ILLUSTRATION BY OLI WINWARD

Feeling the heat

Earth-observation scientists are forging a way through an uncertain funding landscape to better understand a changing climate.

BY KRISTOPHER JAMES KENT

Steve Montzka, a chemist at the US National Oceanographic and Atmospheric Administration (NOAA) in Boulder, Colorado, is pragmatic when it comes to funding his research. "Throughout the 27 years that's been my career here, it's always been an issue, trying to maintain our capabilities and justifying our existence — and rightly so," he says.

Montzka leads a NOAA project that tracks the atmospheric levels of ozone-depleting substances, and made headlines this May after he and an international research team discovered an uptick of up to 38% since 2012 in global emissions of CFC-11, one of the chemicals banned under international law since 1987 (see S. A. Montzka *Nature* **557**, 413–417; 2018).

After narrowing down the possible causes of these results — eliminating factors such as a natural shift in the atmosphere or the demolition of CFC-containing buildings — the researchers concluded that new CFC-11 is being emitted somewhere in eastern Asia. In July, the Environmental Investigation Agency, a London-based non-profit organization, identified one culprit by reporting widespread use of CFC-11 in the Chinese construction industry, at a level that the organization says could explain the hike in emissions.

Montzka believes that discoveries such as that of his team prove the merits of atmospheric research.

But that isn't enough reason to rest easy. Even before Donald Trump took over the United States' presidency in January 2017, his often-hostile approach to global environmental policy, and corresponding proposed budget cuts to US environmental agencies such as the Environmental Protection Agency (EPA), had alarmed researchers.

The budget that Trump proposed for fiscal year 2018 would have reduced the EPA's budget by more than 30% to US$5.7 billion, before Congress stepped in to preserve the agency's funding. Trump's 2019 budget proposes a similarly huge cut to the EPA's budget.

Montzka explains that declining resources even before Trump's proposed cuts, such as the 2017 rollback from six to four NOAA Atmospheric Baseline Observatories, which carry out solar and atmospheric measurements, make it tougher to analyse the abundant data available. Further cuts would only exacerbate this problem. "News you can use: that's what we'd like to provide," Montzka says. "Substantial budget cuts, if they do occur, would make that more difficult."

What Montzka finds most worrisome, however, is "the waning interest of young scientists. Less funding from government programmes to government science agencies ▶

and universities means many fewer young scientists pursuing the field. Young scientists today are not turning to climate research in the US because of the negative outlook."

Earth observation is especially vulnerable to financial cuts, owing to the sheer expense of the equipment: a typical weather satellite might cost in the region of $290 million.

But climate scientists are finding ways to navigate the uncertain funding landscape. And they are also finding more opportunities for data-driven experimentation, made possible by new technologies and high-performance computing.

OBSERVING FROM A DISTANCE

Boris Quennehen is an atmospheric scientist at the French start-up Plume Labs in Paris, which is producing a personal, mobile-app-linked pollution monitor for the general public. Despite the company's focus on the personal, Quennehen believes that government-funded institutes have an indispensable role in environmental observation, one that companies such as his cannot be expected to fill in the wake of dissipating budgets. "The satellite data that agencies such as NASA provide for free are absolutely mandatory if we want to continue to understand the changing climate as our planet evolves," he says.

Kristie Ebi, a public-health scientist at the University of Washington in Seattle, says that underfunded national meteorological services, especially those from low income countries, sometimes try to make up the deficit by charging researchers exorbitant amounts of money to access their data. She recalls a time when her research group was quoted more than $100,000 for ten years of weather data. For this reason, she says, and in areas lacking other means of data collection, satellites are incredibly important.

Satellite technology has been fuelling Earth-observation studies since the launch of Sputnik 1 in 1957. Now, hundreds of satellites comprising systems such as the European Union's Copernicus, and NASA's Earth Observing System, collect and offer data on a host of measurements including sea and land temperature, atmospheric gases, air quality and sea-level changes. These data are typically given to the research community through open-source platforms. Why? To help with understanding, says European Space Agency (ESA) astronaut and geophysicist Alexander Gerst.

Speaking to *Nature* from aboard the International Space Station (ISS), Gerst says that improving understanding of complex Earth systems is the single most important ingredient for the success of future environmental research. "It's like a machine with a thousand buttons and levers; we do not know what this machine does," he says, "and how do we fix it, right? Can we just turn another two or three buttons, or is this going to make it better, or worse? We cannot answer this if we do not have any understanding of this climate system — things are going to get worse whatever we do."

Climate-change research is a focal point for ESA, says Gerst, something that will "of course" continue in future. Earth observation is an ongoing mission aboard the ISS, including studies into developing new technologies for satellites. This year ESA celebrated a significant milestone in its Earth monitoring. On 11 July, the agency announced that Sentinel-5P, its latest satellite and the first Copernicus satellite dedicated to atmospheric measurement, has produced its first data: air-pollution maps showing a range of trace gases that affect air quality. Using a cutting-edge spectrometer, Sentinel-5P can detect multiple air pollutants at city-level resolution.

PRIVATE AIR PURITY

Quennehen and his colleagues at Plume Labs are attempting to use their palm-sized pollution-detection device, dubbed Flow, which is nearing the end of its development and production phase, to educate the public. "People really do want to know what they breathe, but today they can't access that data by themselves," he says. "Ultra-local data is missing today in the existing monitoring networks."

Plume Labs is collaborating with research groups across Europe, in particular the atmospheric research laboratory CNRS-LISA in Paris, which provides the company with lab space and facilities. Quennehen says that, in return, Plume could help the CNRS, France's national scientific research organization, to save costs in mapping areas where data collection is challenging. "It's not easy to find funding for such projects," he explains. "Flow could help them to map pollution in remote areas for quite low prices."

PEOPLE REALLY DO WANT TO KNOW WHAT THEY BREATHE, BUT TODAY THEY CAN'T ACCESS THAT DATA BY THEMSELVES.

Because of the portability of the device, Plume is also courting interest from epidemiologists, who are keen to understand the pollution exposure of their study participants.

Another collaboration between a private company and researchers is taking place in London. The company Air Monitors, based in Tewksbury, UK, alongside researchers at the University of Cambridge's chemistry department, the National Physical Laboratory in Teddington and other partners, is installing 100 air-quality monitors across London. The monitors will connect wirelessly with a database, and will operate alongside Google Street View cars to draw a map of pollution on the city's streets in close to real time.

MANJUNATH KIRAN/AFP/GETTY IMAGES

Other private ventures are also taking advantage of greater public awareness to market new products to remove, measure and contextualize pollutants in the air. Molekule, in San Francisco, California, for example, says that its air purifier destroys indoor pollutants through a chemical process of photoelectrochemical oxidation. Foobot, based in San Francisco and Luxembourg, offers a home detector that tracks air pollutants and visualizes their concentration by the intensity of its LED display. And the Shit, I Smoke! app draws an equivalence between air quality in a city and cigarette consumption. (A day in Beijing? Four cigarettes.)

THINKING OUTSIDE THE BOX

Sean Beevers, an air-quality researcher at King's College London, and his team have produced pollution maps at an even higher resolution than those from Sentinel-5P, using models that combine road-vehicle data with an understanding of atmospheric processes.

"Satellite measurements are useful in some respects, but have a high level of uncertainty" when it comes to making accurate measurements, says Andrew Beddows, a member of the team. In addition, the Sentinel-5P can measure pollution only during the daytime and with clear skies, he points out. Nevertheless, Beevers is hoping to apply his team's modelling prowess to parts of the world that lack sufficient traffic data, by using satellite imagery to count

Houses destroyed by a landslide in Kerala, India, after exceptionally heavy rain in August.

vehicles and estimate their speed.

Like Quennehen and his colleagues, Beevers says that detailed air-quality maps will be useful in estimating an individual's exposure to pollution, and can power investigations into air quality and health. But he says that he retains a healthy degree of scepticism regarding technology such as Plume's. "Whether the wearable tech things will add to that, I don't know," he says. "So far, it's not provided everything it's promised to, but things are changing quite rapidly in that area, so you never know."

HIGH-PERFORMANCE SCIENCE

A key driver in understanding how our planet works is the development of high-performance computing, says Ajaya Ravindran, a climate scientist at New York University Abu Dhabi.

A climate researcher for almost 20 years, Ravindran, who hails from India, says that over the course of his career "improvement in computational power is the most important change I can see". Rainfall in particular, Ravindran says, is enormously taxing to model accurately.

Early this year, he and his colleagues predicted a 45% decline in the atmospheric low-pressure systems that drive monsoon rainfall, accompanied by a directional shift that threatens to increase the risk of extreme weather events in India (see S. Sandeep *et al. Proc. Natl Acad. Sci. USA* **115,** 2681–2686; 2018). One occurred this summer, when floods killed nearly 400 people and displaced more than 1 million after heavy rain in Kerala.

Ravindran and a colleague have also predicted that the monsoon season would shorten by about 11 days (C. T. Sabeerali and R. S. Ajayamohan *Clim. Dyn.* **50**, 1609–1624; 2018). "A changing climate is crucial — it's crucial everywhere in the world, but in India? Even more so," he says.

Ravindran believes that short-termism is at least partly to blame for the relaxed attitudes of policymakers when it comes to climate change, but he says that the global mood is shifting. "Trump is an anomaly," he says, adding that the governments of Canada and some EU countries are increasingly prioritizing the issue of climate change. But, he says, there is still work to be done.

Ebi says that linking climate change to public health is key to combating short-termism. In May, she and her colleagues reported that increased carbon dioxide levels in this century will reduce the nutritional quality of rice, threatening the health of 600 million people in low-income southeast Asian countries (see C. Zhu *Sci. Adv.* **4**, eaaq1012; 2018).

"Not just America, but every country needs to put more money into climate change," says Ravindran. "But the US is especially sad to see. Some of the major observation networks are there. They're the ones maintaining the best satellites, and some of the best scientists are also there."

Montzka agrees: "Climate research in the US runs a very real risk in the future of falling from being the best in the world, to soon becoming irrelevant."

As the public start to feel the heat, their responses will be reflected in elections, says Ravindran. "People have started feeling it. Even in Kerala, one of the highest-rainfall provinces in India, there is water scarcity nowadays. Every year it's becoming hotter, and more real." ■

Kristopher James Kent *is a freelance journalist in Liverpool, UK.*