEARCH GROUP

No flash in the pan: researchers are generating their own lightning (above) to gain insight into bolts from the blue.

Protect and survive

The rod is part of a commercial lightning-protection system, which aims to divert most of the lightning's current away from the house to the ground. This protection system has generally performed as designed, but in all the triggered experiments the currents recorded in the house have exceeded theoretical expectations. "The measurements so far look very good," says Uman, "but we don't understand them completely, which means that it's not the simple situation everyone would like to think."

Uman explains that most protection systems are based on laboratory experiments

N. MEDINA/SPL

and theory, rather than on studies of lightning itself. But customers need to know how well the equipment works in practice. For example, power companies want to protect their power lines from the disruption caused by lightning but they need to weigh the benefits against the cost of upgrading their protection systems.

When lightning hits the house, detectors at the site measure each bolt's electric field, and digital cameras capture the strikes from every angle, providing data for fundamental research. Uman and the researchers at Camp Blanding work closely with scientists from other institutions, such as Joseph Dwyer of the Florida Institute of Technology in Melbourne.

In 2002 Dwyer began tackling a question that lightning researchers have struggled with since the 1920s: does lightning produce X-rays? The debate has rumbled on for decades, although researchers at New Mexico Tech published tantalizing results in 2001 that strongly indicated that X-rays are emitted near natural lightning[1]. Dwyer believes that triggered lightning offers the potential to answer the question once and for all.

Dwyer and his colleagues measure X-rays using off-the-shelf radiation detectors held inside heavy, welded aluminium cases that block out electromagnetic interference from thunderstorms. The equipment also features fibre-optic connections to protect against stray incoming electrical signals.

The team first deployed the detectors near the rocket launch tower in 2002 and, after studying 26 triggered bolts, became convinced that lightning reliably produces X-rays[2]. Dwyer says that the data were so decisive and repeatable that it is now clear that X-ray emission is a major characteristic of lightning omitted from previous models. "There is something fundamentally wrong with our understanding of how lightning works if we can miss such a big ingredient," he says.

In general, the emissions seem to be associated with the upward sparks and possibly the very beginning of the bright lightning stroke. They come in brief microsecond-long bursts, with energies comparable to those used to take dental X-rays.

Shock to the system

But in summer 2003, the group's last rocket-triggered bolt of the season revealed something even more incredible than the X-ray emissions. An unusually strong current pulse arrived at the detector before the lightning was fully under way. Such spikes happen occasionally, but are not well understood.

During this early spike, the instruments recorded hundreds of γ-rays 10 to 300 times more powerful than the X-rays they had been observing[3]. The team believes that these rays originated several kilometres above the ground, based on the time that they arrived at the detectors. Such intense γ-rays could possibly be detected from space if anyone were looking. They might even explain radiation bursts recorded by Earth-orbiting satellites during thunderstorms.

Because of atmospheric absorption, the intensity of γ-rays at the detector is far lower than would be found in the cloud. But the exact point at which the bursts originate has yet to be confirmed. This year, Dwyer and his team hope to pinpoint the source by using modified detectors that are shielded so that only rays from a single direction can get in.

It is not yet clear what causes either the X-rays or the γ-rays, but Dwyer leans towards an unproven atmospheric process called runaway breakdown, first suggested in 1961. Subatomic particles such as electrons are peculiar in that the faster they move, the more the drag acting on them is reduced. The idea is that electrons could be accelerated by strong electric fields inside a thundercloud or near lightning, ultimately approaching the speed of light because of reduced drag. As these high-energy electrons collide with air molecules they could create yet more electrons, eventually generating the X-rays and γ-rays.

Storming ahead

Dwyer also believes that runaway breakdown could play a role in causing lightning itself. Conventional wisdom says that lightning is initiated when charge builds up in clouds to such an extent that the associated electric field overcomes air's insulating ability. The resulting breakdown allows current to flow through the air, creating the first spark. But this would theoretically require an electric field larger than has ever been measured in association with lightning. Runaway breakdown, in contrast, could involve an electric field ten times smaller, which is closer to the measured values.

We can expect lightning research to accelerate if work planned for later this year at New Mexico Tech proves successful. An international collaboration plans to test the idea that laser pulses can be used to trigger lightning by ionizing air to create discharge paths. Historically, all tests of this theory have failed, but the group will be using a terawatt laser — the most powerful laser ever applied to the problem. Lasers are more expensive than rocket launchers, but laser triggering would allow almost unlimited attempts at lightning generation during thunderstorms.

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> — Joseph Dwyer

Even without such power, Dwyer feels lucky to be doing lightning research. "Usually there are so many people in a field that you have to spend years doing something to make your mark," he says, "but we can make a discovery with just about every measurement." ■

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