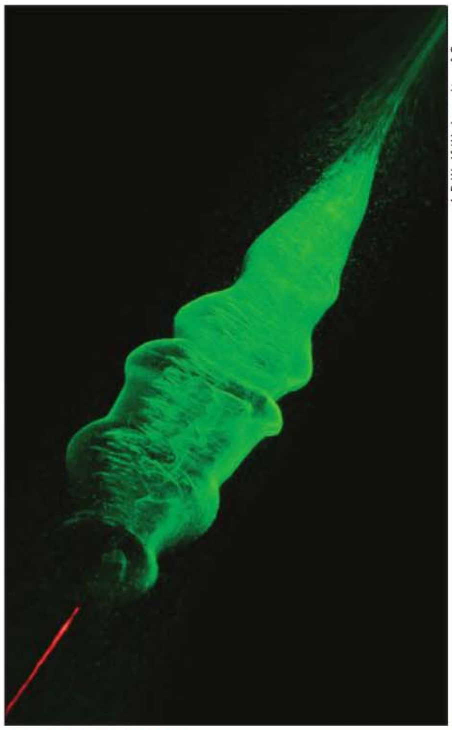
And let there be rain

Shooting laser beams into the sky could one day be used to control the weather. Belle Dumé investigates one research project that has managed to create the precursor to rain and direct the course of lightning bolts using high-power laser pulses

For millennia humans have dreamed of commanding the weather at will. However, with the exception of some cloud-seeding techniques, there has only been limited success in this endeavour. One promising new technique for controlling both rainfall and lightning involves firing lasers into the air to ionize nitrogen and oxygen atoms. Called laser-assisted water condensation, the method is being developed by Jérôme Kasparian and colleagues at the University of Geneva in collaboration with Ludger Wöste's team at the Free University of Berlin.

Conventional cloud seeding usually involves dispersing tiny particles such as silver iodide in the air using aeroplanes, rockets or cannon. These particles act as nucleation centres for the formation of ice crystals that grow until they are so heavy that they fall to the ground. As well as attempting to make it rain in a certain place, cloud seeding is also done to suppress hail and fog or even to prevent it from raining at a downwind location. However, not everyone is convinced of its efficacy and large quantities of silver iodide can be toxic. As a result, scientists are looking for alternative ways of making it rain.



J-P Wolf/University of Geneva

Explosion of droplets When a red laser is fired into a cloud chamber, it creates a trail of condensation, which is shown illuminated in green.

Thunderbolts and lightning

One such technique involves "laser filamentation", which is a non-linear mode of light propagation that occurs when ultrashort, high-power laser pulses are fired through the air. Such pulses are typically femtoseconds in duration and deliver peak powers in the gigawatt and terawatt range.

In this propagation mode, the light pulses are confined to a filament as small as 0.1 mm in diameter, but which can stretch across tens to hundreds of metres in the air. The filament is created from a dynamic balance between self-focusing of the laser light caused by the Kerr effect and defocusing effects related to free electrons produced when the intensely focused laser beam ionizes oxygen and nitrogen atoms in the air to create a plasma.

It is this long plasma channel that allows such a laser beam to control lightning. The plasma conducts electricity, offering an easier path for electric discharges. "We have already shown that this easier path allows the breakdown voltage in a laboratory 'storm' to reduce by 30%," Kasparian explains. "The discharge, or lightning streak, can be guided across distances of several metres, and the plasma channels could even influence how lightning precursors, such as corona discharges, form in thunderclouds." Ultimately, the technique could be used to divert lightning strikes away from sensitive areas and equipment towards safe areas where little or no damage would be done. The technique could also be used to improve our understanding of the underlying physics behind lightning – with the aim of building more sophisticated lightning-protection systems in the future.

> The possibility of controlling some aspects of the weather provides a powerful incentive for developing appropriate technologies

Making it rain

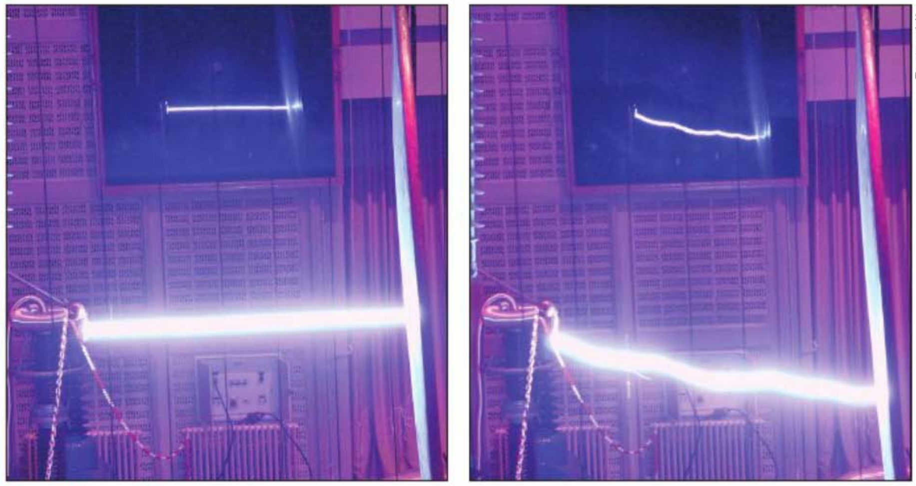
The method for producing rain works on a slightly different principle. Intense pulses of infrared laser light with a wavelength of about 800 nm are used to initiate chemical reactions in the air within the filament. This process produces compounds such as nitric acid, which are hygroscopic and are able to bind water molecules to their surface. This attracts more water that eventually forms droplets, which then coalesce and become as large as several micrometres in diameter. Such droplets are still too small to form raindrops, but Kasparian hopes that the technique will one day be able to produce larger drops that are several millimetres across.

The technique could deliver several benefits over current seeding methods. A laser beam can be swept across the sky, for example, allowing rain to be created in a much larger region than is possible with conventional seeding. Furthermore, the laser pulses appear to create droplets under a wider range of atmospheric conditions than silver iodide – at least in the laboratory.

The concept could be used to create raindrops near mountains, for example, or in areas with 70–80% relative humidity. "Water droplets normally evaporate in these areas, but this might be prevented to some extent if the atmosphere is first activated by a laser," explains Kasparian. The technique might even be employed to delay rain from an air mass arriving over land from the the sea. In Mediterranean regions, for example, this may help to move rain deeper into the land.

The technology is possible thanks to a technique called chirped pulse amplification, which allows the researchers to create the beams of high-power femtosecond pulses. "The increase in the available peak power – for example by a factor of almost 100 for commercially available systems in the last 10 years – has opened the way to up-scaling laboratory trials to real-world demonstrations in the atmosphere," says Kasparian.

Laser weather control



Laser-like precision A 3 m long electrical discharge follows the linear path of a laser beam (left) rather than the familiar jagged path with no laser beam (right).

Teramobile

Future challenges

Despite these developments, it is not all plain sailing from here, with weather control using laser filamentation facing three main challenges, according to Kasparian. First, researchers must find a way to increase the available laser power even further to be able to affect the atmosphere over the range of a few kilometres. Second, more effective pulse-shaping strategies will be needed to increase the lifetime of the plasma – something that will be crucial to guiding lightning strikes over these distances. Finally, although laser technology has advanced significantly in recent years, making more compact and robust systems possible, these need to be reduced in size even more so that they can be easily transported in the back of a van, for example, to the site of interest. This is simply not possible at the moment.

The possibility of controlling some aspects of the weather provides a powerful incentive for developing appropriate technologies – especially for vendors of laser and optics equipment. "Experiments on weather modification currently amount to hundreds of millions of dollars a year around the world, despite the lack of real proof that the strategies will work, and new techniques would certainly increase this budget even further," explains Kasparian. "Even if the laser-technology part remains a small fraction of this budget, it still represents a huge opportunity for the community".

Jean-Claude Diels of the University of New Mexico, who holds several patents on related technologies, cautions that the development process is indeed "not plain sailing". "Numerous groups around the world have started such research, to see their funding terminated by impatient sponsors," he explains. He applauds the Geneva-based World Meteorological Organization for supporting Kasparian's team and also for hosting the first Conference on Laser-based Weather Control in October 2011. "It will take international collaboration and long-term support to succeed, that is what basic research is all about," he adds.

Geopolitics will be crucial

Beyond the technology challenges, anyone wanting to make it rain would have to consider the broader geopolitical issues. For example, if rain is made in one country or state, could the neighbouring areas lose out? Water is a rare commodity in many regions of the world, and competition between different countries, regions, or even people living in the same territory, for this precious resource are predicted to lead to conflicts in the future, which could be exacerbated by effective rain-making technologies. Indeed, Kasparian says that the issues are not restricted to laser technology itself, or even cloud seeding, but already concern more basic techniques linked to water demand and supply – even simple pumping and irrigation.

"Examples of such conflicts can already be cited," he states. "They include the exploitation of transnational water tables, such as those in some South American countries; river pumping, for example in the Rio Grande or Jordan rivers; or sharing limited water resources between agriculture and tourism in arid regions, but also in areas like the Alps, where large amounts of water are often needed to produce artificial snow."

Cloud seeding is not that different from these issues, Kasparian claims, except that clouds would never condense more than a few tens of per cent of the available water vapour in any given region. "While it is technically possible to pump almost the entire contents of a river, the same cannot be said for the water harvested during weather modification, which could never exploit the whole resource," he says.