# Mathematics **in the Borderlands**

Normally, **Peter Benner** and his colleagues at the **Max Planck Institute for Dynamics of Complex Technical Systems** in Magdeburg work on complicated numerical methods to optimize the automatic control of technical systems and equipment. Recently, however, their research was applied to resolve a political conflict centering around drug cultivation, herbicide spraying and border violations in South America.

TEXT **UTE KEHSE**

Back in 2008, Peter Benner and his former doctoral student Hermann Mena were presented with a very unusual challenge: they were asked to calculate the drift of the herbicide glyphosate in the border region between Colombia and Ecuador. Ecuador had just brought a lawsuit against Colombia in the International Court of Justice. It accused Colombia of having for years sprayed coca plantations near the Ecuadorian border with glyphosate, and claimed that the poison had also settled on Ecuadorian soil.

The lawsuit was the culmination of a conflict with a long history. The spraying campaign was launched in 2000 as part of Plan Colombia, a US-funded program initiated in 1999 to fight drug cultivation across Colombia. The object was to destroy the coca plants that provide the raw material for cocaine by spraying them with the non-selective herbicide glyphosate. Until 2005, Colombian aircraft circled at least once a week over the forested mountains in the south of Colombia, spraying the herbicide over the coca fields.

## THE WAR ON DRUGS HAD SIDE EFFECTS

In doing so, Ecuador claimed, the Colombian aircraft had repeatedly committed border violations. The herbicide not only caused the coca plants to wither, but also killed corn crops and plantain and yucca plants in Ecuador – at least according to inhabitants of the border region. They also reported damage to their health, including skin irritations, respiratory disorders, gastrointestinal problems, dizziness and headaches.

In 2005, the two countries reached an agreement: a 10-kilometer strip along the border on the Colombian side was

Chemical cudgel from the air: The herbicide glyphosate was sprayed from aircraft to destroy illegal coca plantations.

Photo: dpa Picture-Alliance


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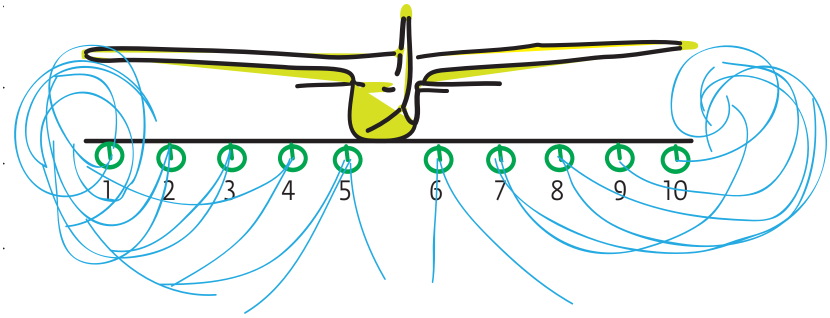
to remain a glyphosate-free zone. Officially, the crop-spraying aircraft haven't been in operation since 2007. Nevertheless, Ecuador has repeatedly accused its neighbor of violating the agreement. By bringing a lawsuit against Colombia in 2008, Ecuador wanted to put an end to the incursions once and for all.

However, it turned out to be very difficult to prove the accusations. The border runs through jungle terrain, the airspace isn't monitored, and glyphosate decomposes rapidly so that, after three weeks, it is no longer detectable in the environment. Thus, no traces of the substance could be found when people from the competent authorities, following up on complaints from inhabitants, traveled to the border region to collect samples.

## A YOUNG MATHEMATICIAN FROM ECUADOR

The question was thus how to prove the alleged border violations. This is where Hermann Mena enters the picture. Formerly an associate professor at the Escuela Politécnica Nacional (EPN) in the Ecuadorian capital of Quito and now assistant professor at the University of Innsbruck in Austria, Mena was tasked with carrying out a research project for the Ecuadorian Science Foundation SENESCYT.

Hermann Mena and Peter Benner had met in 2003 during a DAAD-sponsored program between TU Berlin and the Escuela Politécnica Nacional. The aim of the program was to expand postdoctoral education in mathematics in Ecuador. Benner gave an intensive



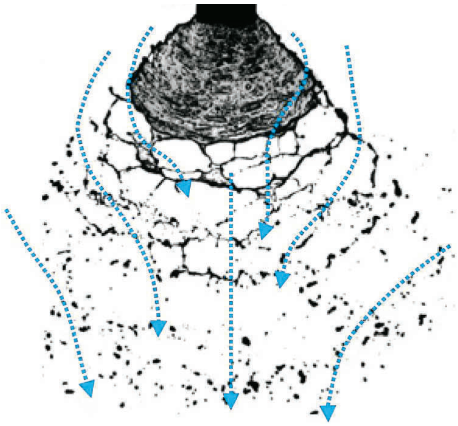



Photo: dpa Picture-Alliance; graphic: MPI for Dynamics of Complex Technical Systems

left page: In the dense jungle, coca plantations are best spotted from the air. The photo shows a plantation in Guaviare, a thinly populated region in the southeast of Colombia.

this page: Members of an anti-drug police unit destroyed a cocaine laboratory in the province of Tolima.

course in applied mathematics in Quito and was able to take Mena on as a doctoral student. In 2007, Mena became the first mathematician to be awarded a Ph.D. by an Ecuadorian university.

## USING MATHEMATICAL FORMULAS TO COLLECT EVIDENCE

In order to present iron-clad scientific proof against Colombia, the Ecuadorian government launched a total of four research projects. Two of them concerned the long-term effects of glyphosate on humans and amphibians. A third investigated whether the substance has long-term effects on plant growth. The fourth project dealt with applied mathematics: a computer program was to numerically simulate the drift of the herbicide sprayed within the border zone.

It's no big deal for mathematicians to calculate the mixing of two substances. To do so, they use what are known as convection-diffusion models. The numerical equations for such models describe how particles interact and spread as a result of random motions and large-scale currents.

"It's a classic. Such models are used, for example, in meteorology and chemical engineering, and also in various ways at our institute," says Peter Benner, now Managing Director at the Max Planck Institute for Dynamics of Complex Technical Systems in Magdeburg. "Specifically, the aim here was to determine whether and, if so, under what conditions the sprayed glyphosate could reach Ecuador." Hermann Mena was appointed project head. He

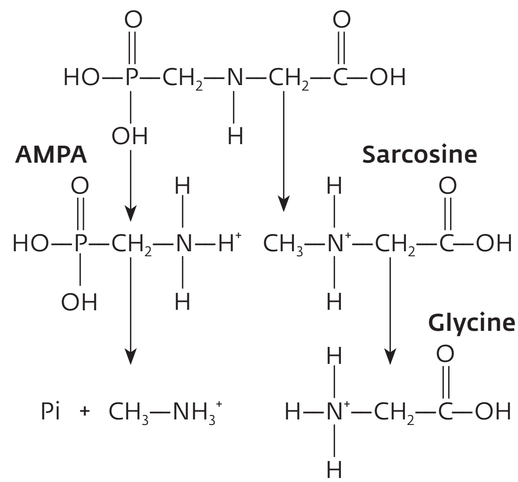
left page, left: Diagram of the wake turbulence behind a crop sprayer. The eddy currents are formed as a result of lift generated on the wings. They affect the drift of the sprayed glyphosate.

left page, right: Flow characteristics near the spray nozzle: In the zone just behind the nozzle, the individual drops break up and are dispersed as a fine mist.

this page: High-speed photographs of a glyphosate droplet. The droplet initially flattens, then turns inside out and finally breaks up into myriad droplets.

Photo: dpa Picture-Alliance; graphic: MPI for Dynamics of Complex Technical Systems

Glyphosate




Chemical formula and breakdown pathways of glyphosate. The main breakdown product is amino-methylphosphonic acid (AMPA); sarcosine and glycine are also formed. The herbicide glyphosate was introduced in 1974 under the name Roundup. The substance inhibits the enzyme 5-enolpyruvylshikimate-3-phosphate synthase (EPSPS), which plants require to synthesize certain amino acids.

recruited his former doctoral supervisor as an advisor, because at the time there were still no scientific institutions in Ecuador capable of carrying out such a project.

The two scientists were faced with the task of calculating the drift of the sprayed herbicide droplets. This isn't a daunting problem in itself: "The mathematical description of the basic problem is standard, and good software exists for solving it," says Benner. To adapt the software to their specific needs, the researchers worked with Jens Lang from TU Darmstadt.

Several physical processes determine the movement of droplets: first, diffusion, or in other words, random motion; second, convection, that is, transport via air currents. A third factor, turbulence, also plays a role, for example in the wake generated by an aircraft. "But we didn't take turbulence into account because, otherwise, the calculations would have required too much computing power," says Hermann Mena.

## SIMPLE MODELS THE COMPUTER CAN HANDLE

Simplifying complicated mathematical models without sacrificing the accuracy of the simulation results is Peter Benner's forte. He heads the Computational Methods in Systems and Control Theory Group at the Max Planck Institute in Magdeburg. Researchers there investigate complex technical processes, particularly in the fields of chemical engineering and biotechnology. With their simulations and models, Peter Benner and his colleagues are a great boon to chemical engineers. "Computer simulations are increasingly being used to optimize the control of complex systems," he says.

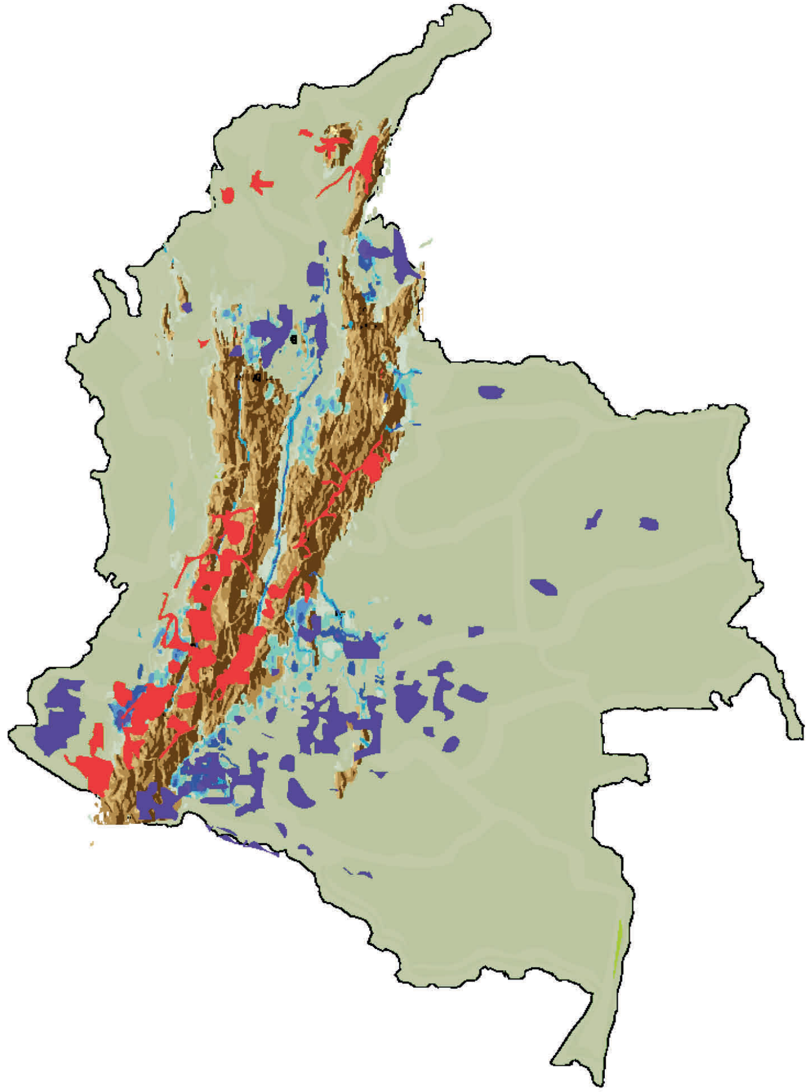
For example, when engineers develop a chemical process, they have to consider many factors. How rapidly do the substances mix in the reactor? What is the optimum mixing ratio? Which catalyst is suitable? "Engineers generally have a good grasp of how to proceed, but mathematicians can often improve the yield by several percentage points," Benner points out. In the chemical industry, that can mean savings of millions of euros.

But to achieve this optimization effect, the models have to run countless times with many different parameters. Because that still takes too long even with today's computers, Peter Benner and his fellow scientists develop so-called surrogates – simplified models that are automatically calculated by mathematical methods, but whose accuracy is sufficient for the task at hand.

"It's a bit like the approach taken in digital photography," says the Max Planck Director. If the color value of every pixel were stored, the memory cards of modern cameras with a resolution of ten megapixels or more would soon be full. In the JPEG format, the image data isn't stored pixel

Peter Benner, Managing Director at the Max Planck Institute for Dynamics of Complex Technical Systems, is an expert in computer modeling.

Photo: MPI for Dynamics of Complex Technical Systems – Bastian Ehl; graphic: MPI for Dynamics of Complex Technical Systems



Drug cultivation in Colombia: The map shows plantations of coca (blue) and opium poppy (red) in 2005. The border with Ecuador runs in the southwest of the country, where the fields are concentrated.

by pixel. Instead, it is compressed with the help of computer algorithms with only acceptable information loss in the process. The researchers in Peter Benner's department develop mathematical methods to compress numerical models, so to speak.

To calculate the glyphosate drift, Benner and Mena had to introduce only a few simplifications to make the model manageable. They selected a zone 13 kilometers long, 10 kilometers wide and 200 meters deep in the border area. They then divided the zone into innumerable cells using the classical finite element method and began to calculate.

## TOO MANY UNCERTAINTIES HINDER CONCLUSIONS

The dimensions chosen were based on the real dimensions of a model region. The researchers first calculated the drift in only one air layer and later in the entire quadrant. "The question was whether the entire glyphosate cloud settles within the ten-kilometer stretch leading to the border, or whether it continues to spread out," Peter Benner explains.

The main problem for the researchers was that they knew very little about the aircraft that sprayed the glyphosate. What was the shape of the spray nozzles? How large were the droplets? In what formulation was the glyphosate sprayed? How fast did the aircraft fly? At what altitude? In what weather? Because they were unable to answer these questions, Mena and Benner relied on estimates and published data. Consequently, they were unable to answer the original question unambiguously. "The quality of the result depends crucially on our ability to model the peripheral conditions," Benner stresses.

Theoretically, certain guidelines should be followed when spraying glyphosate. For example, the aircraft should take off only if the wind speed, air humidity and temperature are low. They should fly no higher than 25 meters above the ground and should produce the largest droplets possible so that the herbicide cloud doesn't drift widely. It's questionable whether these precautions were actually observed along the Colombia-Ecuador border.

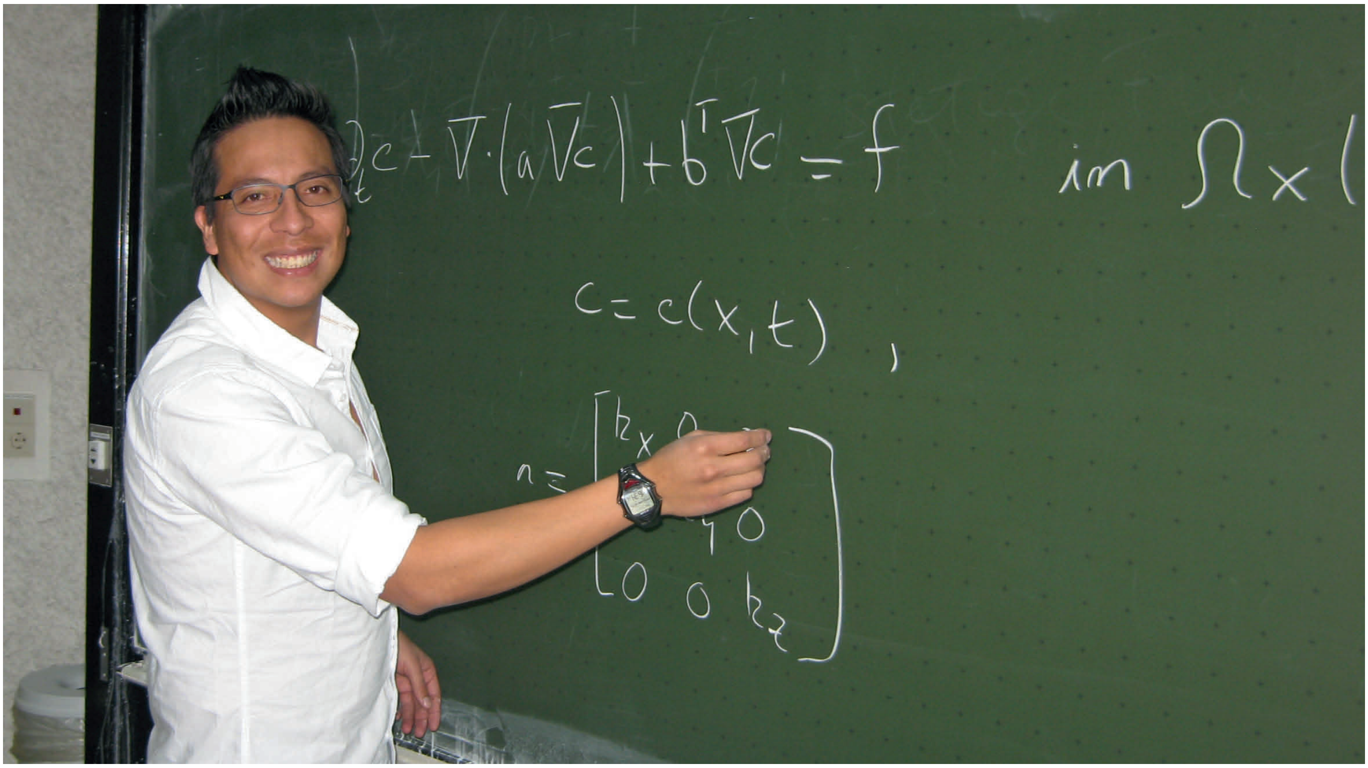
"The altitude of 25 meters is completely unrealistic," says Hermann Mena. The high trees in the Amazon rainforest and the mountainous topography prevent the pilots from flying low. According to Ecuadorian reports, the aircraft actually flew at an altitude of 80 to 100 meters above the ground. Colombia claimed they flew at an altitude of 30 to 40 meters.

## GLYPHOSATE DRIFT ACROSS THE BORDER IS POSSIBLE

For the researchers, the political conflict necessitated a fine balancing act. Both sides tried to influence the results. "We endeavored to be as objective as possible," says Hermann Mena. Together with Peter Benner and René Schneider of Technische Universität Chemnitz, he summarized the results in a recently published book, which draws no conclusion as to whether or not glyphosate drifted across the border.

The scientists merely investigated various scenarios and concluded that it is possible for the sprayed herbicide to have drifted to the Ecuadorian side un-

Graphic: MPI for Dynamics of Complex Technical Systems




Hermann Mena explains at the blackboard the model that he and his colleagues used to investigate the airborne drift of glyphosate. In 2007, Mena became the first mathematician to earn a Ph.D. in Ecuador.

der certain conditions, for example if the aircraft flew too high, the droplets were too large, the temperature and humidity were too high or the wind was too strong. "The reader can decide what conclusions should be drawn from the scenarios," says Mena.

Despite this rather vague outcome, the study was an important step forward for Ecuador. With the 203,026.80 dollars the government earmarked for the project, Hermann Mena built a powerful computer center for simulations at EPN Quito. "It was the first basic research project in Ecuador to be financed by the government," he says.

Peter Benner also regards the project as a success: "It greatly improved the standing of science and particularly applied mathematics in Ecuador." Politicians and industrialists now know that they can turn to mathematicians at the country's own universities to solve problems.

In September 2013, Ecuador withdrew its lawsuit in the International Court of Justice because the evidence wouldn't stand up in court. Nevertheless, Colombia has promised to pay 15 million dollars in compensation to Ecuador. Hermann Mena doesn't believe that Colombia will dare spray the herbicide so carelessly near the border again. In that sense, the conflict, which also drew on scientific arguments, was worthwhile: "The pilots will be much more cautious. That's a huge success for the people there." ◂

## TO THE POINT

- **Ecuador brought legal action against its neighbor Colombia in the International Court of Justice because of aerial spraying of the herbicide glyphosate.**
- **Scientists were asked to calculate the drift of glyphosate in the border region using methods from applied mathematics.**
- **Because of the multitude of parameters involved, the researchers were unable to provide an unambiguous answer. However, the project indirectly promoted scientific development in Ecuador.**

## GLOSSARY

**Glyphosate:** Discovered in 1950 by Swiss chemist Henri Martin, glyphosate is a chemical compound belonging to the family of phosphonates. The herbicide has been in use for more than 30 years to kill weeds. In comparison with other herbicides, glyphosate generally has lower mobility, shorter persistence in the environment and lower toxicity for animals – properties that are desirable for agricultural use.

**Plan Colombia:** The program was launched in September 1999 and was described by the Colombian President Andrés Pastrana as a "plan for peace, prosperity and rejuvenation of the state." It called for the deployment of the army for policing duties. Plan Colombia was motivated by the war on drugs, and aerial spraying of coca plantations was an important element of the project. However, the spraying led to environmental damage and health damage, particularly to inhabitants of the affected regions.