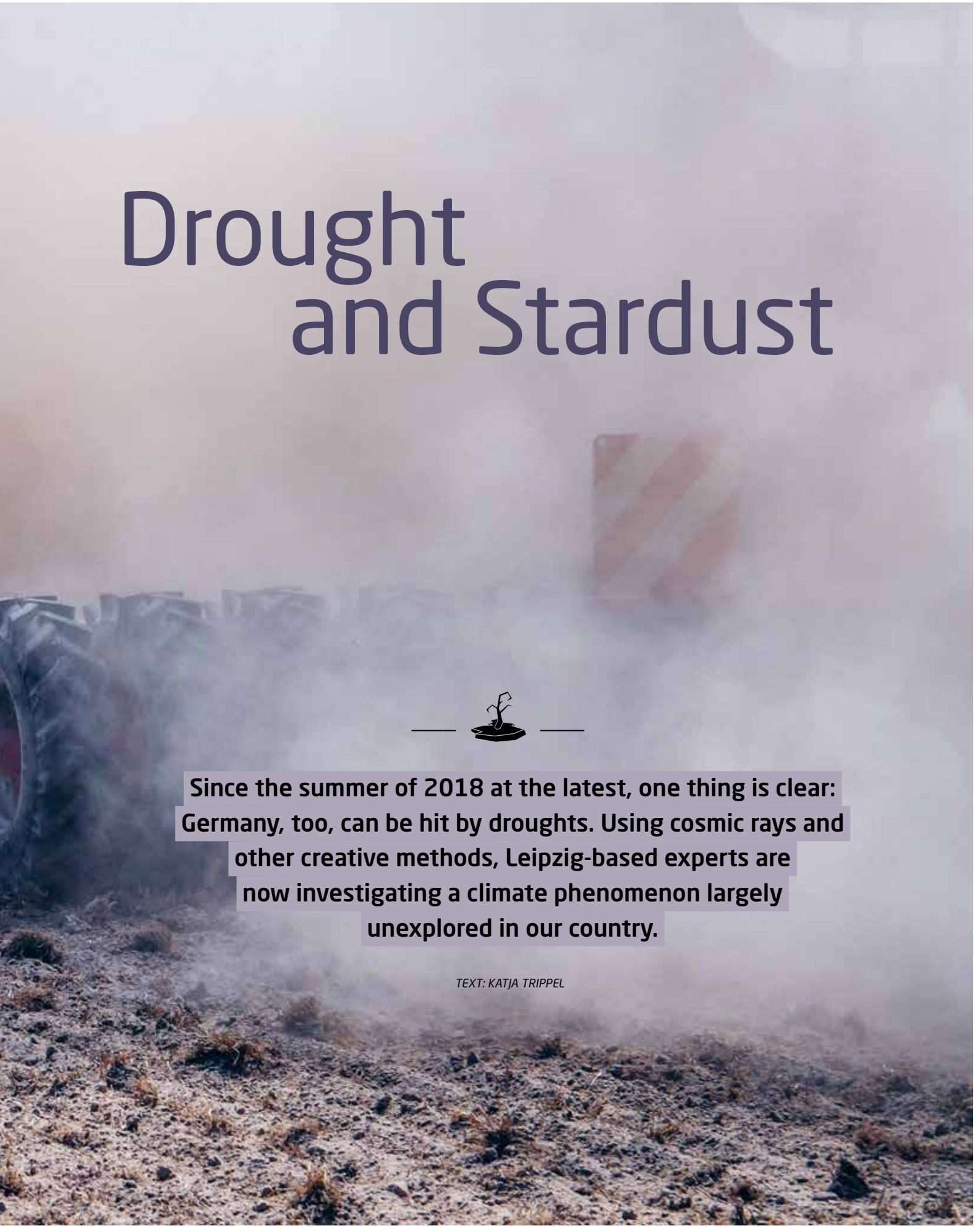
Clouds of dust are kicked up and obscure the view as a farmer drills rapeseed into the dry soil near the town of Heinersdorf, Brandenburg in August 2018.

Drought and Stardust



Since the summer of 2018 at the latest, one thing is clear: Germany, too, can be hit by droughts. Using cosmic rays and other creative methods, Leipzig-based experts are now investigating a climate phenomenon largely unexplored in our country.

TEXT: KATJA TRIPPEL

In October 2018, this jetty on the Edersee reservoir in northern Hessen is still high and dry. Due to prolonged extremely dry conditions, the reservoir's water level shrank to just a quarter of the normal level.

PARTICIPATING HELMHOLTZ CENTRES: FZJ, GEOMAR, GFZ, HMGU, KIT, UFZ

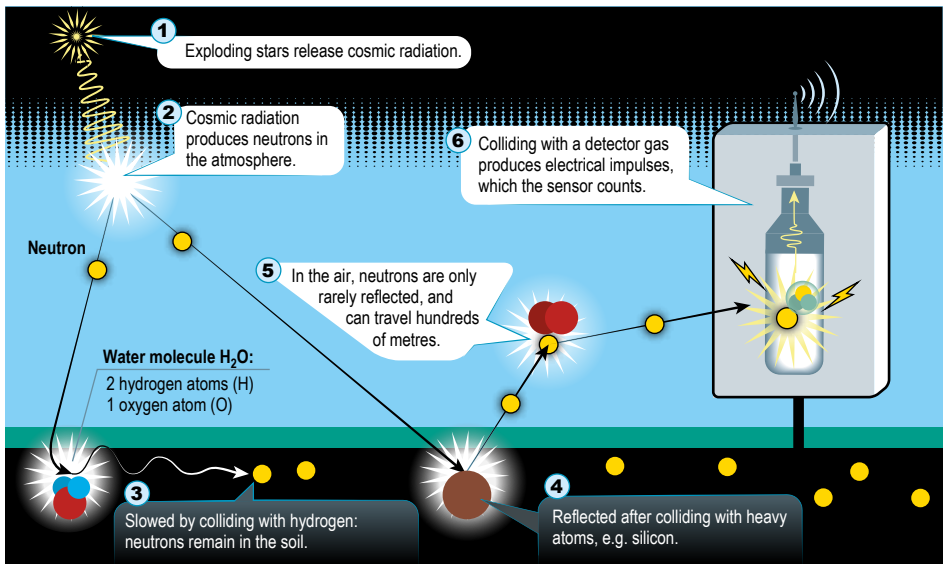
The cosmic-ray measuring device in the boot of the UFZ Land Rover can gauge the soil moisture in a 150-m radius and down to a depth of 50 centimetres.

All of us can recall the 'endless summer' in 2018: blue skies, sun, and temperatures that felt like Bella Italia. But there were other aspects, too: fields of withered crops, ships sitting on dry land, trees shedding their leaves in August, even wildfires. In Mecklenburg-Vorpommern, the peatlands began drying up, and in Bingen am Rhein, tourists could walk to the Mouse Tower, located on an island, without getting their feet wet – the riverbed had hardened into a bricklike surface.

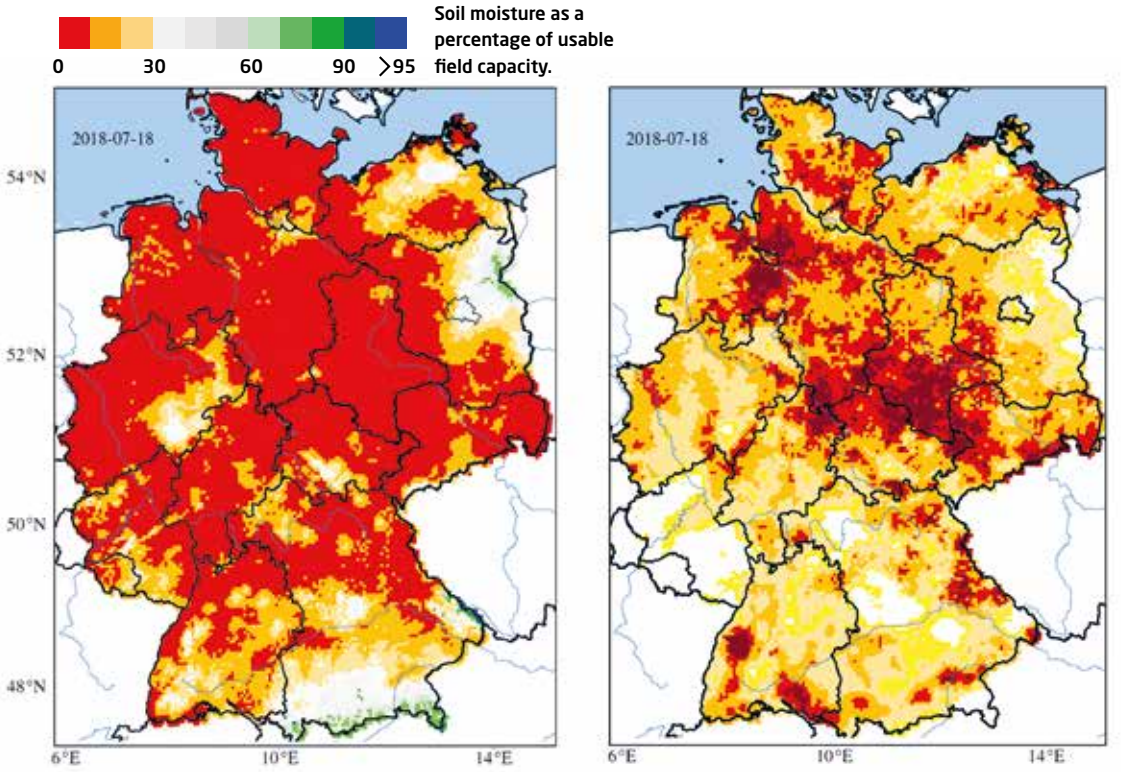
A question of soil moisture

In fact, last year's temperatures nearly beat the 'heat wave summer' of 2003, the hottest in Germany since the beginning of weather records in 1881. By early April, in Ohlsbach, Baden the mercury had already risen above the 30-degree mark, and in May and June the whole country suffered temperatures up to 34 degrees. That being said, in 2018 we had virtually no rain from April to November. As a result, the 'hot phase' – Germany's phrase of the year for 2018 – became a veritable drought. But are droughts even possible in Central Europe? "Unfortunately, yes," says Dr Andreas Marx from the Helmholtz Centre for Environmental Research (UFZ) in Leipzig. He and his team began investigating the topic back in 2008. Marx explains: "It's not heat that creates droughts, but dryness. However, heat can accelerate evaporation on and in the soil."

As a result, on a 30-degree day, small bodies of water like garden ponds can lose up to six litres of water per square metre. And dried-out soils make it harder for trees and plants to pump sufficient water to supply their trunks, stems, leaves or fruits. "Accordingly, the key criterion for identifying a drought



A cosmic-ray measuring device counts the number of neutrons reflected by the soil. The more moisture the soil contains, the more neutrons remain in the soil.



DROUGHT MONITOR:
In August 2018, the conditions in several large regions in Germany ranged from unusually dry to extreme drought conditions (right-hand map). The absolute moisture in the topsoil, i.e., the amount of water available to plants, was predominantly less than 10 percent, as the left-hand map shows. By way of comparison: if the number drops below 30 percent, most plants begin suffering the effects of water stress.

is the soil moisture," Marx says. "When it drops to 20% below the long-term average for a respective site, it's considered to be a drought."

Drought Monitor gives an overview

To share their findings with the public, in 2014 the researchers introduced the online 'Drought Monitor' on the UFZ website. All it takes is a quick glance at the map of Germany to see the status quo: colours from blue to dark red indicate whether or not there is a drought. For example, in late August 2018, more than 95 percent of the country was red, i.e., the soil was dry as a bone - drier than in any summer since 1951, the first-ever year to be entered in the Drought Monitor. Though temperatures dropped somewhat in the autumn, the lack of rainfall worsened the drought.

"The Drought Monitor has attracted considerable attention, particularly in agriculture or forestry," says Marx. "But also among people working in shipping or drinking-water provision." In addition, hobby gardeners often call the UFZ to ask how often they should water their flowerbeds; or because they don't trust the results on the Drought Monitor. For example, in the autumn of 2018 several citizens of Brandenburg wanted to know why their region wasn't marked dark red on the Monitor map; it had to be (they were sure) a mistake! Marx's response: Brandenburg's soils become so dry nearly every summer that the deviation in 2018 was less extreme than elsewhere. The situation was just the opposite in the Harz, Germany's wettest region: here the map entry was dark red, even though there had been rainfall – but much less than normal.

"So as to show the difference between relative and absolute soil moisture, we've now also put a map of absolute moisture values online. It simply shows the current situation, without any comparison to the normal values," Marx relates. As such, what it shows isn't the deviation from the norm, but the usable field capacity (uFC): the amount of water available to plants, which can range from 1 to ca. 300 percent. When the number dips below 50 percent, farmers begin watering their fields; if it drops below 30 percent, most plants start showing signs of water stress.

"Requests like this one are a great motivation for us to provide even better data," says Marx. The experts originally based their research on precipitation records, which have been gathered for centuries. By feeding this data into models, they can calculate how much water is stored in the soil, dating back to 1951. In contrast, direct measurements of soil moisture are hard to come by, and don't reach far back into the past.

For the latest generation of models, e.g. the mesoscale Hydrological Model (mHM), a team of researchers led by the hydrologist Dr Luis Samaniego from the UFZ relies on temperature, precipitation and evaporation data. They also combine it with satellite and geological data on the soil conditions. This is relevant because, depending on the type of terrain (mountains, prairies), ground (sand, stone, black soil) or land use (forest, crop field, asphalt-sealed surface), the capacity to absorb, store and evaporate water can vary substantially.

EXPERT SUPPORT IN TIMES OF NEED

Together with her father, Marion Gensel manages the agricultural and forestry operation Forsthof Sörgel in Grabow, Mecklenburg-Vorpommern. Over the past several years, she has planted a young mixed forest on a ca. 50-hectare plot (from a total of 670 hectares), which suffered massively from the drought-like conditions in 2018.

➡ ***Ms Gensel, why are you engaged in such large-scale reforestation efforts?***
Working on behalf of the City of Schwerin Roads Office (Straßenbauamt), we're carrying out ecological compensation measures, which were made necessary by the construction of the A14 motorway. In the autumn of 2015 we began working on unprofitable cropland and the former grounds of the defunct brickyard in Malliß, where we started planting a mixture of field maple, sycamore maple, Norway maple, pines, locusts, oaks, larches, orchard trees, firs etc., as well as colourful forest borders with hedges and wild fruit-tree species. The reforestation was slated for completion in 2018.

➡ ***But then the drought kept you from completing your plans?***
Yes, unfortunately. Because of the extremely dry conditions last summer and autumn, especially the young trees we'd planted in the autumn of 2017 and spring of 2018 were hard hit: more than half of the conifers didn't survive, and some areas were a total loss, because the young plants' roots never had a chance to reach the moist soil layers deeper down. Many of the trees planted the previous year also withered.

➡ ***Why did you then turn to the Drought Monitor for help?***
We had to prove to our customer that the damage was caused by abiotic factors – in this case, the unusually dry conditions – before we could apply for new funding, and to avoid having to pay a fine for breach of contract. After all, we had promised to deliver a healthy young forest on schedule. When I learned about the Drought Monitor, I requested detailed soil moisture data on our plot of land from the experts in Leipzig. The data showed minimal moisture levels, and confirmed that we hadn't done anything wrong; the drought was to blame. Thanks in part to this professionally prepared data analysis, the Roads Office agreed to cover the costs. Therefore, now we can replant the cultures we managed to salvage … and hope that 2019 turns out to be a wetter year! ■

Using cosmic-rays

Nevertheless, the best evidence that the experts were on the right track came from the stars. "Not from astrology," laughs Andreas Marx, "but with the aid of supernovae." Come again? As Dr Martin Schrön, a physicist at the UFZ in Leipzig, explains, "In Germany, roughly 30 'cosmic-ray' detectors are now being used to monitor soil moisture. Each is the size of a suitcase, and most are located at the sites of the TERENO network."
Schrön, Germany's Science Slam Master in 2015, has plenty of experience in making topics like measuring stardust easier to understand. "Cosmic radiation mainly comes from the explosion when a star dies. When these high-energy particles reach the Earth's atmosphere, they can set off various reactions. One of these leads to the creation of electrically neutral particles, or neutrons, which drift down to the Earth's surface, and can even penetrate the ground. In fact, neutrons can penetrate almost any material because they don't interact with the electrical field of atoms. However, sometimes neutrons hit an atomic nucleus. Since most nuclei are heavier than neutrons, this leads to a simple collision without significant energy loss. But the lightweight hydrogen atom is one exception where the neutron can lose most of its energy – and that's exactly where hydrology comes into play!"
While neutrons usually rebound from dry soils back into the air, the energy loss from hydrogen collisions leaves most neutrons stuck in wet soils. Hence, a detector for reflected neutrons above the ground can be used to gauge its water content. Moreover, the reflected neutrons travel hundreds of metres through the air and thereby provide a representative mean value over several hectares at any sampled location.
The method can be used to measure water in the ground, but also above ground. For example, at the TERENO site 'Hohes Holz' in Sachsen-Anhalt, Schrön installed cosmic-ray detectors in the forest canopy. "Trees intercept rainwater on its way to the ground, thereby reducing soil and ground water recharge," Schrön says. "With conventional methods it is virtually impossible to measure

LOOKING AHEAD

I'd like to find out whether neutron sensing could also work as an airborne technique, for example by using drones. If so, we'd no longer be limited to roads and could much more easily survey larger and less accessible areas like fields with heavy vegetation, conservation areas, and flood plains.

MARTIN SCHRÖN
Physicist, Helmholtz Centre for Environmental Research (UFZ)

Stunted and withered: the maize in a field in Ostwestfalen-Lippe in August 2018. This is representative of the significantly lower crop yields throughout Germany in the wake of the drought.

this intercepted water in the foliage. Cosmic-ray neutrons, however, interact with the water by scattering in large quantities before they are detected. With the new technology we can now estimate this important component."

Measuring with a Land Rover

Since 2014 the physicist has also been using a mobile cosmic-ray neutron detector in the boot of a UFZ Land Rover to conduct surveys all across Germany: through forests, across meadows and potato fields, motorways and mountain roads. "Our goal is to assess the reliability in various land use types. It has proven to be incredibly reliable, especially if the soil and vegetation properties in the area are already known," Schrön enthuses. "Taking the actual measurement is very convenient, since all I have to do is push the 'on/off' button. By nature, the detected neutrons interact with the soil root-zone down to a depth of 50 cm and within a radius of roughly 150 metres. This allows us to determine the area-average water content on the fly."

This year, Schrön's plan is to focus the campaigns with the rover on regions where the Drought Monitor requires better observations. Moreover, they will study the impact of heat waves – a highly relevant aspect for farmers and scientists alike. "In Nebraska, one of the USA's most important regions for maize production, this approach is already used to determine the irrigation demand in crop fields," says Schrön. In turn, researchers can use soil moisture data to estimate the likelihood of floods or droughts in various global-warming scenarios – e.g. depending on whether global temperatures rise by 1.5 degrees or 3 degrees over the next few decades.

However, neither the Drought Monitor nor the cosmic-ray Land Rover can tell us whether Germany will be struck by another drought in 2019. "The answer to that question truly does lie in the stars," says Andreas Marx.

IN BRIEF

- **With a mean temperature of 10.4 degrees Celsius, 2018 was the warmest year since the beginning of weather records in 1881. In addition, it was the third-driest year ever recorded.**
- **Whenever the soil moisture drops to 20% below the long-term average for a respective site and month, it's considered to be a drought.**
- **Soil moisture can be measured with the aid of 'cosmic-ray sensors', which continuously count the number of neutrons that fall from the sky and are reflected from the ground.**