



UNITED NATIONS
INDUSTRIAL DEVELOPMENT ORGANIZATION

Bureau
International des
Poids et
Mesures



Accurate Measurements of Carbon Dioxide for Climate Action

VNIIM has developed SI-traceable measurement capabilities for atmospheric CO₂ amount fraction and its isotopic composition ($\delta^{13}\text{C}$ and $\delta^{18}\text{O}$) at ambient levels, enabling reliable greenhouse gas monitoring and source attribution

*D.I. Mendeleyev Institute for Metrology (VNIIM)
Russia (RU)*



The Challenge

Monitoring greenhouse gases, including carbon dioxide (CO₂), in the atmosphere remains a constant challenge for the global metrology community. Accurate and reliable measurement of carbon dioxide concentration under real-world atmospheric conditions is critically important for climate action and for supporting national commitments under the Paris Agreement. While such measurements also have secondary applications in industrial safety control, the primary focus of this case study is on strengthening measurement capabilities for atmospheric background monitoring under the WMO Global Atmosphere Watch (GAW) network and enabling verifiable reporting of greenhouse gas emissions.

As the national metrology institute of the Russian Federation, VNIIM is responsible for providing SI-traceable reference materials and calibration services to support national greenhouse gas monitoring programmes and participation in global atmospheric networks such as the WMO GAW. The developed capability focuses primarily on background atmospheric monitoring at WMO GAW stations, which measure ambient CO₂ levels. While the primary application is climate-related greenhouse gas monitoring rather than urban air quality, the improved accuracy of CO₂ measurements also benefits urban-scale flux monitoring and provides reference data for validating satellite-based CO₂ retrievals. The capability has been rolled out through collaboration with Roshydromet,¹ which operates the Russian GAW network.

Monitoring CO₂ levels in industrial settings is also important for preventing accidents, ensuring a safe working environment, and optimizing production processes. CO₂ sensors are used in ventilation and air conditioning systems to automatically monitor gas levels and ensure optimal air quality. Thus, accurate and reliable measurement of carbon dioxide concentration under real-world atmospheric conditions is not only important for climate action but also directly contributes to promoting safe and sustainable urban zones and industrial practices.

The primary drivers for developing this capability were: (1) the need to support Russia's national greenhouse gas monitoring plan and enable verifiable reporting; (2) the aspiration to align Russian calibration materials with WMO GAW requirements; (3) the technical motivation to establish a national metrological capability for isotopic composition measurements ($\delta^{13}\text{C}$, $\delta^{18}\text{O}$), which are essential for distinguishing fossil-fuel emissions from biogenic CO₂ — a key requirement for effective climate policy and carbon accounting.

¹ Russian monitoring of atmosphere “Roshydromet”: <https://www.meteorf.gov.ru/>

The Solution

For the development of metrology capability at the Saint-Petersburg D.I. Mendeleyev Institute for Metrology (VNIIM), the analytical challenge was to prepare standards of carbon dioxide in air that are fit for purpose for the atmospheric monitoring community, with stringent requirements on matrix composition and on the measurement uncertainty of the CO₂ mole fraction. The mole fraction of carbon dioxide of the test samples was required to be within $\pm 10 \mu\text{mol/mol}$ of the nominal mole fraction of the standard mixture.

Furthermore, accurate measurements of the isotopic ratios $\delta^{13}\text{C}$ and $\delta^{18}\text{O}$ were difficult to obtain with the prior metrological capability. Without reliable isotopic data, distinguishing fossil fuel emissions from biogenic CO₂ was impossible, ultimately hindering effective GHG monitoring and climate action policy. Russian measurement data could not be directly compared with other WMO Global Atmosphere Watch (GAW) monitoring stations, reducing trust in national reports for use in global climate action models and related applications.

Interlaboratory comparisons conducted under the auspices of the CIPM are designed to ensure global measurement consistency and support calibration and measurement capabilities (CMCs) under the CIPM MRA. These are considered a “top-tier” demonstration of a nation’s measurement capabilities and provide both the opportunity and motivation for NMIs and DIs to build and demonstrate cutting-edge metrology capabilities.

Participation in the international comparison CCQM-K120, "Carbon dioxide in air at the atmospheric level",² confirmed VNIIM's measurement and calibration capabilities, with an uncertainty of 0.1 %. Such low uncertainty values were also obtained using the isotopic-ratio measurement method. Fourteen NMIs and DIs took part in both comparisons (CCQM-K120.a and CCQM-K120.b: BFKH, GUM, KRISS, LNE, NIM, NIST, NMII, NMISA, NOAA, NPL, NPLI, UME, VNIIM, and VSL) and only one solely in the CCQM-K120.b comparison (INRIM), which was a bilateral study linked through the BIPM.

A Quantifiable Impact

VNIIM's calibration and measurement capabilities were significantly improved from a typical uncertainty of about 0.5 % before the intervention and reduced to 0.1 %, a five-fold improvement, following the completion of the CCQM-K120 interlaboratory comparison. This new approach enables more precise measurement control at four Roshydromet greenhouse gas monitoring stations, including background monitoring stations within the WMO GAW observing network. This included the A.I. Voeikov Main Geophysical Observatory (MGO) in St. Petersburg, the Voeikov Main Geophysical Observatory near St. Petersburg, the Teriberka Global Atmosphere Watch (GAW) regional station located on the Kola Peninsula shoreline of the Barents Sea, and the Tiksi Hydrometeorological Climate Observatory along the Laptev Sea.

² Edgar Flores *et al* 2019 *Metrologia* **56** 08001

Because of this interlaboratory comparison, new reference materials have been developed at VNIIM for the composition of gas mixtures. The range has been expanded, reliability has increased, and measurement accuracy has improved. Over the 2016–2020 period, VNIIM reduced CO₂ measurement uncertainty from 0.2 % to 0.1 % and established new capabilities for $\delta^{13}\text{C}$ and $\delta^{18}\text{O}$ isotope ratio measurements with uncertainties of 0.10 ‰ and 0.15 ‰, respectively. A new measurement method has also been developed using high-precision cavity ring-down spectroscopy equipment (Picarro G2401 CRDS analyzer for volume fraction analysis and Picarro G2131i CRDS analyzer for isotopic composition analysis), enabling the determination of carbon dioxide isotopic composition in addition to its total content, thereby increasing overall measurement accuracy. Reducing measurement uncertainty from 0.5 % to 0.1 % directly improves the accuracy of national carbon accounting in Russia and the global effort as a whole.

Beyond the reduction in CO₂ amount fraction uncertainty, the CCQM-K120 participation enabled VNIIM to establish, for the first time, measurement capabilities for carbon and oxygen isotope ratios ($\delta^{13}\text{C}$ and $\delta^{18}\text{O}$) in atmospheric CO₂. After the intervention, VNIIM achieved expanded uncertainties ($k=2$) of 0.10 ‰ for $\delta^{13}\text{C}$ and 0.15 ‰ for $\delta^{18}\text{O}$ (metrologically traceable to the VPDB and VSMOW scales, respectively). This, and the results from the numerous other NMIs and DIs that participated in the CCQM-K120 comparisons, is a direct demonstration that improvements in metrology deliver tangible policy benefits for climate action.

The improved measurement capability supports Russia's national greenhouse gas monitoring plan and enables verifiable reporting under the UNFCCC, contributing to the Paris Agreement's transparency framework. The effort facilitated cooperation between VNIIM and Roshydromet and helped align Russian national calibration standards with WMO GAW requirements. Regular participation in international comparisons under the CIPM MRA is essential for building trust in national emission data.

POC: Anna Kolobov, fhi@b10.vniim.ru