Dual benefits of novel nitrogen dioxide remote sensing instrument

A novel instrument is being developed to capture data on nitrogen dioxide (NO2), which not only measures this important pollutant but also provides vital data on carbon dioxide (CO2) emissions.

Nitrogen dioxide is mainly produced during the combustion of fossil fuels and can have a major impact on health. Short-term exposure to concentrations of NO2 can cause inflammation of the airways and increase susceptibility to respiratory infections. It can also exacerbate the symptoms of those already suffering from lung or heart conditions.

Inhaling high levels of NO2 reduces the ability of the blood to carry oxygen, which can lead to respiratory illnesses and reduced lung function, while longer term exposure is linked to severe asthma, permanent lung damage disease, and a plethora of other conditions including higher rates of dementia, lung cancer and lower birth weights.

In 2018, Public Health England reported that the total cost of NO2 to the NHS and social care is estimated to be £230 million by 2035 and up to £9.2 billion if other related diseases are included.

Additionally, NO2 can impact the environment both in its gas form and through precipitation, by changing soil chemistry and affecting biodiversity in sensitive habitats.

Nitrogen dioxide as a proxy for CO2 emissions

Observations of NO2 have a dual use, both as a direct measurement of this toxic gas, and as a tracer and proxy for CO2 emissions from combustion sources.

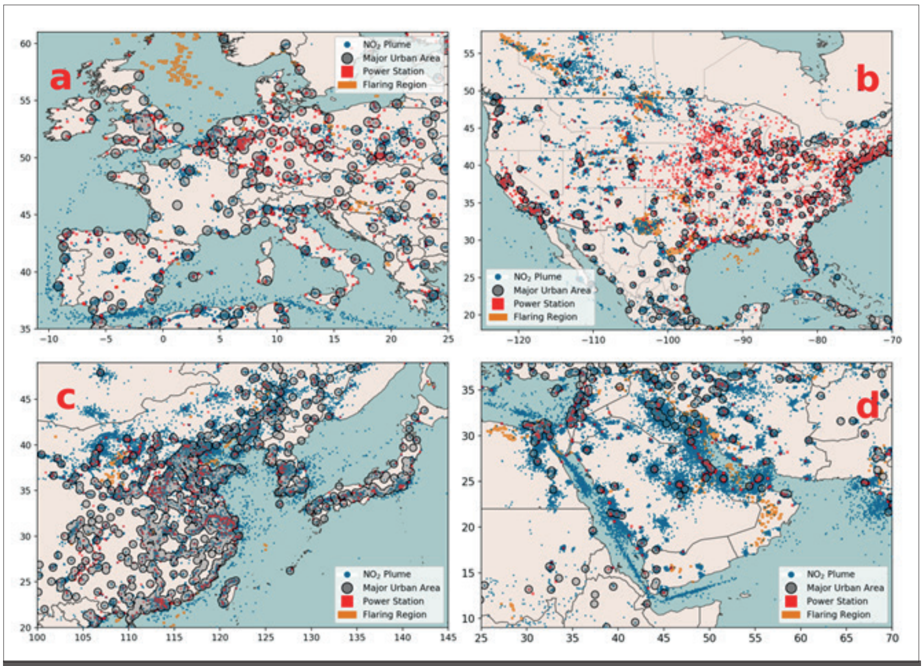
Carbon dioxide is the most important greenhouse gas released into the atmosphere through human activities.

High levels of CO2 have a significant influence on Earth's climate because it results in more infrared radiation being absorbed, leading to global warming.

Along with warmer temperatures, rising levels of carbon dioxide can cause extreme weather events such as increased hurricane intensity, along with rising sea levels.

However, capturing high-resolution data on CO2 directly is difficult. This is due to the fact that the natural background level of CO2 is high, and because CO2 has a long atmospheric lifetime.

CO2 emissions are hard to distinguish from the already high background levels, and they are also hard to attribute to specific sources, as the long atmospheric lifetime means an emission plume may have moved from where it was emitted (for example driven by local winds) by the time it is observed.



Example of NO2 plumes detected using a machine learning model developed at Edinburgh in TROPOMI satellite data

It is much easier to measure NO2 and as NO2 is co-emitted with CO2 during combustion, it can be used as a proxy by which to measure carbon dioxide.

As NO2 is directly linked to combustion emissions, it can help separate natural and anthropogenic CO2 sources and can be measured with much higher spatial resolution from satellite instruments than CO2. Crucially, NO2 has a short lifetime, resulting in observable plumes close to the point of emission. NO2 background levels are also much lower, so localised enhancements above background are more easily spotted.

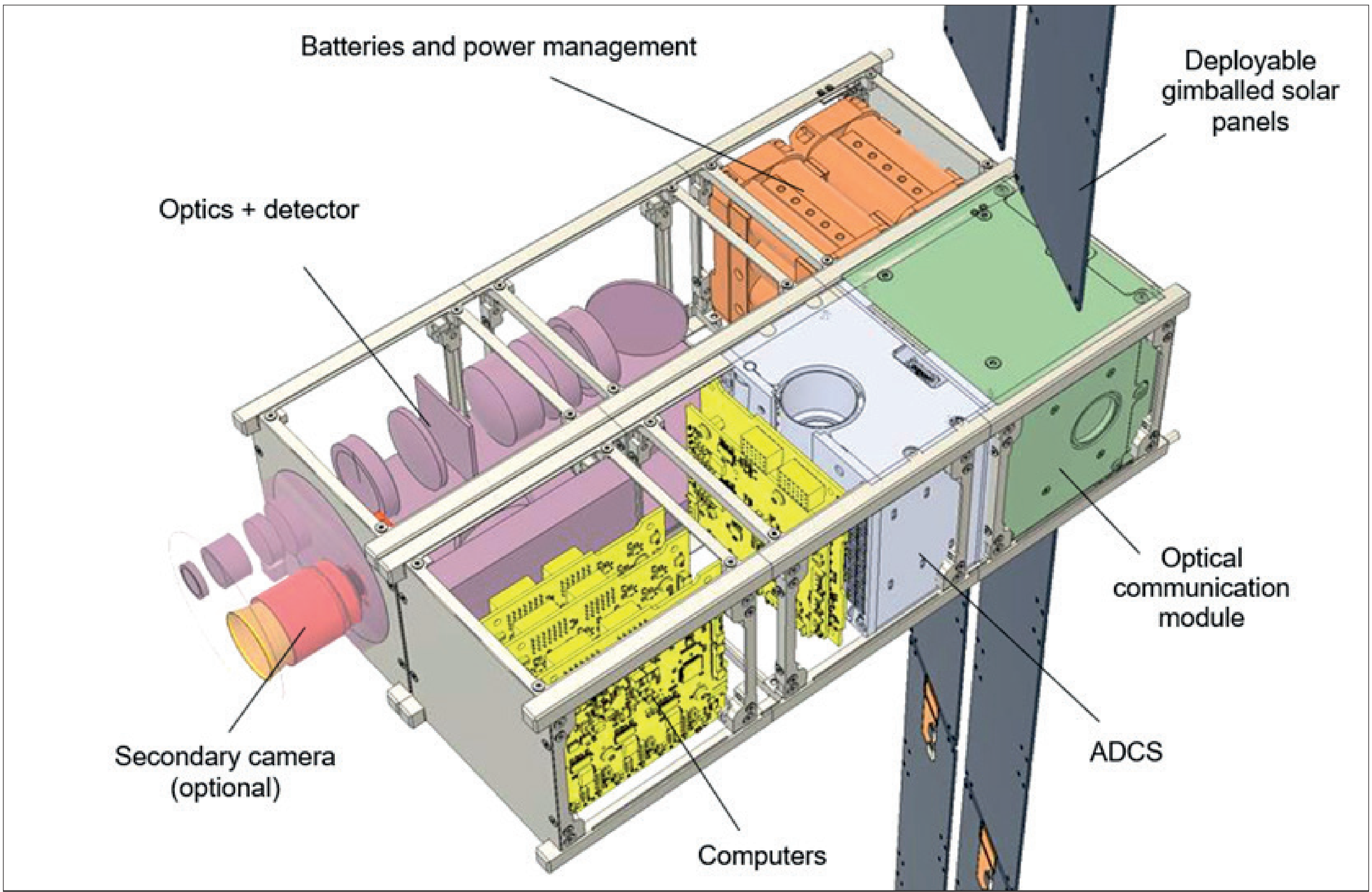
Quantifying how much NO2 is being released by combustion processes allows scientists to relate that to the amount of CO2 that process is emitting.

Improving nitrogen dioxide measurements

Satellite remote sensing of Earth's atmosphere at spatial resolutions below 200 metres is a new and fast-growing market, with increasing demand from industry, scientists, and policy makers for more and higher quality data.
High spatial resolution satellite observations can help monitor point source NO2 emissions and track atmospheric concentration gradients of urban areas with an accuracy and response time that was previously impossible.
A team from the University of Leicester demonstrated the potential to provide NO2 observations at unprecedented spatial and temporal resolution, after developing the novel instrument HAPI, a High-resolution Anthropogenic Pollution Imager.
HAPI was developed for use in a constellation of small satellites as a low-cost solution to the observational data gap in nitrogen dioxide, at the necessary spatio-temporal resolution to resolve fine-scale sources. The team demonstrated that HAPI could be a valuable complement to the existing air quality monitoring landscape.

Enter SNEEZI

In 2023, on the back of the HAPI project, a team from the University of Edinburgh began building on the concept.
With funding support from the Centre for Earth Observation Instrumentation (CEOI), the team set out to address shortcomings in current NO2 remote sensing capabilities, improving spatial resolution and lowering point emitter detection limits in order to detect smaller sources.
Applying learning from another of the University of Edinburgh team's projects, the Near Infrared Multispectral Camera for Atmospheric Methane (NIMCAM), a novel instrument was developed – Sensing NO2 Emissions to Evaluate Net-Zero Initiatives (SNEEZI).
SNEEZI aims to deliver a global, high-spatial resolution dataset of tropospheric NO2, using a constellation of instruments in a bespoke orbital configuration. A sophisticated data analysis framework is designed to deliver timely and reliable information about combustion CO2 emissions from cities and individual assets to help deliver net zero goals and meet air quality targets.



Satellite concept

In the words of Jerome Woodwark

Senior Research Engineer, School of GeoSciences, University of Edinburgh

"As part of the United Nations' Paris Agreement, countries are responsible for creating national inventory reports of anthropogenic emissions by sources and removals by sinks of greenhouse gases. These establish nationally determined contributions and outline what actions each country will take to reduce greenhouse gas emissions, and how that will be monitored.

The biggest motivator for SNEEZI is that it's currently quite hard to use satellite data in the creation of these national inventory reports. Currently, emissions are measured and monitored through a bottom-up approach, with each country reporting the number of plants and factories in operation, the number of vehicles on the road and so on. This is the data used to estimate how much CO_2 is emitted.

Currently, what's difficult to do with satellite observations is to check whether a particular factory is actually emitting the reported amount of CO_2 or not. The factory may have changed its processes, it may have introduced measures to reduce emissions, or emissions may have increased and we don't know about it. That's what is lacking in the current data because so much is done on estimates and scaling factors based on how many cars you have on the road or how many plants you have, rather than direct, top-down observations.

At the same time it's hard to do those observations for CO_2 directly because the background level is high. With NO_2, the background levels are lower and it's easier to spot. We can spot leaks in the NO_2 image that we wouldn't be able to see if we were looking in the CO_2 image. Using NO_2 also allows us to see changes to CO_2 over time."

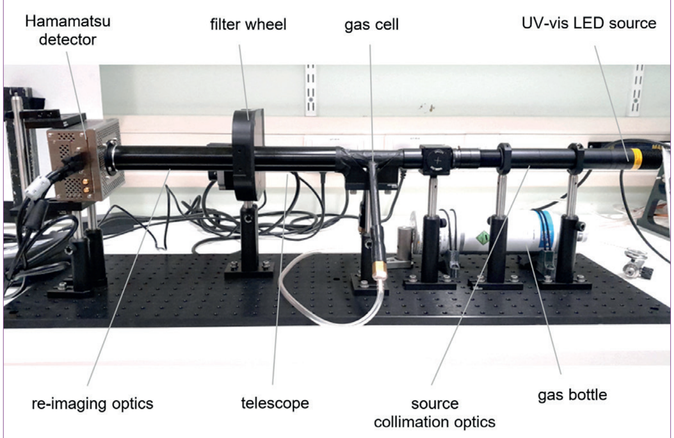
What's next?

Funding from the UK Space Agency has allowed the team to continue developing SNEEZI as a National Space Innovation Programme Kick Start project. This has involved further lab and field testing, business case development, relevant environment testing, and computer modelling.

The tunable source system itself represents a valuable new metrology capability and may see useful applications in other areas of remote sensing instrument design.

Going forward, benefits of SNEEZI include the development of a next-generation in-house greenhouse gas monitoring satellite, providing a clear demonstration of UK capabilities in end-to-end space mission design and execution.

It also serves as an opportunity to show leadership in best practice monitoring of an important pollutant in the context of international obligations, while supporting the development of the next generation of scientists, engineers and technologists.



Laboratory demonstrator

At a glance

- **Total project cost:** £1.78 million
- **Total funding from CEOI:** £102,125
- **Capability of SNEEZI:** 10 channel multispectral UV-visible imager, delivering 200 metre resolution across a 200 km swath. Designed for daily global coverage from a constellation of 9 CubeSats
- **Current Technology Readiness Level:** 3
- **Comprises:** Telescope, narrow bandpass filter array and camera, designed for CubeSat platform
- **Number of people involved in the project:** Approximately 15
- **Project partners:** The University of Edinburgh and UK Astronomy Technology Centre