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THE EYES THAT WATCH THE SKY

When it launches in 2026, the Copernicus programme's Anthropogenic Carbon Dioxide Monitoring satellite will give us a new window on to Earth's atmosphere... And how we're altering it

by DR STUART CLARK

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It's a rather delicious irony that one of the most valuable things to come out of the space programme wasn't the ability to look into the deepest regions of the Universe, but to look back at Earth; to see our world as a beautiful disc of white clouds, blue oceans and multicoloured continents.

Since Sputnik, the first artificial satellite, was launched more than 70 years ago, an armada of Earth-observation spacecraft has been put into orbit. Together with more than a century and a half of consistent Earth-based weather measurements, the data these satellites have gathered has allowed us to develop a much better understanding of our planet's climate and our effects upon it.

As is now well known, Earth's climate is changing, with average global temperatures increasing. This occurs because of the industrial and domestic burning of fossil fuels, which releases carbon dioxide (CO_2) into the atmosphere, where it traps heat. We rely on this 'greenhouse effect' to make the planet habitable, but in recent decades so much CO_2 has been released by humans that we've thrown Earth's natural balance off-kilter.

In December 2015, 196 Parties at the UN Climate Change Conference (COP21) in Paris, France, agreed to a legally binding international treaty on climate change. This treaty's goal is to hold global temperatures to below an increase of 2°C. To do this, countries are required to report how much anthropogenic (man-made) CO_2 they emit and, starting this year, they must also report on the actions they're taking to reduce these emissions.

This will allow us to do a global carbon 'stocktake' and, from that, recommend further actions that →

→ need to be taken on a country-by-country basis. At present, countries calculate their carbon emissions based on statistical and economic factors, such as how much fuel is being imported or produced in the country. The assumption is then that this fuel is used within the country and produces its waste CO_2.

"There are specific guidelines that have been agreed as part of the IPCC [Intergovernmental Panel on Climate Change], and people work hard to make sure it's all accurate. It's a huge task," says Dr Richard Engelen, the Deputy Director of the Copernicus Atmosphere Monitoring Service at the European Centre for Medium-Range Weather Forecasting (ECMWF) in Bonn, Germany.

The good news, however, is that Engelen and an army of scientists, engineers and technicians are about to make the job of reporting a country's CO_2 emissions much easier. In 2026, the European Space Agency (ESA) will launch the first spacecraft in its Copernicus Anthropogenic Carbon Dioxide Monitoring (CO2M) mission. It won't be the first European satellite to measure CO_2. That honour will go to the MicroCarb mission. This joint venture between CNES, the French space agency, the UK Space Agency and the European Union, is slated for launch next year. But CO2M will take the measurement of carbon dioxide being released into Earth's atmosphere to another level.

"Nobody has measured these gasses with the accuracies that we have to meet. The scale of this development is orders of magnitude bigger than for previous greenhouse gas missions – and it has to be like this in order to make a difference," says Dr Ruediger Lang, CO2M missions scientist for the European Organisation for the Exploitation of Meteorological Satellites (EUMETSAT), Darmstadt, Germany.

CO2M will make it easier to tie CO_2 and other greenhouse and industrial gases to their points of origin. It'll provide more detail in our understanding of how and where carbon dioxide is emitted, how it interacts with any vegetation around it and how much of it ends up in the atmosphere.

THE SCIENTIFIC CHALLENGES

CO2M is an ambitious mission. When it comes to greenhouse gas monitoring, previous spacecraft have either concentrated on providing detailed views of small regions (so that emission plumes from factories, power plants or cities could be seen) or observations that cover large swathes of the ground – but never both combined. This was the challenge handed to Dr Yasjka Meijer, ESA's CO2M mission scientist.

"I was given the set of requirements to observe plumes. But at the same time be able to estimate country-scale emissions. So that required us to have wider swathes and also to be very accurate," he says.

To do this, the satellite will be placed in a polar orbit at an altitude of 735km (about 455 miles). It'll continuously measure sunlight reflected from Earth →

"NOBODY HAS MEASURED THESE GASES WITH THE ACCURACIES THAT WE HAVE TO MEET"

Copernicus: the Sentinel fleet

LEFT The Copernicus Carbon Dioxide Monitoring (CO2M) mission will measure the amount of man-made CO_2 in Earth's atmosphere

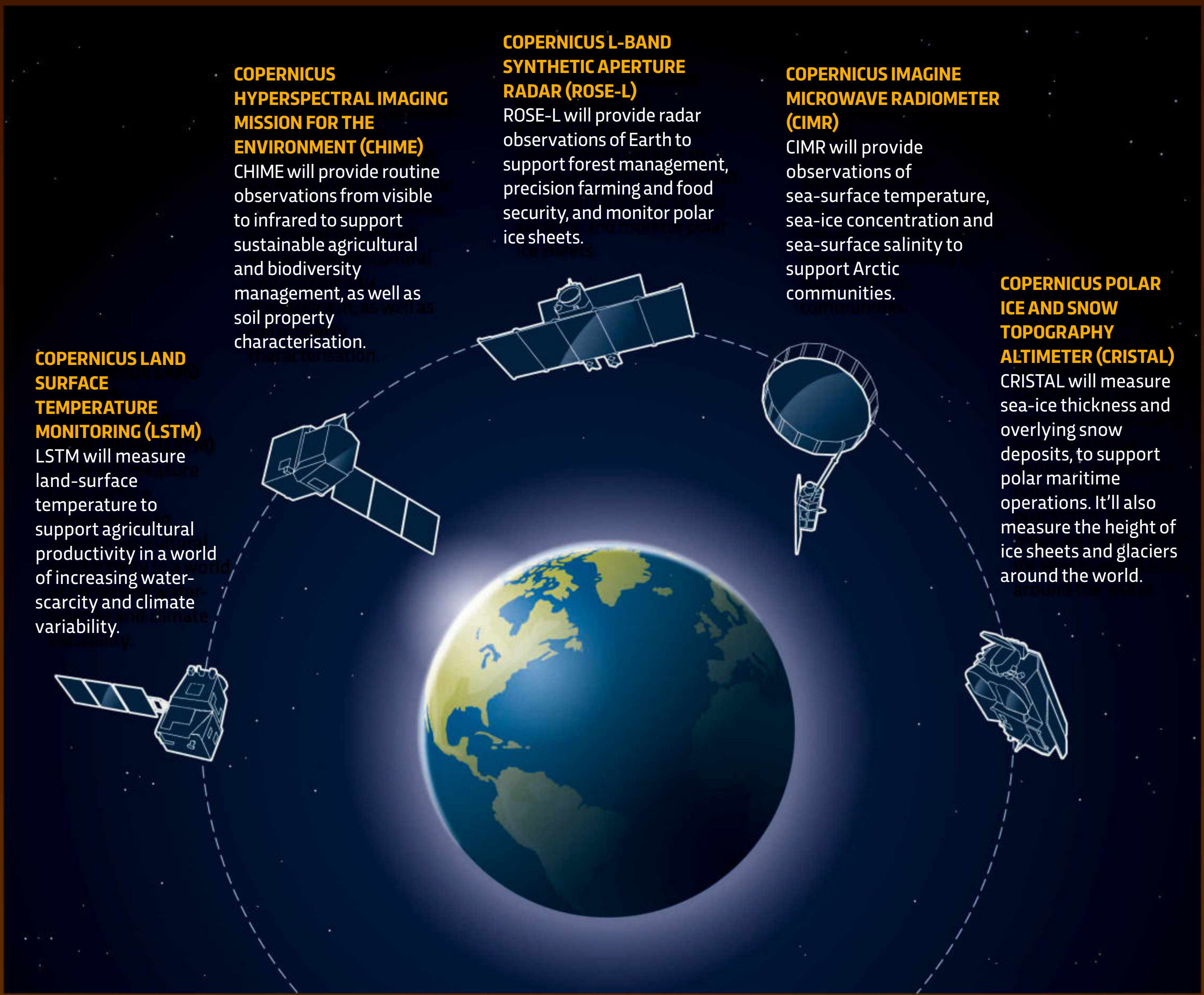
BELOW LEFT The Paris Agreement was agreed by 194 states and the European Union at COP21 in December 2015. The city was decorated to mark the occasion

Europe's Copernicus programme is the world's largest supplier of Earth observation data. This data is collected by the Sentinels, a flotilla of spacecraft designed to monitor different aspects of Earth's environment.

Funded by the European Commission, Copernicus is implemented by the EU Member States through the European Space Agency (ESA), the European Organisation for the Exploitation of Meteorological Satellites (EUMETSAT), the European Centre for Medium-Range Weather Forecasting (ECMWF) and others.

Following Brexit, the UK was forced to leave the Copernicus programme, but a bespoke agreement announced in September 2023 has essentially allowed the UK to rejoin.

The Anthropogenic Carbon Dioxide Monitoring (CO2M) is one of six Copernicus Sentinel Expansion missions that ESA is developing on behalf of the EU. The other five missions are...



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→ across a 250km-wide (155 mile) swathe, split into 4 x 4km (2.5 x 2.5 miles) columns of atmosphere, or 'pixels'. As that light passes through the atmosphere, the gases will absorb certain wavelengths. These will show up as dark lines when the sunlight is split into a spectrum by CO2M. The intensity of those dark lines will reveal the concentration of gases in each pixel. But to get to those final figures is a complex multistage process.

Once the data is collected by the spacecraft and beamed back to Earth, it must be prepared for analysis. "The raw data coming out of the spacecraft is voltages or binary counts," says Lang, readings he and his EUMETSAT colleagues can't immediately make sense of. These readings are subject to the way the instruments work. So, Lang and his team are developing computer models to remove the instrumental effects from the data.

"SOMEWHERE HIDDEN IN THERE ARE THE EMISSIONS FROM THE POWER PLANT"

"We have to get [the readings] back to what will be measured by the instrument, just before the light enters it," he says. It's an incredibly difficult task, but absolutely necessary to meet the required accuracies for the mission. Whereas MicroCarb will measure CO_2 to around one part per million, CO2M will measured it to a precision of 0.07 parts per million, and another greenhouse gas, methane (CH_4), to 10 parts per billion.

THE NATURAL CHALLENGES

Once thoroughly cleaned of instrumental effects, the data is sent to ECMWF for analysis. Here, the big issue is knowing which emissions are anthropogenic and which are natural. "That's the ultimate challenge we face because the atmosphere is a big mixer," says Engelen.

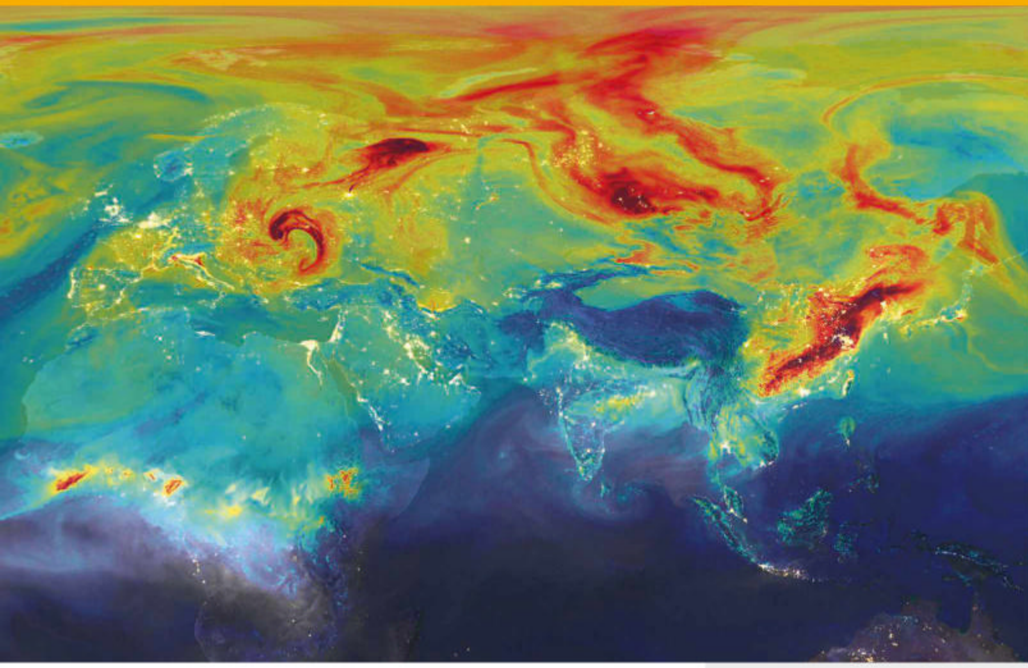
Once the CO_2 is released it quickly diffuses into the atmosphere, and its origins become ever more difficult to determine. The problem is that, in general, the satellite doesn't actually observe the emissions directly; instead, it observes the changes in the atmospheric concentrations that come from the emissions. So, the analysis must work out the likely origin of the gasses that are changing the concentration.

To help with this procedure, CO2M will also detect nitrogen dioxide (NO_2). This gas is mainly produced by combustion engines and manufacturing. Even existing satellites can see the plumes of NO_2 rising from power plants or from cities, so, it's easier to visualise exactly where the gas is coming from. For CO_2, however, it's a different story.

While there are still plumes of the gas pouring out of power plants and cities, biology then gets involved. "There's a huge

LEFT Daily and seasonal variations in the amount of CO_2 absorption by vegetation makes it difficult to accurately calculate the gas emissions from a single factory or power plant

ABOVE RIGHT A map showing CO_2 emissions over Europe and Asia, with higher concentrations in red and lower concentrations in blue



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interaction between land surfaces and the atmosphere through vegetation," says Engelen.

For example, if there's a forest near the power plant, this will alter the amount of CO_2 that makes it into the atmosphere. This is because plants absorb CO_2 during the day, when sunlight is available, and emit CO_2 during the night, when the sunlight has gone away. This results in a diurnal cycle of CO_2 emissions coming from the forest. And it doesn't end there. A seasonal variation is present too. In spring, summer and autumn there's a lot of CO_2 absorption; in winter, the reverse.

"Somewhere hidden in there are the emissions from the power plant," says Engelen.

This means that the project must also monitor the ways vegetation absorbs and emits CO_2, so that sophisticated computer models can make all the necessary adjustments.

One thing in the team's favour is that they already know where the main CO_2 sources are located. Power plants, roads and cities are all marked on maps and this information will help guide their analysis. Better still, in the US, cities are often found in the middle of deserts, so the emissions aren't contaminated or modified by vegetation.

THE POTENTIAL OUTCOME

While the challenge of unpicking this information from the data isn't to be underestimated, over time, the mission will build a continuous map of greenhouse gas emissions that will all be made publicly available. Users, both big and small, from governments to individual businesses, can then freely use the data. "It's really there to support countries in their obligations to report emissions, but I can see in the future that there are a lot of people that would like to demonstrate that they're making progress," says Meijer. For example, he can see the data being used by city authorities to show how carbon-efficient they are, or by financial institutions to provide evidence that they're investing in green infrastructure and companies.

The clear, accurate measurement of greenhouse gas emissions is a giant step forward for fact-based environmental stewardship of the planet – and a real coming of age for Earth observation.

Dr Simon Pinnock is an Earth Observation Applications Engineer at ESA's Climate Office, in the UK. He started working with Earth observation satellite data in the mid-90s. Back then, his job was to monitor forest fires from space. While the satellite infrastructure to assist with weather forecasting was well established, for wider environmental monitoring there were still huge gaps.

"For much of Earth, there was just a bit of a question mark. It's amazing to think how much has changed in just over 25 years," he says, "It's only really been in the last 10 years with the Sentinels that we've really got operational environmental monitoring." (See 'Copernicus: the Sentinel fleet', p51.)

These days, Pinnock is managing projects in ESA's Climate Change Initiative, which is designed to collect data on essential climate variables (ECVs). There are 55 ECVs; their measurement and analysis form the basis upon which Earth's changing climate can be assessed.

At present, about 60 per cent of these variables can be supplied by satellite data. The rest come from ground-based observations and measurements. Of those available to satellites, the Climate Change Initiative focuses on the 21 ECVs for which there are satellite records that not only cover the entire globe, but also stretch back more than 30 years.

"We take data from all the available satellites, not just ESA satellites," says Pinnock.

It's a huge job, but by collating the various Earth-observation satellite data, ESA's climate office is developing the global, long-term data records that show the evidence of our changing climate. As such, it forms the foundation for international action to be formulated and agreed upon through the United Nations Framework Convention on Climate Change.

CO2M is the central component of this work. Rather than just a single mission, up to two follow-on CO2M missions are planned. And while they may not be showing us other worlds in the Solar System, if their data makes it easier for us to avoid the worst ravages of climate change, then that alone could be said to justify the whole programme of space exploration. **SF**

by DR STUART CLARK

Stuart is an astronomer, science journalist and author of several popular science books. His latest, Beneath the Night: How the stars have shaped the history of humankind *(Guardian Faber, £14.99) is out now.*