- 26 October 2023

Scientists call out rogue emissions from China at global ozone summit

Researchers confirm a powerful greenhouse gas being emitted from eastern China despite reports to the contrary.

- Jeff Tollefson

The manufacturing process for a refrigerant still used in air conditioners in developing countries can release a by-product called HFC-23, which is a powerful greenhouse gas.Credit: Andrew Aitchison/In Pictures via Getty

Efforts to curb emissions of a powerful greenhouse gas commonly produced as a by-product of refrigerant

manufacture might be falling short, and it seems eastern China is a major culprit.

The hydrofluorocarbon gas, HFC-23, is around 14,700 times as powerful as carbon dioxide at warming the globe and has long been the subject of national and international climate-change mitigation efforts. Those efforts gained new traction nearly a decade ago when China and India — the world's largest producers of the chemical — agreed to dial down its emissions. New research[1], however, confirms that emissions continued to rise in subsequent years, and an analysis of data from atmospheric-monitoring stations suggests that factories in eastern China are responsible for nearly half of the total.

The chemists policing Earth's atmosphere for rogue pollution

The rogue emissions are one of several air-pollution sources under discussion at the latest meeting of the Montreal Protocol, held in Nairobi, Kenya, this week. Signed in 1987, the Montreal Protocol is generally considered the most effective international environmental treaty in history, having halted the destruction of the ozone layer while also slowing down global warming. But scientists have often played a role, scanning the atmosphere for chemicals, such as

ozone-depleting chlorofluorocarbons (CFCs), that governments have agreed to phase out.

“Science has been instrumental in evaluating compliance under the treaty,” says Megan Lickley, a climate scientist at Georgetown University in Washington DC.

Finding the source

HFC-23, which also has some specialty industrial uses, has a controversial history. In 2007, scientists raised the alarm about HFC-23 transactions stemming from a United Nations programme that allowed wealthy countries to purchase carbon credits from lower-income nations. Destroying the chemical was an easy source of carbon credits, and it was also enormously profitable for factories in lower-income countries. The fear was that some factories increased their HFC-23 production for the sole purpose of selling carbon credits.

China feels the heat over rogue CFC emissions

Major HFC-23 producers eventually agreed to halt emissions of the chemical unilaterally. In 2020, however, atmospheric scientists reported evidence[2] of an increase in HFC-23 emissions that ran counter to an expected decline of 87% from 2014 to 2017. A second team followed up this August with a more detailed analysis[1] of atmospheric samples collected on an island off the southern tip of South Korea, downwind of China. They confirmed the increase, and pinpointed eastern China as the source of nearly half of the unexpected HFC-23 found in the atmosphere from 2015 to 2019, contradicting a 99% reduction in emissions reported by China.

Overall, the analysis suggests that HFC-23 emissions in China nearly doubled, from some 5,000 tonnes in 2008, to around 9,500 tonnes in 2019, although those emissions were not covered under the Montreal Protocol at the time. (In 2016, the protocol was amended such that governments agreed to destroy HFC-23 'to the extent practicable', but only from 2020 onwards.)

The monitoring stations that scientists use to track global trends in trace gases such as HFC-23 are too sparse and remote to pinpoint where all the remaining emissions of the chemical are coming from.

A spokesperson for the Chinese embassy in Washington DC declined to answer questions regarding the HFC-23 emissions trends. *Nature* was unable to reach China's Ministry of Ecology and Environment for comment.

Considering the evidence, "it may be that China has got a problem", says Durwood Zaelke, the president of the Institute for Governance & Sustainable Development, an advocacy group based in Washington DC. But Zaelke says that scientists have raised similar evidence in the past, and governments have ultimately taken action under the treaty. "History suggests that this will be taken care of."

Smaller fish

The HFC-23 case has parallels to that of trichlorofluoromethane, or CFC-11, an ozone-destroying chemical that was used in spray-foam insulation before being banned in 2010. A team led by scientists at the US National Oceanic and Atmospheric Administration (NOAA) revealed a mysterious spike in emissions in 2018, and a year later those emissions were tracked back to factories in northeast China. Scientists later confirmed that CFC-11 emissions declined sharply in 2019 and 2020, which limited the chemical's effect on stratospheric ozone.

'This shouldn't be happening': levels of banned CFCs rising

“It was clear that there was a big response, and emissions dropped,” says Steve Montzka, an atmospheric chemist at NOAA in Boulder, Colorado, who discovered the problem.

Countries will have their first opportunity to take action on the recently published evidence of ongoing HFC-23 emissions as the meeting comes to a close this week. Discussions have also arisen regarding new evidence of ongoing emissions of several CFCs, including some that are probably produced as building blocks — or feedstocks — for other chemicals, and are thus exempt from controls under the Montreal Protocol.

Lickley says that the exemption was originally created under the assumption that it would not lead to huge emissions, because most of the feedstocks would be consumed in the synthesis of new chemicals rather than be released into the environment. But the latest evidence on CFCs suggests that some of these substances are already beginning to accumulate in the atmosphere. “This underscores the need for the parties to the Montreal Protocol to tighten controls on feedstocks,” she says.

For Montzka, the current focus on these lesser, residual emissions of HFCs and CFCs can be taken as a sign of broader success. Action taken under the Montreal Protocol has already stabilized the ozone layer by

phasing out the bulk of CFCs, and the 2016 amendment curbing HFC emissions could on its own avert as much as 0.5 °C of global warming by 2100, according to a 2022 scientific assessment by the World Meteorological Organization and the United Nations Environment Programme. “We’ve gotten all of the big fish in the pond, and now there are a bunch of little fish swimming around,” he says. Catching the small ones, he adds, “will require some more work”.

doi: https://doi.org/10.1038/d41586-023-03325-7

References

- Park, H. *et al. Atmos. Chem. Phys.* **23**, 9401–9411 (2023).
  Article
  Google Scholar

  Stanley, K. M. *et al. Nature Comm.* **11**, 397 (2020).
  Article
  Google Scholar

- 03 April 2023

‘This shouldn’t be happening’: levels of banned CFCs rising

- **Researchers have detected increased emissions for five ozone-depleting chlorofluorocarbons.**

- Katherine Bourzac
- Twitter
  Facebook
  Email

Researchers detected a surprising rise in levels of chlorofluorocarbons between 2010 and 2020 using a monitoring network that includes the Jungfraujoch research station in Switzerland.Credit: Shutterstock

- The Montreal Protocol, which banned most uses of ozone-destroying chemicals known as chlorofluorocarbons (CFCs) and called for their global phase-out by 2010, has been a great success story: Earth's ozone layer is projected to recover by the 2060s.

- So atmospheric chemists were surprised to see a troubling signal in recent data. They found that the levels of five CFCs rose rapidly in the atmosphere from 2010 to 2020. Their results are published today in *Nature Geoscience*[1].

-

- “This shouldn’t be happening,” says Martin Vollmer, an atmospheric chemist at the Swiss Federal Laboratories for Materials Science and Technology in Dübendorf who helped to analyse data from an international network of CFC monitors. “We expect the opposite trend, we expect them to slowly go down.”

- At current levels, these CFCs do not pose much threat to the ozone layer’s healing, said Luke Western, a chemist at the University of Bristol, UK, at an online press conference on 30 March. CFCs, once used as refrigerants and aerosols, can persist in the atmosphere for hundreds of years. Given that they are potent greenhouse gases, eliminating emissions of these CFCs will also have a positive impact on Earth’s climate. The collective annual warming effect of these five chemicals on the planet is equivalent to the emissions produced by a small country like Switzerland.

- It’s highly likely that manufacturing plants are accidently releasing three of the chemicals — CFC-113a, CFC-114a and CFC-115 — while producing replacements for CFCs. When CFCs were phased out, hydrofluorocarbons (HFCs) were brought in as substitutes. But CFCs can crop up as unintended by-products during HFC manufacture. This accidental production is discouraged by the Montreal Protocol, but not prohibited by it.

- “A lot of this probably boils down to the factory level,” Vollmer says, pointing out that HFC production is on the rise. “A factory can be run relatively clean or relatively dirty.”

- **Eyes on the skies**
- The rise in the levels of the two other CFCs is a mystery. “CFC-13 and CFC-112a should not currently be used or produced,” says Rona Thompson, an atmospheric scientist at the Norwegian Institute for Air Research in Kjeller who was not involved in the analysis.

- The researchers speculate that levels of CFC-112a might be on the rise because of its use as a solvent or as a chemical feedstock. However, they say they need to discuss this idea further with chemical engineers to confirm that assessment.

- 
- **Illegal CFC emissions have stopped since scientists raised alarm**
- But the appearance of CFC-13 is much more baffling. “We really have no clue” where the emissions are coming from, Vollmer says. “We don’t know of any chemical process where this will show up as a by-product.” And, because there aren’t enough monitoring stations around the globe, it is difficult to pinpoint where this and the other CFC emissions are coming from, Thompson says.

- Nonetheless, Andreas Engel, an atmospheric scientist at Goethe University Frankfurt in Germany, says this research shows that the global monitoring system is largely working. Scientists are keeping a close watch on the planet’s atmosphere

and spotting problems. “We just need to find out where it is coming from and then people will be willing and obliged to fix it,” Engel says.

- This is what happened a few years ago, when researchers detected high levels of CFC-11 in the atmosphere[2], and traced them to eastern China[3]. They deduced the source on the basis of readings from monitoring stations in South Korea and Japan, reporting it in May 2019, and afterwards, levels began to fall. Scientists got somewhat lucky with CFC-11: monitoring stations equipped to detect that particular chemical happened to be located relatively close to the source.

- **China feels the heat over rogue CFC emissions**
- Engel says it would help to increase the coverage of CFC-monitoring stations — for instance, the continents of Africa and South America have little if any coverage.

- If most emissions of the five recently detected CFCs are coming from the production of CFC-replacement chemicals, the world might need to think differently about HFCs, and perhaps even the next-generation of refrigerant chemicals — hydrofluoroolefins (HFOs) — Vollmer says. HFO production can emit CFCs too, he says.

- And if the problem continues, Vollmer adds, amendments might be needed to the Montreal Protocol to address this by-product problem head-on.

- "What this does show is that we need to keep our eyes open," Engel says. "The story is not over."

- *doi: https://doi.org/10.1038/d41586-023-00940-2*

- **References**
- Western, L. M. *et al. Nature Geosci*. https://doi.org/10.1038/s41561-023-01147-w (2023).
Article
Google Scholar

Montzka, S. A. *et al. Nature* **557**, 413–417 (2018).
Article

PubMed
Google Scholar
Rigby, M. *et al. Nature* **569**, 546–550 (2019).
Article
PubMed
Google Scholar

22 January 2020

- Correction 04 February 2020

The chemists policing Earth's atmosphere for rogue pollution

These researchers tracked down mysterious sources of ozone-destroying chemicals in China and guard the planet against future illicit emissions.

- Jane Palmer

The Jungfraujoch research station in Switzerland is part of a global networkthat monitors the atmosphere.Credit: Udo Bernhart/Dumont Bildarchiv/picture alliance

High in the Swiss Alps, scientists in a small research station are busy fingerprinting the atmosphere.

Perched on a mountain ridge at around 3,450 metres altitude, the Jungfraujoch centre boasts five laboratories, a workshop, a library, a tiny kitchen and ten small bedrooms. Day and night, funnels suck in the thin mountain air and channel it into a series of instruments

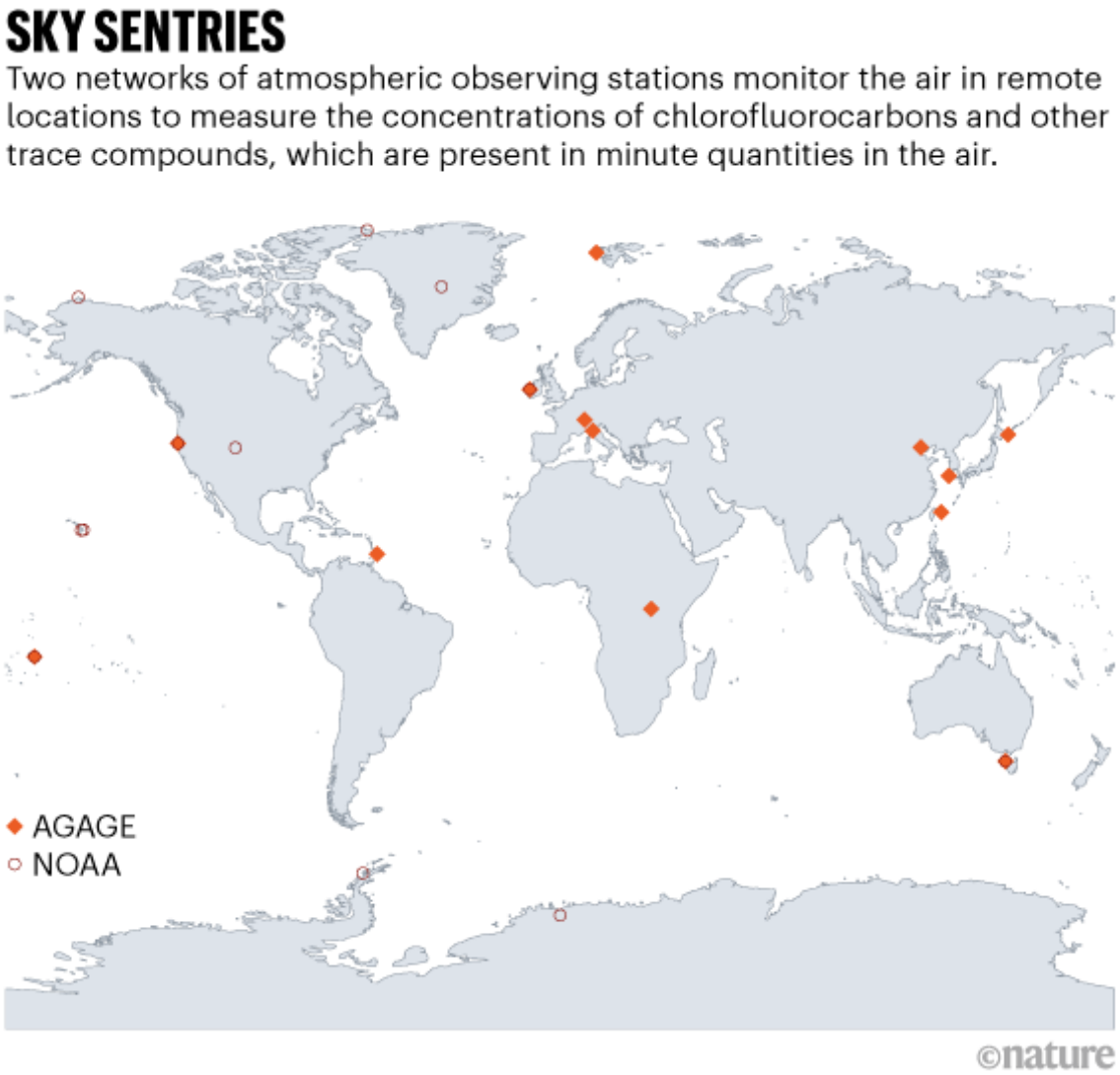
designed to separate, identify and measure the chemicals swirling through this pristine locale. “We are scanning the whole spectrum of thousands and thousands of molecules,” says atmospheric chemist Martin Vollmer. “It is like we are taking the DNA of the atmosphere.”

Vollmer, who works at the Swiss Federal Laboratories for Materials Science and Technology (EMPA) in Dübendorf, specializes in sniffing out newly emerging trace gases, which make up less than 1% by volume of the planet’s atmosphere. Some of the most notorious are the chlorofluorocarbon (CFC) coolants used for refrigeration and foam production. These destroy the ozone layer, the shield that protects life on Earth from damaging ultraviolet light. In 1987, after researchers demonstrated the threat posed by CFCs, nations banded together to adopt an international agreement known as the Montreal Protocol, to control and eventually phase out CFCs. Updates to the treaty have outlawed some of their replacements, which also turned out to damage the ozone layer, climate or both.

Behind the scenes, scientists such as Vollmer are keeping watch over the health of the atmosphere — in part to make sure nations are honouring their promises. “This is detective work,” says Stephen Montzka of the US National Oceanic and Atmospheric Administration

(NOAA) in Boulder, Colorado. “Our remit is to understand if things are changing as expected.”

For many years, the news coming from these air-monitoring campaigns was good. Concentrations of CFCs and several other dangerous compounds were declining steadily. It was the biggest win in environmental policy the world has ever seen, say researchers.



Then, in May 2018, Montzka reported a disturbing blip: levels of one of the most harmful chemicals, trichlorofluoromethane, known as CFC-11, weren't dropping as fast as expected[1], suggesting that companies were producing this compound somewhere, in violation of the protocol. "It was the most surprising and shocking thing I've seen in my entire career," Montzka says.

Montzka's research pointed to eastern Asia, and a follow-up study last May pinpointed the source of a significant fraction of the emissions to two provinces in China[2]. The discovery of these rogue CFC-11 emissions has highlighted just how much the Montreal Protocol relies on the vigilance of scientists. But it has also raised questions about whether researchers can keep up with an ever-growing list of damaging compounds — some so new that their impacts remain unknown.

For the moment, they hope they are winning. Last November, nations that are parties to the Montreal Protocol gathered in Rome, where Montzka presented some positive news about the illegal CFC emissions.

Fresh start

It all starts with fresh air. Every week, come rain, shine or, more typically, snow, Jen Morse makes the trek up to a small green shack on Colorado's Niwot Ridge, which lies on the Front Range of the southern Rocky

Mountains. In summer, she can drive part of the way and has to hike only the final kilometre of the 6-kilometre trip; in winter, she has to ski the entire distance to the remote, wind-swept spot at 3,523 metres altitude, carrying four large gas canisters in her backpack.

Once in the shack, Morse, who is a climate technician at the University of Colorado, Boulder, connects each flask to an inlet and waits for them to fill. She then heads back down and delivers the snapshots of mountain air to NOAA's Global Monitoring Division in Boulder, just 40 kilometres away. At the lab, Montzka and his colleagues run the flasks' contents through three separate gas chromatographs to determine what resides in the 'background' atmosphere, which doesn't have any nearby contamination and therefore provides a reading of chemicals circling the entire globe. "We have to pick special locations far away from local sources of pollution to do that," Montzka says. "These are desolate areas that are hard and expensive and difficult to be at."

Jen Morse collects samples of air from a shack on Colorado's Niwot Ridge.Credit: Jane Palmer

Flasks are shipped to the lab from 16 sites around the world, including the South Pole, the top of Greenland's ice cap and the tip of Tasmania in Australia.

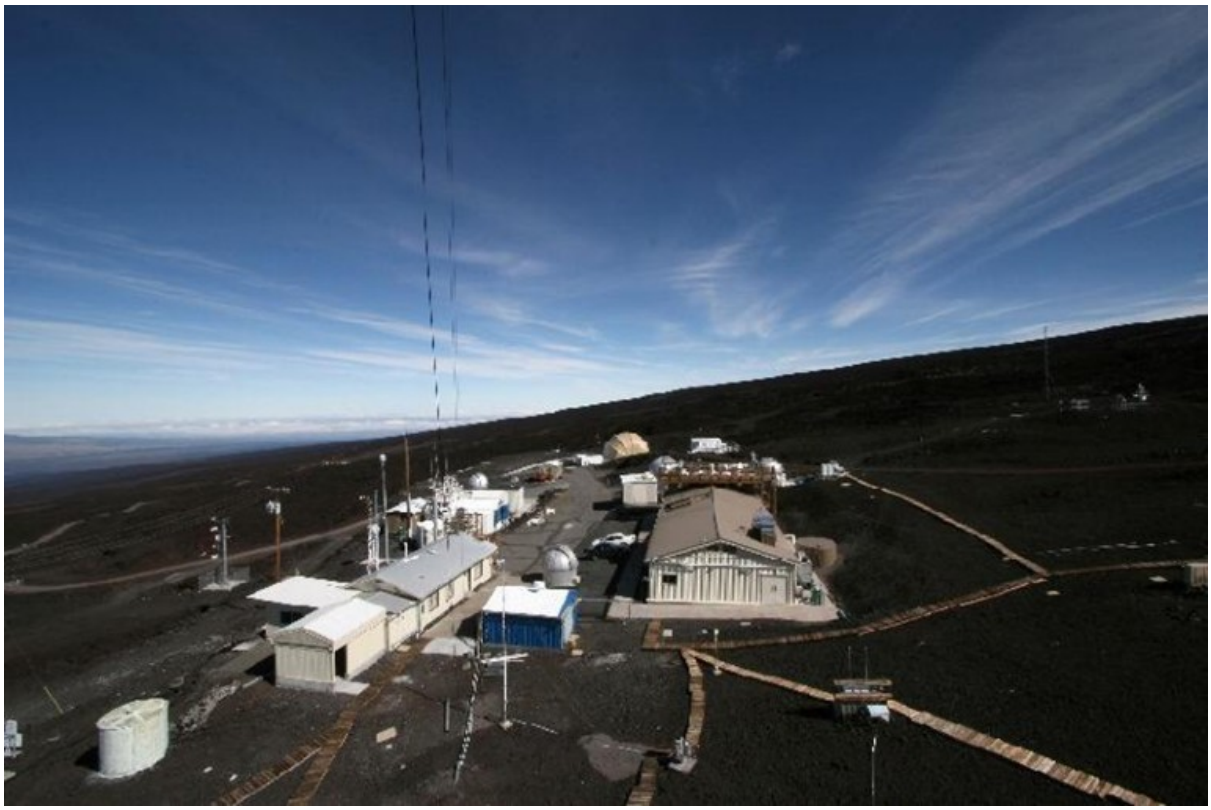
The NOAA team runs samples through its instruments to determine the levels of 50 trace gases in the atmosphere. The Jungfraujoch lab is part of a second, NASA-sponsored network called the Advanced Global Atmospheric Gases Experiment (AGAGE), which has 13 active stations in a dozen nations.

Some of these sites have been monitoring CFCs and related compounds since the 1970s. When these compounds were invented in the 1920s, chemists regarded them as safe. But by the 1970s, researchers recognized that CFCs could drift up to the stratosphere and erode the protective ozone layer. This realization — along with the shocking discovery in 1985 of a hole in the ozone layer over Antarctica — led nations to adopt the Montreal Protocol.

NOAA and AGAGE researchers meet regularly to discuss their findings, which they summarize in reports for the parties to the Montreal Protocol. These reports document the decline in the concentrations of CFCs in the atmosphere and they have identified other ozone-damaging chemicals. As such, scientists have continued to provide input into the protocol, which nations have updated to limit the production of other harmful gases.

“It wasn’t a one-stop scientific treaty,” says David Fahey, an atmospheric chemist with NOAA, and one of the four co-chairs of the Scientific Assessment Panel of the Montreal Protocol.

The teams monitoring the air are forever playing catch up as new compounds appear in the skies. Even before CFCs were banned, manufacturers developed substitute coolants such as hydrochlorofluorocarbons (HCFCs). But researchers quickly found that these compounds also damage the ozone layer, and a 2007 amendment to the protocol called for the complete ban of production and consumption of HCFCs by 2030. Next came a third generation of coolant, the hydrofluorocarbons, or HFCs. These don’t contain chlorine or bromine, and so they don’t damage the ozone layer. But they turned out to be powerful greenhouse gases; most have a warming power between 1,400 and 5,000 times greater than that of carbon dioxide.



Air samples from the flank of Mauna Loa volcano in Hawaii helped researchers detect illicit emissions of CFC-11 from Asia.Credit: Forrest M. Mims III

Consequently, in 2016, delegates agreed on the Kigali Amendment to the Montreal Protocol, which calls for cutting the production and use of HFCs by 80–85% by the late 2040s. The amendment entered into force at the start of 2019 with the goal of avoiding warming by up to 0.5 °C.

Monitoring stations such as Jungfraujoch track progress towards those goals in different parts of the world; sometimes they find problems. Scientists at the station found that northern Italy had emitted between 26 and 56 tonnes of HFC-23 per year in 2008–10, yet the official Italian inventory had estimated only 2.6 tonnes for the whole country.

Blindsided

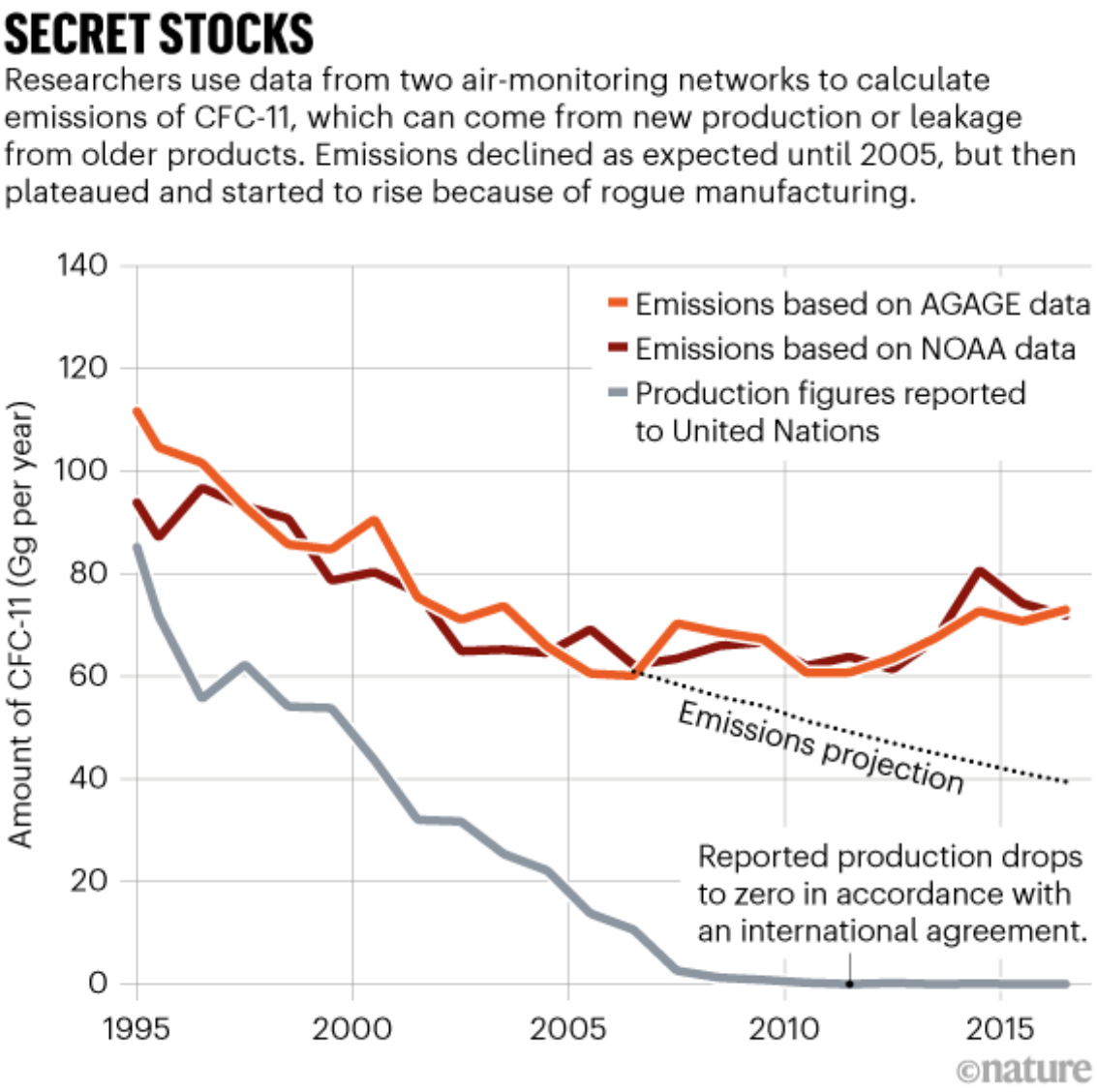
Until a few years ago, it seemed that the main threats to the ozone layer were on their way out and scientists could focus on the newer gases. Then came the first hints of trouble.

One day in 2013, Montzka ran the air from his weekly delivery of flasks through the mass spectrometer he had designed nearly 30 years earlier. But when he looked at the output of these routine measurements from the previous few months, he noticed something odd: the levels of CFC-11 were not declining as fast as before.

To Montzka, the observation made no sense — production of CFCs had been phased out worldwide three years earlier. Before 2012, the concentration of CFC-11 had dropped by about 0.8% per year, but Montzka's flask data suggested the decline rate had slowed substantially. "I was totally amazed, I couldn't believe it," Montzka says. "Then I thought to myself that it was just some blip that will go away next year — something weird has happened in the atmosphere, or in my instrument."

Montzka double-checked his measurements and then, for the next few years, he and the international team searched for possible explanations. Eventually, the trail of evidence led to a single conclusion: emissions of CFC-11 were going up rather than down, pointing to a

violation of the Montreal Protocol (see ‘Secret stocks’). “It did take a while to unravel the story in a way that I thought would be useful to the international community,” Montzka says.



Between 2002 and 2012, CFC-11 emissions averaged 54,000 tonnes per year, owing to gradual leakage of old stores of the compound contained in foam insulation and appliances made before the mid 1990s. But the researchers found that between 2014 and 2016, average

emissions grew to 67,000 tonnes a year — an increase of roughly 25%[1]. They also noted that, in 2013, the flask data at the Mauna Loa Observatory in Hawaii suddenly showed increased levels of CFC-11 in the pollution plumes regularly recorded at the site. On closer investigation, they found that the sources of those plumes, and the uptick in CFC-11 emissions, came from eastern Asia.

A team of scientists immediately began to look for clues in an independent set of measurements, in particular those from the AGAGE stations on Jeju Island in South Korea, and Hateruma in Japan. Data from these stations revealed spikes in CFC-11 whenever plumes of pollution passed by. And the spikes had grown since 2013.

With this information, the scientists ran computer models using atmospheric circulation data and the monitoring-station measurements to determine where the pollution was coming from. Four independent modelling groups worked on solving the puzzle, and all came back with the same answer: about 7,000 tonnes per year were coming from the Chinese provinces of Shandong and Hebei[2].

The newly discovered emissions will not significantly delay recovery of the ozone layer, says Matthew Rigby, an atmospheric chemist at the University of Bristol, UK.

“But if they carry on, we could be seeing delays of years or more,” he says.

A close call

On 4 November 2019, Tina Birmpili, executive secretary of the UN Ozone Secretariat, delivered her opening speech at the 31st Meeting of the Parties to the Montreal Protocol in Rome. She began by praising the success of the treaty so far and the decisive action taken by China to address its emissions of CFC-11, including setting up a national monitoring network and increased penalties for companies that violate production bans. “CFC-11 was an alarm for all parties to ensure that they address illegal production swiftly and send a clear message to those who would break the law,” Birmpili says.

Then Birmpili turned her attention to some unanswered questions around the unexpected CFC-11 emissions. The researchers’ most recent published findings estimate that CFC-11 emissions from China account for 40–60% of the global increase between 2014 and 2017, but that leaves 4,000–10,000 tonnes unaccounted for[2].

Right now, the researchers aren’t in a position to say whether there are other sources of illegal emissions or whether uncertainties in their models can account for the remaining percentage of the global trend, Rigby says. In the future, they will try to improve their models

to see if they can glean a more accurate picture of the CFC-11 changes, he says. Montzka thinks that this time the monitoring community was lucky: researchers were able to detect the global trend change fairly early and happened to be making measurements near the region where at least some of the new emissions were coming from. But if CFC-11 had emanated from India, Russia or South America, the existing networks wouldn't have been able to identify the location of the source because no regional stations exist nearby.

When Montzka stepped up to the podium in Rome, he presented some fresh observations from the global monitoring data. In 2018, the rogue emissions seemed to slow or disappear. The decline of the global concentrations of CFC-11 accelerated, and the amount of the gas in plumes reaching the monitoring stations in Hawaii and Jeju Island substantially decreased. Although researchers have yet to fully check the latest measurements, they take heart from the trend. "The evidence suggests that the Montreal Protocol is being effective in yet another set of circumstances — in this case, unprecedented circumstances," Fahey says.

If the CFC-11 concentrations continue to decline over the next few years, it will mark a significant victory for the scientists and their monitoring networks. "There's always the discussion of whether it is really important that we are still here," says Stefan Reimann, an

atmospheric chemist at EMPA. “And, yes, history proves that we still have to be here.”

The rogue-emissions incident highlights weaknesses in the current system, which was developed to investigate the science of how the atmosphere is changing, not to track emissions, says geochemist Ray Weiss at the University of California, San Diego. “We never expected to see a violation, which is a lesson in itself really.”

In response to the latest challenge, NOAA added a flask-collection site on the west coast of South Korea to gather more information from eastern Asia. And this year, the parties will continue to discuss what is needed to ensure a similar violation doesn’t happen again, Birmpili says.

Meanwhile, the scientists are maintaining their strategy of watching, waiting and investigating. At Jungfraujoch, Vollmer is paying close attention to the latest generation of coolants: hydrofluoroolefins (HFOs). As those break down, some of them, such as one known as HFO-1234yf, can decompose into trifluoroacetic acid, which is toxic to some plants and soil organisms. The German and Norwegian environment agencies have recommended more research on the HFOs.

Measurements at Jungfraujoch show a rapid rise in these compounds. In 2011, HFO-1234yf appeared in none of Vollmer’s samples. By 2018, it was in 71% of them.

Currently, industry produces only a small amount of HFOs because the phase-out of HFCs has just begun. "But if you make a back-of-the-envelope calculation and you replace all the compounds that we've been using previously by the HFOs, there are going to be huge quantities of these gases," Vollmer says.

So he makes the journey each month to the high, glaciated saddle between two peaks in the Alps, where Jungfraujoch's instruments hum away day and night. "We have to keep watching," he says.

Nature **577**, 464-466 (2020)

doi: https://doi.org/10.1038/d41586-020-00110-8

UPDATES & CORRECTIONS

- **Correction 04 February 2020**: An earlier version of the graphic 'Secret stocks' erroneously stated that the unit for CFC-11 emissions was gigatons per year.

References

- Montzka, S. A. *et al. Nature* **557**, 413–417 (2018).
Article
PubMed
Google Scholar

Rigby, M. *et al. Nature* **569**, 546–550 (2019).
Article
PubMed

Google Scholar