European Metrology Programme for Innovation and Research

Delivering Impact

Reducing the cost and improving the accuracy of radiometric sensor calibrations: Terrestrial and space

From the 1960s to mid-2020s, the annual global emission of carbon dioxide more than tripled. Whilst nations compile inventories on the amounts they produce, contributions can be missed. Measurements from space can give a secondary estimate, precisely track the movement of this potent greenhouse gas, and inform on how it interacts with the wider climate system. To do this requires accurate satellite instruments, verified by metrology.

Europe's National Measurement Institutes working together

The European Metrology Programme for Innovation and Research (EMPIR) has been developed as part of Horizon 2020, the EU Framework Programme for Research and Innovation. EMPIR funding is drawn from 28 participating EURAMET member states to support collaborative research between Measurement Institutes, academia and industry both within and outside Europe to address key metrology challenges and ensure that measurement science meets the future.

Challenge

Over the last few centuries, carbon trapped by millions of years of plant and animal deposition has been released into the environment as carbon dioxide (CO_2) through the burning of fossil fuels. In 1958 the measured level of this greenhouse gas in the atmosphere was 315 parts per million (ppm), in 2024 it reached 423.9 ppm and continues to grow. 2024 was also the first year that the Intergovernmental Panel on Climate Change (IPCC) recorded global temperatures exceeding 1.5ºC above pre-industrial levels. This is considered a critical threshold by many environmental experts and, if unaddressed, could irreversibly change the climate we rely on, leading to increased flooding, fires, droughts, biodiversity loss and global food insecurity.

Signatory nations of the 2015 Paris Agreement are obliged to compile and communicate how much CO_2 they produce, based on self-assessment of the amount emitted from sectors including energy, construction, and automotive. However, measurement uncertainties can arise when comparing data from different sources. Satellite remote sensing has been identified by the IPCC as an independent method of verifying national CO_2 inventories and other greenhouse gases. Orbital measurements can also separate out natural and manmade sources of CO_2 and provide the location and assess efficacy of the 'sinks' e.g. forests and oceans which absorb it.

To do this, Earth observation satellites require the highest accuracy sensors to determine sub-ppm changes that only state-of-the-art metrology can provide.

Solution

In the EURAMET project MetEOC-3, the National Physical Laboratory (NPL), the National Metrology Institute (NMI) of the UK, developed methods utilising a new generation of widely tuneable laser, replacing incandescent lamps traditionally used for the spectral radiometric calibration of sensors.

This improvement fundamentally changed the way the spectral shape of the bandwidth of any sensor under test is determined, while also allowing a more direct traceability to the SI primary standard detector at NPL, so vastly reducing the achievable uncertainties. The laser and new methodology were integrated into a new facility, the *Spectroscopically Tuneable Absolute Radiance calibration and characterisation Optical Ground Support Equipment* (STAR-cc-OGSE, or "STAR"). Capable of radiometric calibration and characterisation of satellite sensors to an accuracy of <0.5%, the facility was also designed to be transportable, allowing cost-effective NMI level measurements to be made at either NPL or at a customer's location.

Impact

In 2022, following the end of MetEOC-3, STAR was transported to the premises of Airbus in France and, over a 56-day period, was used to calibrate the spectrometer of the MicroCarb CO_2 satellite, a mission of the French space agency CNES supported by the UK government. This was to be the first European satellite designed to track atmospheric CO_2 levels down to <1 ppm. The spectrometer was assessed for its optical, geometric, spectral, and radiometric performance. In 2025, MicroCarb was successfully launched, returning its first measurements of the Amazon Basin later that year – a region believed crucial in the global carbon cycle, but for which few ground-based CO_2 measurements existed.

In the subsequent MetEOC-4 project, STAR's accuracy was further improved, towards the 0.1% level - necessary for optical SITSat missions, such as ESA TRUTHS. After MetEOC-4, in 2023 the STAR blueprint was used to build two sister facilities, STARWELL, designed to provide quick, affordable calibration of small-sat radiometric instrumentation, and CARES for calibrating drone mounted and portable field instruments.

European infrastructure now exists to ensure that a range of satellite and in-situ data can access the highest accuracy possible. Amongst many other applications it also allows the sources and sinks of greenhouse gases to be independently verified, providing policy makers with the information needed for present and future mitigation strategies.

Metrology for SI traceable climate observations

Over half of the 55 Essential Climate Variables, used to predict how the Earth's climate is evolving, has a space-based contribution.

The MetEOC series of projects:

- MetEOC (2011-2014) improved NMI calibration facilities, including ones used to calibrate instruments in the field.
- MetEOC-2 (2014–2017) improved performance of an originally lab-based cryogenic solar radiometer to enable improvements of measurements of incoming solar radiation by a factor of 10 and developed standards and instrumentation for the characterisation of large areas of ocean, vegetation and desert, used to confirm satellite-borne instrumentation performance.
- MetEOC-3 (2017-2021) integrated tuneable laser methods into calibration facilities such as STAR, to allow enhanced calibrations of spectroscopic instruments, for example, to retrieve localised measurements of CO_2.
- MetEOC-4 (2020-2023) further improved the accuracy of calibration facilities, developing new instrumentation and standards to allow more comparable data on sky radiance from ground-based networks.

These results will provide trustworthy evidence to policy makers and help timely and measured mitigation strategies to be implemented.

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