

Environment impact report

A summary of the outputs and impact of the first EMRP joint research projects in Environment.

The aim of this theme is to improve data quality for environmental policy making, underpin environmental research activities and stimulate technological innovation. The research is focused at both the local environmental level for air, water and soil quality and at the global level for challenges relating to climate change.

Measurement matters

Measurement underpins virtually every aspect of our daily lives, helping to ensure quality and safety, support technological innovation and keep our economy competitive.

Supported by the European Commission, EURAMET's **European Metrology Research Programme (EMRP)** brings together National Measurement Institutes in 23 countries to pool scientific and financial resources to address key measurement challenges at a European level.

The programme is designed to ensure that measurement science meets the future needs of industry and wider society. Research is structured around four themes – Energy, Environment, Health and Industry – as well as the measurement needs of emerging technologies and the fundamentals of the SI measurement units that form the basis of Europe's measurement infrastructure.

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Introduction: Metrology for environment

A key challenge facing Europe is the need to ensure sustainable growth, while protecting the environment and safeguarding our quality of life.

Managing and protecting the environment requires robust and reliable data to assess and monitor environmental parameters. National and international agencies rely on this data to ensure that environment treaties and regulation are both well-designed and enforced effectively, and climate scientists need reliable data to understand and monitor climate change.

Meeting the demanding requirements of environmental regulation and climate science presents a range of fundamental and practical measurement challenges. EURAMET's European Metrology Research Programme (EMRP) supports a coordinated approach to research in environmental measurement, providing Europe's research and innovation base, as well as policy-makers, public agencies and instrument manufacturers, with access to the combined experience and capability of Europe's National Measurement Institutes (NMIs).

45 metrology research groups came together with academia, industry and public environment agencies to conduct research under the first call of the EMRP Environment theme. These projects aimed to improve data quality and stimulate the development of innovative technologies, to support an improved quality of life for European citizens.

The research focused on two areas: **increasing our understanding and assessment of climate change; and ensuring a safe, clean environment.**

This report presents the key technical achievements of these research projects and highlights early examples of the impact generated within the climate and environmental monitoring community.

Research continues under a second EMRP Environment theme call.

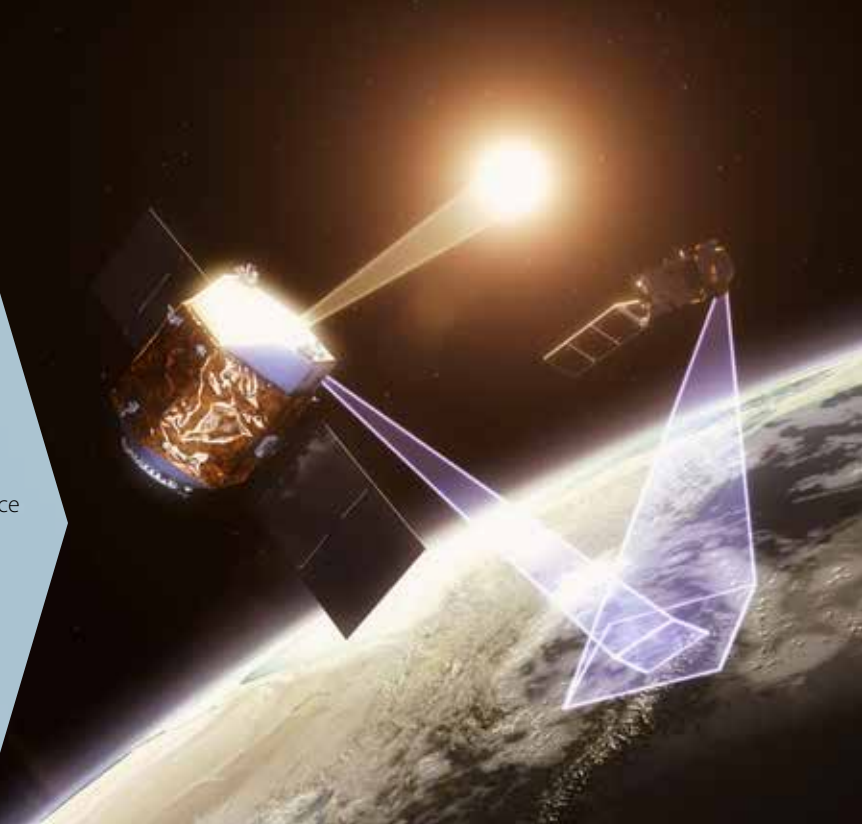




Highlights

An NMI in space – supporting better climate data

EMRP research has made significant developments towards the goal of an 'NMI in space' that will calibrate and validate the climate data from Earth observation satellites. The metrology community worked closely with the European Space Agency and climate scientists to develop and test high-level metrology instrumentation for the space environment. The instrument, a primary radiometer, is capable of a radiometric accuracy of 0.3 %, a factor of 10 improvement on previous traceability methods. The instrument is the key component of the planned TRUTHS mission (Traceable Radiometry Underpinning Terrestrial- and Helio- Studies) that will establish an NMI in space.



Multidisciplinary solutions for environmental needs

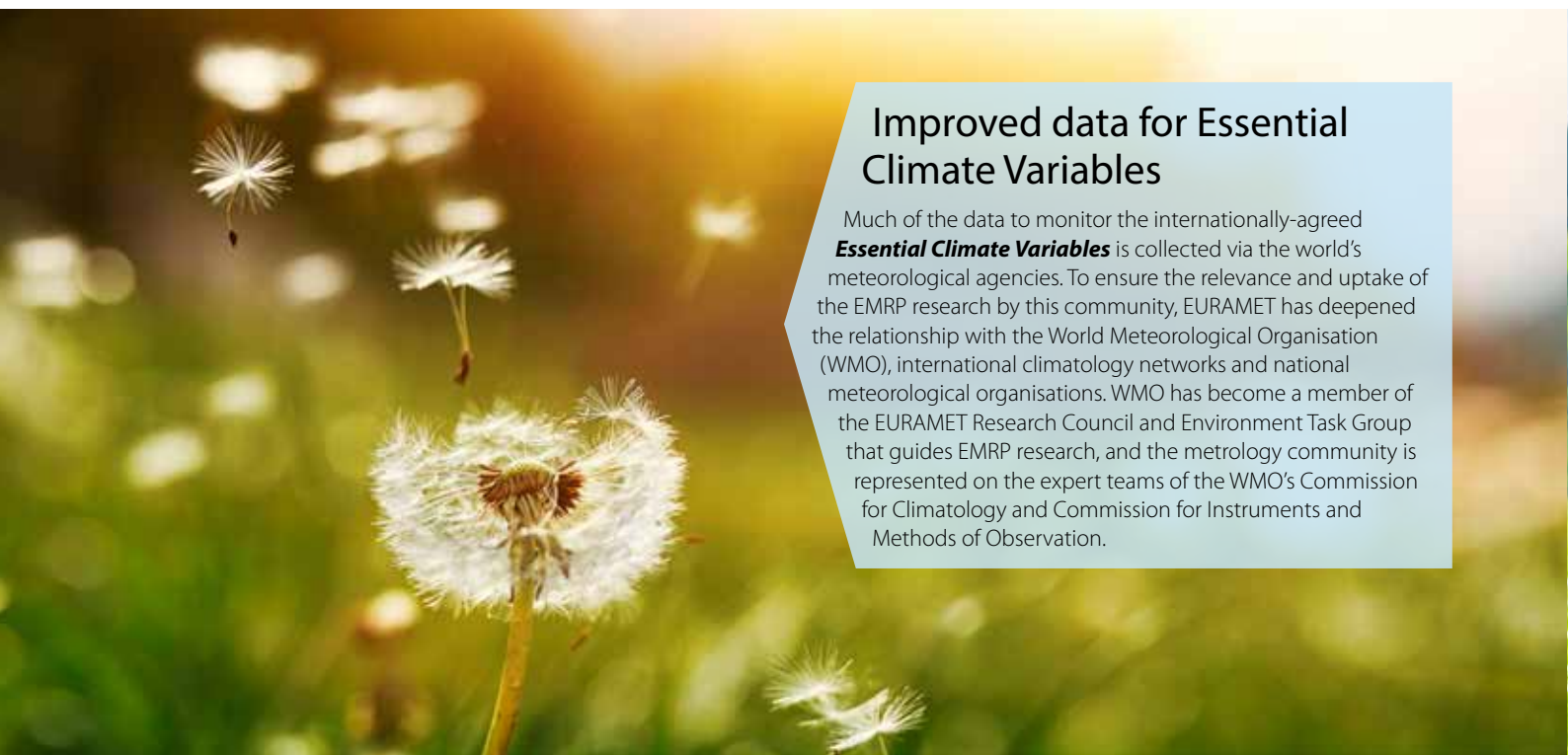
For the first time the European metrology community is working collectively to design and conduct the research needed to improve the quality and reliability of environmental measurements.

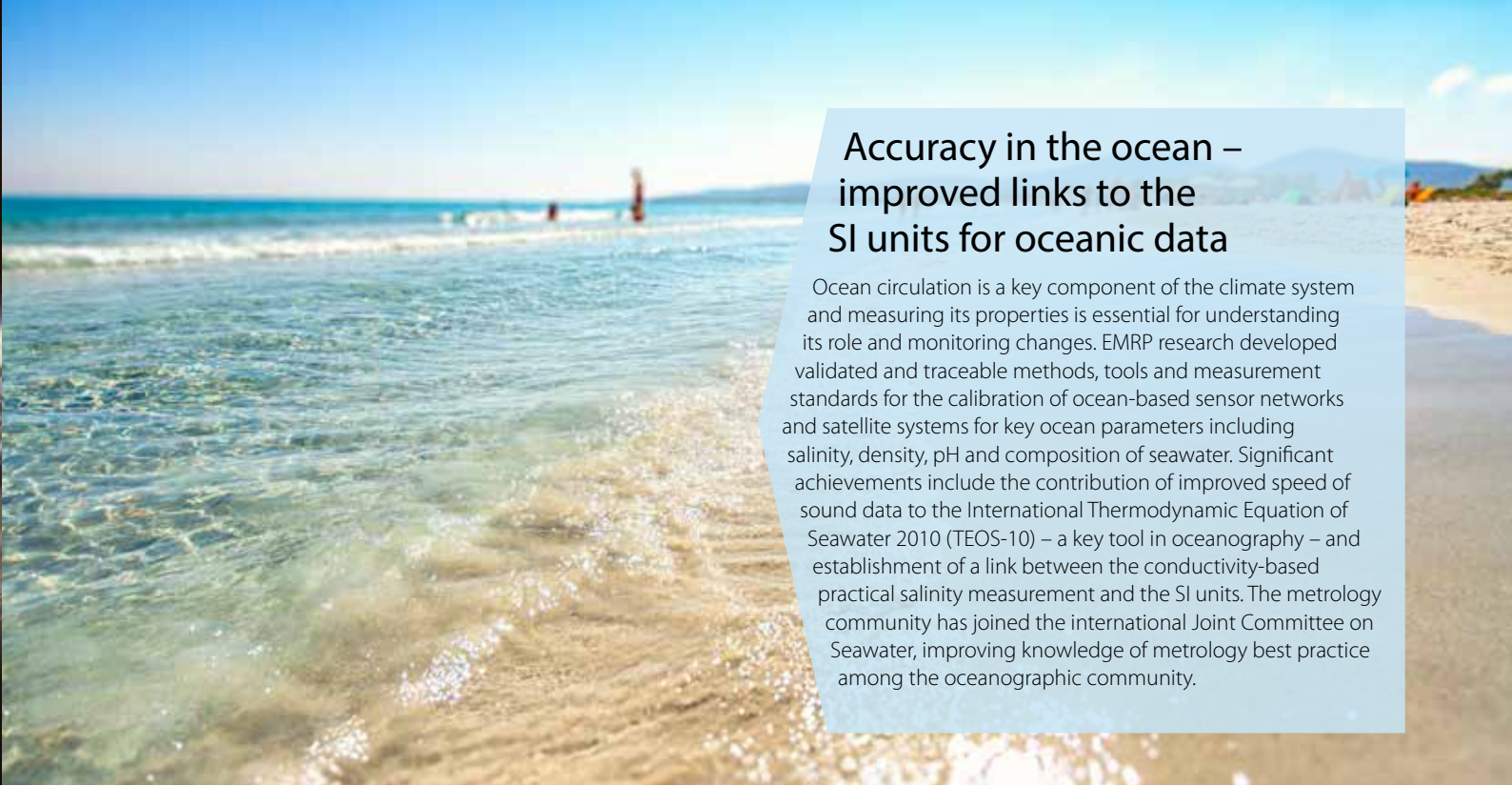
The EMRP established a multidisciplinary **Environment research theme** that brings together fields relevant to climate and environmental monitoring – such as radiometry, and chemical, temperature and pressure metrology. The European Commission and national governments invested €40M in collaborative environmental research involving research groups in 45 European National Measurement Institutes and Designated Institutes, along with 19 academic groups, 27 public agencies with environmental remits and 37 businesses.

EURAMET established an interdisciplinary **Environment Task Group** to bring together metrology experts across a range of measurement areas with the organisations that collect and use environmental data to ensure the relevance and use of the research supported by EMRP.

Improved data for Essential Climate Variables

Much of the data to monitor the internationally-agreed **Essential Climate Variables** is collected via the world's meteorological agencies. To ensure the relevance and uptake of the EMRP research by this community, EURAMET has deepened the relationship with the World Meteorological Organisation (WMO), international climatology networks and national meteorological organisations. WMO has become a member of the EURAMET Research Council and Environment Task Group that guides EMRP research, and the metrology community is represented on the expert teams of the WMO's Commission for Climatology and Commission for Instruments and Methods of Observation.





Accuracy in the ocean – improved links to the SI units for oceanic data


Ocean circulation is a key component of the climate system and measuring its properties is essential for understanding its role and monitoring changes. EMRP research developed validated and traceable methods, tools and measurement standards for the calibration of ocean-based sensor networks and satellite systems for key ocean parameters including salinity, density, pH and composition of seawater. Significant achievements include the contribution of improved speed of sound data to the International Thermodynamic Equation of Seawater 2010 (TEOS-10) – a key tool in oceanography – and establishment of a link between the conductivity-based practical salinity measurement and the SI units. The metrology community has joined the international Joint Committee on Seawater, improving knowledge of metrology best practice among the oceanographic community.

Improving water quality – reducing harmful pollutants

The European Water Framework Directive specifies very low permitted levels of pollutants that present a significant risk to or via the aquatic environment. Toxic pollutants such as tributyltin (TBT), polybrominated diphenylether (PBDE) and selected polycyclic aromatic hydrocarbons (PAH) are particularly harmful as they are liable to accumulate in the food chain and endanger a wide range of living organisms. EMRP research developed validated primary reference methods (traceable to the SI units) based on isotope dilution for the analysis of these pollutants (TBT, PBDE, PAH) in whole water (i.e. real-world) samples at the low levels required to comply with the Directive. These methods allow the quality of measurements made in public and commercial labs to be validated and are already being deployed in a number of European regions.

Improving air quality – reducing particulates

Particulates are classified as carcinogenic by the World Health Organisation and each generation of the European emissions regulation reduces the levels permitted in vehicle exhausts. Euro 6, the latest version of the regulation, introduces a limit on particle number as well as particle mass. EMRP research developed a new validated aerosol for calibrating the condensation particle counters used to type-test and certify new engines and ensured its uptake through incorporation of measurement best practice in the relevant ISO standard. The research has also supported the development of instrumentation for the new requirement for periodic emissions testing to include both static and on-road conditions. Together these developments in metrology are ensuring that new tighter regulation can be complied with and contribute to reduced harmful emissions.



Improving air quality – reducing NO₂ emissions

Improving air quality requires accurate measurements of pollutants at the low concentrations permitted by European regulation. EMRP research developed preparation methods for calibration gases for SO₂, NO and NO₂ at or near the limit values of the regulation and a practical portable NO₂ generator for cost-effective calibration of air quality sensors in the field. The NO₂ generator has been used by the City of Zürich Health and Environment Department to calibrate its installed air quality sensors, enabling it to evaluate its pollution reduction strategy and maintain its lead in reducing city centre pollution.

First EMRP Environment projects at a glance



Pooling expertise of
45 NMIs and **25** European
DIs from **25** countries
plus the NMIs from **USA, Japan,**
Korea, and **New Zealand**



businesses



public
agencies



134

**articles
in peer-reviewed
journals**



446
**presentations
at conferences**



16 **articles
in the
trade
and popular press**



21
**published newsletters
and press releases**



Supported the
development of improved
instrumentation for
environmental
monitoring, with
€12M
of sales projected to date

6
**media
interviews**



8

**contributions to draft standards
and published standards**

Understanding climate change

Metrology has a critical role to play in understanding, modelling and monitoring climate change. European policies aimed at mitigating anthropogenic climate change and implementing adaptation measures need to be based upon sound science and accurate data. Robust data on the atmosphere, oceans and land, as well as solar and terrestrial radiation, is essential for climate change assessments and effective policymaking. Only through collaborative effort can Europe's National Metrology Institutes make the necessary advances in measurement quality to underpin reliable climate assessments, models and predictions.

Measurement challenges

Monitoring and modelling the Earth's climate requires the measurement of a wide range of climate parameters – the Global Climate Observing System¹ has defined 50 Essential Climate Variables to assess features of the atmosphere, oceans and land. Measurements of these variables need to be comparable irrespective of location and time and the instrumentation or method used. At the heart of this challenge is ensuring traceability to the SI units. Daily satellite- and surface-based measurements of climate variables require robust quality assurance, while climate records covering many decades demand rigorous methods for the assignment of measurement uncertainties. Climate measurement methods and instrumentation have been developed over decades by organisations and research groups worldwide and measurement comparability becomes increasingly important as international and national policymakers seek to implement climate protocols, agreements and regulation.

EMRP research has supported improved accuracy of measurement data for Essential Climate Variables and the development of new measurement methods and technologies in three areas:

- **Earth observation**
- **Mapping ocean circulation**
- **Atmospheric data**



¹GCOS is a joint undertaking of the World Meteorological Organization (WMO), the Intergovernmental Oceanographic Commission (IOC) of the United Nations Educational Scientific and Cultural Organization (UNESCO), the United Nations Environment Programme (UNEP) and the International Council for Science (ICSU).

Key technical achievements

Earth observation

Earth observation agencies worldwide are moving towards a more coordinated approach to data gathering. With the increased importance of the data they provide, they are demanding improved measurement accuracy of the instrumentation on board Earth observation satellites. Satellites remain in service for several decades and in-flight calibration is critical to long-term comparability of climate data. A factor of 10 improvement in key variables would enable robust discrimination between the natural variability of the climate system and anthropogenic change in the shortest time possible.

Achieving this accuracy improvement is a long-term global endeavour and the EMRP research project [ENV04 European metrology for Earth observation and climate](#) developed key components of the metrological infrastructure for the calibration and validation of satellite and air-borne radiometric instrumentation, traceable to the SI units. The infrastructure comprises:

- **Improved NMI calibration facilities** – the LAVRAS (large field-of-view camera systems) calibration facility that provides traceability to transfer standards used to calibrate instrumentation in the field.
- **Derivation of uncertainty budgets and procedures** for Earth observation measurements.
- **Transfer standards and instrumentation** for the characterisation of large areas of ocean, vegetation and desert, to be used to confirm satellite-borne instrumentation performance.
- **A radiometric transfer standard for the planned TRUTHS mission** (an ‘NMI in space’) with higher sensitivity and accuracy than previously possible. The prototype in-flight primary radiometer is capable of a radiometric accuracy of 0.3 % – a factor of 10 improvement on previous transfer standards.

The project is part of a wider endeavour of the metrology community to improve the Earth observation data available to climate scientists. The project team worked closely with the Earth observation community throughout the project to design and demonstrate new capabilities. For example, a portable leaf goniometer was used to generate initial data for a new leaf reflectance reference library, which will enable satellite data to be linked to real bio-geophysical parameters leading to the capability to ‘calibrate’ Earth targets (e.g. forests). Based on the work of the project a small sensor web (RADCALNET – developed by a number of space agencies) was constructed to demonstrate the feasibility of SI traceable verification for satellite-based instrumentation flying over ground sites post launch. The new infrastructure will contribute to improved performance of the joint EU and European Space Agency network of Earth observation satellites (Copernicus mission) currently under development.



Courtesy of ESA

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| More information is available at | ENV04 European metrology for Earth observation and climate (MetEOC) www.euramet.org/project-ENV04 | |
| | Details of the follow-on EMRP project: Metrology for Earth observation and climate (MetEOC2) www.euramet.org/project-ENV53 | |
| Contact | Nigel Fox (NPL) | nigel.fox@npl.co.uk |

Ocean circulation

The ocean is a key component in the global climate system. It is a sink for carbon dioxide and increasing ocean temperatures lead to rising sea-levels. The characterisation of the status of the oceans and their circulation requires world-wide monitoring of a wide variety of physical and chemical parameters over long time periods and over the full range of pressures and salinities present in the ocean. Changes in these parameters are typically small but have a large impact on oceanic and climate behaviour.

The EMRP project [ENV05 Metrology for ocean salinity and acidity](#) developed:

- **A standardised method for determining ocean salinity** with reduced uncertainties and traceability to the SI for typical ocean pressure and temperature conditions. It established a link between oceanographers' practical salinity measurements and the SI, enabling the International Association for the Physical Sciences of the Ocean defined standard seawater (a primary reference solution) to be assessed for stability over time and future-proofing salinity standards against increasing global seawater dilution as the polar ice caps melt.
- **A new traceability chain for the measurement of pH in seawater** based on validated measurement methods and procedures.
- **Improved NMI speed of sound in water calibration facilities** leading to an improved understanding of the effect of salinity and temperature on this fundamental seawater parameter and its inclusion in the Thermodynamic Equation of State for Seawater 2010 (TEOS-10) – a key tool in oceanography.
- **A high-accuracy modification to the Winkler titration method** for dissolved oxygen determination (an essential factor for aquatic life) with associated uncertainty budget derivation enabling greater accuracy in the calibration of commercial electrochemical and optical dissolved oxygen sensors.

The project team worked with the international oceanographic community to ensure their results were relevant and communicated, and to bridge the gap between the oceanographic and metrology communities. The metrology community is now a member of the international Joint Committee on Seawater (a joint group of the three key oceanographic associations). The research outputs have contributed to new ISO standard, ISO 18191 *Water quality — Determination of pH in sea water*, and other outputs will be considered in future standardisation work of the International Association for the Properties of Water and Steam. In the longer-term, reliable oceanic data will support deep sea research, the exploration of ocean resources and improved climate modelling.



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| More information is available at | ENV05 Metrology for ocean salinity and acidity (Ocean) www.euramet.org/project-ENV05 | |
| Contact | Stephen Seitz (PTB) | stephen.seitz@ptb.de |

Atmospheric data

The EMRP project [ENV07 Metrology for pressure, temperature, humidity and airspeed in the atmosphere](#) addressed improved data for a group of Essential Climate Variables – surface and upper air measurements of temperature, pressure, humidity and airspeed – collected at weather stations worldwide. The research focused on improved measurement accuracy, innovative practical calibration methods and instrumentation for use in the field. The project developed:

- **A traceability chain for upper air humidity, temperature and wind-speed sensor calibration** based on improved facilities at NMIs.
- **Novel instrumentation for measuring humidity** – a self-calibrating hygrometer based on tunable diode laser absorption spectroscopy (TDLAS) that will reduce operating costs; a new generation of compact, robust and high-sensitivity hygrometers; and a novel portable humidity transfer standard for use in situ at weather stations.
- **Novel free-space non-contact multi-parameter atmospheric measurement sensors and measurement techniques** to enable rapid simultaneous measurements of temperature, pressure and relative humidity of the same air mass, while reducing the influence of the sensors themselves on the measurements.
- **Best practice procedures for cost-effective in-situ calibration of automated weather stations** and the development of an in-situ calibration system, with simultaneous and independent control of pressure, temperature, and humidity. A closed loop wind tunnel, with temperature and pressure control is now available for calibration and testing of weather instruments and contributions were made to revised good practice guides published by WMO and the Global Climate Observing System Reference Upper-Air Network (GRUAN).



Courtesy of ESA

The project team worked with a wide range of stakeholders – such as the World Meteorological Organisation, GRUAN, the International Surface Temperature Initiative, climatology centres, as well as instrumentation suppliers – to understand their needs and provide practical solutions. The new calibration services have been used by a number of meteorological and climate institutes to date and the in-situ calibration system, for example, has been used in harsh environments in the Arctic Circle and Himalaya, supporting improved climate data, analysis and modelling. The instrumentation developed and intercomparisons of existing equipment undertaken are enabling manufacturers to develop a new generation of accurate and robust products.

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| More information is available at | ENV07 Metrology for pressure, temperature, humidity and airspeed in the atmosphere (MeteoMet) www.euramet.org/project-ENV07 | |
| | Details of the follow-on project: ENV58 Metrology for essential climate variables (MeteoMet2) www.euramet.org/project-ENV58 | |
| Contact | Andrea Merlone (INRIM) | a.merlone@inrim.it |

Atmospheric data

The EMRP project [ENV06 Spectral reference data for atmospheric monitoring](#) addressed the need to improve the quality of the reference spectral line data used in a wide range of spectroscopic methods that determine concentrations of greenhouse gases and pollutants in the atmosphere for climate studies and environmental monitoring. The quality of spectroscopic data depends on the accuracy of the underlying molecular spectral line data. As data is needed throughout the atmosphere, a particular challenge is understanding how the properties of the molecules to be measured vary with temperature, pressure and atmospheric composition. With the large number of existing and planned global atmospheric monitoring networks and satellites dedicated to environmental monitoring, there is a global need for a long-term infrastructure to provide high quality spectral data.



Courtesy of ESA

The project established a coordinated European measurement infrastructure for traceable spectral reference data to support accurate atmospheric measurement data, through:

- **A central spectroscopic facility (CF) based on a modified high-resolution visible to mid-infrared Fourier-transform spectrometer was developed.** It determines accurate spectral line data for key molecular species including their dependence on temperature from 200 K to 350 K and pressure from 0.01 mbar to 1000 mbar, covering the relevant conditions for tropospheric and stratospheric studies. The facility is validated via high-resolution laser-based facilities at NMIs across Europe and accurate gravimetric dilution gas reference standards and full uncertainty assessments. It has an open interface structure allowing access by the climate science community.
- **Traceable spectral line data for a range of greenhouse gas species** with metadata including traceability statements and uncertainty flags for key greenhouse gases: carbon dioxide, methane and nitrous oxide. This data will be included in the forthcoming revision of the widely used database of spectroscopic data HITRAN, increasing the amount of SI traceable data in the database.

The ongoing activities to produce accurate spectral line data will improve atmospheric measurements based on spectrometric methods, providing more reliable data for environmental monitoring and modelling. A key user of the HITRAN database, for example, is the Total Carbon Column Observing Network, made up of 23 ground-based atmospheric monitoring stations distributed across the globe that also validate satellite measurements. The improved data will help to remove discrepancies between satellite and surface measurements.

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| More information is available at | ENV06 Spectral Reference Data for Atmospheric Monitoring (EUMETRISPEC) www.euramet.org/project-ENV06 | |
| Contact | Volker Ebert (PTB) | volker.ebert@ptb.de |

Creating a clean, safe environment

Accurate data is essential to monitoring and managing the environment and enabling the design and implementation of effective environmental regulation. Recognising the hazards posed by pollution, the EU has developed an extensive body of legislation which establishes health-based standards and objectives for pollutants in air, water and soil. Key to the successful implementation of these policies is an underpinning measurement infrastructure that ensures that environmental data is robust and consistent across monitoring networks, across national borders and over time.

Measurement challenges

Environmental regulation evolves over time as our understanding increases of the effects of pollutants on human health and the wider environment. This poses an ongoing challenge to the measurement infrastructure. As allowable pollutant levels decrease and new types of pollutant are identified, measurement capabilities must be constantly improved to support robust and fit-for-purpose pollutant monitoring and mitigation. This requires both improved measurement accuracy across the measurement infrastructure – at National Measurement Institutes, in accredited laboratories and in environmental monitoring networks – and the development of innovative, practical and cost-effective measurement technologies.

EMRP research is improving the quality of environmental monitoring data to ensure the effective implementation of European regulation in five areas:

- Air quality
- Water pollutants
- Nuclear waste
- Solar UV radiation
- Nuclear waste



Key technical achievements

Air quality

The EMRP project [ENV01 Metrology for Chemical Pollutants in Air](#) addressed the need to assess the quality of outdoor and indoor air. The European Air Quality Directive (2008/50/EC) sets challenging limit values and data quality objectives for the measurement of pollutants in ambient air and air monitoring networks have struggled to comply with the objectives because of the lack of metrological transfer standards at and below the pollutant limit values specified. In addition, governments are starting to address the quality of indoor air where harmonised regulation does not exist.



The EMRP project developed:

- **Preparation methods for calibration gases for the pollutants SO₂, NO and NO₂** at or near the limit values of the regulation.
- **A certified protocol for preparation and validation of 'zero gas'** for zero-ing analytical instrumentation. This is essential for measurements of pollutants at very low concentrations.
- **Reference methods and reference materials for harmful (semi-) volatile organic compounds ((S)VOCs)**, which originate from emissions from building materials and contaminate indoor air. Preparation methods for (S)VOC transfer standards at levels of interest for emission testing laboratories were validated and a reference material reproducing the gas emission behaviour typical of a construction product was developed for the quality control of emission test chamber measurements.
- **Innovative micro-sensors for air quality monitoring based on graphene.** Two types of graphene sensors were tested for the measurement of ambient levels of NO₂ and a protocol for the evaluation of micro-sensors was developed and implemented. A clustered system of micro-sensors, was developed and evaluated as a potential cost-effective method for the measurement of pollutants under the Air Quality Directive. It demonstrated that an artificial neural network of calibrated sensors achieved the best accuracy.

The new traceable measurement capabilities will improve comparability of data between the air quality reference laboratories responsible for quality assurance and quality control of the air monitoring networks in each country. The project worked with members of the European Network of Air Quality Reference Laboratories (AQUILA) throughout the project to understand their needs and share the research outputs. The new calibration facilities and tools are being trialled in air quality networks in Switzerland and it is expected that the zero-gas protocol will be incorporated in an amended ISO standard for gas purity.

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| More information is available at | ENV01 Metrology for Chemical Pollutants in Air (MACPoll) www.euramet.org/project-ENV01 | |
| Contact | Annarita Baldan (VSL) | abaldan@vsl.nl |

Exhaust emissions

The EMRP project [ENV02 Emerging requirements for measuring pollutants from automotive exhaust emissions](#) addressed a major source of air pollution. Of particular concern are the fine particles emitted by diesel engine exhausts that are classified by the World Health Organization as carcinogenic to humans, as well as platinum group elements (PGE) and mercury released from cars and industrial processes. This project provided the underpinning metrology infrastructure and research to better understand and measure, and therefore control, such emissions.



The project developed:

- **A new validated aerosol** to enable the traceable calibration of condensation particle counting instruments used to measure particulates during the type approval and certification of new automotive engines against European regulation (the *Euro 6c* regulation).
- **A simulated comparison exercise** between existing particle emission meters (based on opacity measurements) and novel prototype instruments based on diffusion chargers and optical methods, providing instrument validation at the low particle levels present in *Euro 6* compliant diesel vehicle exhausts.
- **Improved analysis methods and the associated uncertainties for measurements of small concentrations of PGE** present in sample matrices using two mass spectrometry techniques.
- **The foundations for an improved SI traceable metrological infrastructure for mercury-in-air measurements** ($\leq 15 \text{ ng Hg m}^{-3}$) which is closer to realistic ambient air concentrations ($1\text{--}2 \text{ ng Hg m}^{-3}$) than was previously possible.

This project is supporting the introduction of effective particulate assessment methods to meet the updated *Euro 6c* regulation, which will cover type approval of new engines and mandatory periodic testing of diesel engine exhausts in both static and on-road conditions. Methods developed in the project are expected to be incorporated in the UN Particle Measurement Programme documentation (a key reference for the *Euro 6* regulation) when it is updated in 2016. The new NMI capabilities are being used by manufacturers of particulate measuring instrumentation to provide traceable measurements and develop products for the new on-road testing requirements.

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| More information is available at | ENV02 Emerging requirements for measuring pollutants from automotive exhaust emissions (PartEmission) www.euramet.org/project-ENV02 | |
| Contact | Martin Thedens (PTB) | martin.thedens@ptb.de |

Water quality

Water pollution has a significant negative impact on human health and the environment, and improving the quality of rivers, lakes, groundwater and coastal waters is a priority for policymakers. The European Water Framework Directive was established to protect and improve water quality and prevent further deterioration, through legal limits on a wide range of known pollutants. The Water Framework Directive specifies a list of 33 priority water pollutants, for which maximum allowable concentrations have been defined. As some pollutants are toxic to a wide range of living organisms, the permitted levels are very low and challenging to measure and monitor.



The EMRP project [ENV08 Traceable measurements for monitoring critical pollutants under the European Water Framework Directive](#) addressed the measurement requirements for a group of toxic pollutants: tributyltin (TBT), polybrominated diphenylether (PBDE) and selected polycyclic aromatic hydrocarbons (PAH). The project developed:

- **Validated reference methods for the analysis of TBT, PBDE and PAH traceable to the SI units at the levels and uncertainties required by the Water Framework Directives.** Importantly the methods address measurements in 'whole water' i.e. in real-world samples where pollutants can be present as suspended solids or colloids as well as in solution.
- **Aqueous reference materials for TBT, PBDE and PAH at ng/L levels** with proven short and long time stability. The materials contain dissolved humic acids and suspended particulate matter and are a major step forward towards producing reference materials that mimic whole water.

The project conducted an interlaboratory comparison for field laboratories using the new aqueous reference materials at low concentrations (ng/L for some parameters). This demonstrated that most parameters could be successfully measured with reasonable agreement between the laboratories and was a significant achievement as no such intercomparison has been performed before on whole water samples with such low concentrations. This means that accurate measurement capabilities and quality assurance are now available to enable water monitoring laboratories to meet the requirements of the Water Framework Directive.

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| More information is available at | ENV08 Traceable measurements for monitoring critical pollutants under the European Water Framework Directive (WFD) www.euramet.org/project-ENV08 | |
| Contact | Rosemarie Philipp (BAM) | rosemarie.philipp@bam.de |

Solar UV

Ultraviolet (UV) radiation from the sun has both beneficial and damaging effects. Too much can cause skin cancer and cataracts, while too little leads to harmful vitamin D deficiencies. Therefore accurate assessment of UV radiation at the Earth's surface and long-term trends in solar UV is necessary to enable the development and implementation of relevant policy and regulation.

The EMRP project [ENV03 Traceability for surface spectral solar ultraviolet radiation](#) has improved the accuracy of UV measurements worldwide through shortening the calibration chain between the world reference standard for UV and end-users in order to reduce the measurement uncertainties. As a result of the project:

- **The performance of the world reference UV spectroradiometer (QASUME) located at the World Calibration Centre for UV in Davos Switzerland was significantly improved**, reducing its measurement uncertainty from $\pm 4\%$ to $\pm 1.5\%$. A second generation world reference instrument for solar UV that will replace the original instrument was also designed, developed and tested.
- **An NMI-based tuneable laser calibration chain for solar UV radiance measurements was established.**
- **Accurate and portable reference standards based on traceable portable UV-LED radiance sources were developed** to enable calibration of field instruments in situ, removing the need to take them to the world reference UV spectroradiometer in Switzerland. Methods to accurately characterise typical field instruments (CCD array-based spectroradiometers) were developed and shared with the user community.
- **New technologies for improved solar irradiance measurements were investigated.** A hyperspectral camera to assess the sky radiance distribution was developed and tested and methods to reduce stray light in spectroradiometers were built and assessed.

The project increased and deepened interaction between the metrology and solar UV measurement communities, enabling effective sharing of needs and measurement best practice. The project concluded with a large-scale comparison exercise at the World Calibration Centre for UV in Switzerland, where end-users from public health, environment and meteorology agencies and industry were able to directly compare their measurements to the world reference UV spectroradiometer and be trained in the latest methods and techniques, and so improve the delivery of their public services.



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| More information is available at | ENV03 Traceability for surface spectral solar ultraviolet radiation www.euramet.org/project-ENV03 |
| Contact | Julian Gröbner (PMOD/WRC) julian.groebner@pmodwrc.ch |

Nuclear decommissioning

With more than 100 nuclear reactors in Europe currently undergoing or due to undergo decommissioning by 2025, safe and effective decommissioning is essential to protect European citizens and the environment. This requires the disposal of thousands of tonnes of nuclear waste and, to do this safely and cost effectively, it is necessary to accurately measure the radioactivity of the materials involved.

The EMRP project [ENV09 Metrology for radioactive waste management](#) developed accurate measurement methods and procedures for radioactive waste assessment and consignment, including:

- **A transportable traceable instrument, based on high-purity germanium (HPGe) spectroscopy, for the assessment of solid radioactive waste from nuclear power plants.** This provides a robust and accurate tool to assess waste and consign it either for 'free release' or to waste repositories.
- **A reliable on-site method for radiochemical analysis of bio-shield concrete samples** based on commercial instrumentation for material extraction and analysis. This offers the potential for relatively fast and cost-effective solutions to be delivered on site during the decommissioning process, saving time and money.
- **Demonstration of the feasibility of novel approaches to gas monitoring instruments for tritium and carbon-14 species.** These tools are needed to assess air quality to protect the nuclear workforce and the environment.
- **New radioactive reference materials and standardised sources** for the calibration of the devices and methods developed within the project, to achieve lower uncertainties and more accurate measurement of radionuclide activities. Materials and sources were developed for typical radionuclides and for materials and gases present at decommissioning sites.

The outputs of the project are already in use at decommissioning sites in Europe. The facility for free release measurement has been demonstrated at a nuclear site in the Czech Republic and the next generation version will be used for decommissioning at a site in Italy. The reference materials have been used at the same Italian site to calibrate other instrumentation used for decommissioning and one of the approaches for sampling radioactive gases has been deployed at nuclear facilities in France to support staff radiation protection and gaseous release monitoring. The instrumentation and methods play a role in effective handling of nuclear waste during nuclear decommissioning, so protecting human health and the environment.



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| More information is available at | ENV09 Metrology for radioactive waste management (MetroRWM) www.euramet.org/project-ENV09 | |
| | Details of the follow-on project: ENV54 Metrology for decommissioning nuclear facilities (MetroDecom) www.euramet.org/project-ENV54 | |
| Contact | Petr Kovar (CMI) | pkovar@cmi.cz |

Focus on impact

All EMRP project teams engage widely with the user communities who will benefit from the research. For the Environment theme EMRP projects this included the climatology community, environmental monitoring agencies and laboratories, and key measurement instrumentation suppliers as well as the relevant technical committees and working groups in the standardisation community.

Supporting roadside pollution monitoring

Congested areas such as city centres suffer from elevated levels of certain pollutants, including NO₂, which is associated with adverse effects on health including reduced life expectancy. As part of the EMRP project [Metrology for chemical pollutants in air](#), METAS in Switzerland developed a new traceable mobile NO₂ permeation generator, which can be used in the field to directly calibrate instruments monitoring harmful roadside pollution, improving the reliability of their measurements.

The METAS NO₂ generator has already been used by the City of Zürich Health and Environment Department and in other Swiss cities. METAS and LNI Swissgas, a leading manufacturer of environmental gas calibration systems and gas generators, have been awarded funding to commercialise a novel compact NO₂ permeation generator, which incorporates features of the METAS prototype into LNI Swissgas's existing product, resulting in a fully traceable and user-friendly transfer standard.

Portable and compact field calibration instruments, such as LNI Swissgas's, provide crucial support to the expansion of Europe's air monitoring networks, more comprehensive pollution monitoring and effective protection of Europe's citizens.



Innovative roadside pollution monitors

The introduction of new gas micro-sensor technology promises to significantly increase the capacity of NO₂ monitoring networks within our cities. Micro-sensors provide cost-effective real-time measurements, offering the potential to rapidly disseminate pollution warnings to vulnerable city dwellers.

The EMRP project [Metrology for chemical pollutants in air](#) developed a test protocol for micro-sensors using a specially-designed chamber at JRC Ispra. The facility can be used to evaluate sensor performance at pollutant levels specified in the European Air Quality Directive under typical field conditions.

Through participation in the project and use of the new facility at JRC Ispra, Alphasense, a developer and manufacturer of gas sensors, has revised and improved its innovative NO₂ micro-sensors for roadside monitoring measurement platforms. By establishing traceability to national standards, this project has enabled micro-sensors such as Alphasense's to be used in support of the Air Quality Directive, validating their use as a robust yet cost-effective technology for real-time air pollution monitoring.

Improving indoor air quality

Volatile organic compounds (VOCs), commonly found in furniture, carpets and paints, are known to cause respiratory problems, but until recently there was no harmonised labelling scheme or supporting standard test governing VOC emissions from construction materials in the EU.

The EMRP project [Metrology for chemical pollutants in air](#) developed a new reference material, which reproduces the VOC-emitting behaviour of a typical construction product. Testing laboratories can use the reference material to demonstrate their ability to carry out robust VOC emissions measurements and certification, in compliance with an upcoming CEN standard (prEN 16516:2015).

Testing body eco-INITIUT used the new reference material along with the proposed CEN test method to demonstrate the capability of its VOC emissions measurement system. Manufacturers can be confident in the accuracy of eco-INITIUT's system, which has now been benchmarked against the standard, and the emissions certificates issued for their products. This marks the first step towards EU harmonisation of construction product labelling, which will help remove barriers to international trade and ensure reliable monitoring of indoor environments to protect public health.



Harmonising air quality measurements

The EMRP project [Metrology for chemical pollutants in air](#) developed and validated accurate reference standards for a range of important outdoor pollutants at the very low concentrations required to comply with the European Ambient Air Quality Directive. A certification protocol was also defined for establishing the purity of the 'zero gas' samples used to set the zero point of gas analysers.

The project team worked closely with the European Network of Air Quality Reference Laboratories (AQUILA) to understand their needs and ensure the transfer of project outputs to key users. As a result, several air quality networks are already using the new reference standards, enabling improved demonstration of compliance with the Directive. The team is also working with the standards community to ensure that the certification protocol for zero gases will gain formal standing via a series of ISO standards.

These improved measurement capabilities will support consistent and robust assessment of air pollutants and help minimise their negative impact on human health and the environment.

High-performance particle counters for emissions testing

To improve public health and the quality of the environment, new passenger cars must meet European emission standards before they can be type approved for sale. Of particular concern are the fine particles emitted by diesel engines – consequently, the latest emission standards include a particle number limit.

The EMRP project [Emerging requirements for measuring pollutants from automotive exhaust emissions](#) helped to establish the first direct traceability chain for condensation particle counters, one of the key technologies used to measure particle numbers, through contribution to a new ISO standard (ISO 27891:2015) and the development of a new calibration facility.



TSI, a manufacturer of condensation particle counters, was one of the first beneficiaries of the new calibration facility. TSI's internal reference instrument can now be used with the ISO standard to provide traceability to TSI's commercial condensation particle counters, used by engine manufacturers and emissions testing laboratories. This will ensure they can detect the low levels of particulate permitted by the upcoming *Euro 6c* standard and support robust, comparable emissions testing.

Robust emissions testing under real driving conditions

The low levels of particulates permitted by the European emission standards are now beyond the sensitivity of the technology currently used for periodic engine testing, and from September 2017 the standards will cover emission testing under real driving conditions.

The EMRP project [Emerging requirements for measuring pollutants from automotive exhaust emissions](#) developed a facility to calibrate and validate automotive particle emission instruments which measure particle number concentration at the low levels required by the regulation.

Testo AG, a world leader in the field of portable measurement technology, used the facility to assess the performance of an innovative exhaust monitoring instrument. Using the results and expertise gained, Testo had confidence that, after further modifications, the new technology would be suitable for launch. Testo has since launched the instrument for new engine tests and a portable version suitable for periodic vehicle testing, including under normal driving conditions, will be available in the near future. This will support implementation of the updated emission standards, which will ensure that vehicles deliver reduced exhaust emissions over their entire life span.

Better UV monitoring to protect public health

Balancing the risks and benefits of solar UV radiation is a challenge for policymakers and health advisors, and improved UV measuring instrumentation is needed to produce reliable measurements on which to identify long-term trends and base decisions. The introduction of newer, faster compact CCD array spectroradiometers will provide a cost-effective alternative to conventional instruments and has the potential to increase the worldwide UV monitoring network.

The EMRP project [Traceability for surface spectral solar ultraviolet radiation](#) developed best practice guidelines to improve the accuracy and comparability of solar UV measurements, which were disseminated to operators from monitoring stations across the globe during a comparison exercise at the World Meteorological Organisation in Davos, Switzerland. This comparison enabled operators to compare their CCD array spectroradiometers to the world reference instrument, giving direct traceability for this type of instrument for the first time.



Public Health England (PHE) monitors public exposure to all types of radiation and routinely publishes UV exposure data from its monitoring network for research and trend analysis. PHE took a prototype array spectroradiometer it had developed to the comparison exercise and, following interaction with the project, the instrument, operated with the new best practice procedures, demonstrated improved performance and better agreement with the world reference instrument.

El Arenosillo, an atmospheric research observatory of Spain's space agency, also took part in the comparison exercise and embraced the best practice guidelines derived in the project, improving the comparability and compatibility of both aerial and ground-based measurements performed at the monitoring station.

Advanced optics for atmospheric research

As part of the EMRP project [Traceability for surface spectral solar ultraviolet radiation](#), project partner Aalto University, working with industrial partners Kipp & Zonen and CMS Ing Dr Schreder GmbH, has designed a new type of optical component for Brewer spectrophotometers, the sophisticated instruments used to measure stratospheric ozone and solar UV radiation, using novel quartz-based materials.

The new quartz-based materials can be more easily formed into complex shapes and improve the accuracy of low-angle solar UV measurements. Simulations performed by Aalto University were used to optimise the new design and prototype optics were validated using QASUME, the world's primary spectrophotometer, the performance of which had also been improved using project outputs. Products incorporating the new optics will soon be commercially-available to customers requiring highly-accurate measurements of solar UV for ozone studies.

The incorporation of the quartz optics into new and existing spectrophotometers is giving the UV community greater confidence in the accuracy of the solar UV measurements and helping atmospheric researchers and health protection agencies to reliably assess long-term changes in the Earth's protective ozone layer.

Improving atmospheric data

Spectro-analytical techniques used to identify and quantify concentrations of greenhouse and other gases in the atmosphere are based on the unique spectral ‘fingerprints’, or spectral lines, generated by molecules interacting with electromagnetic radiation. Accurate spectral line data is required to reduce measurement uncertainties and generate more robust data for climate predictions.

The EMRP project [Spectral reference data for atmospheric monitoring](#) has enabled the development and commissioning of a new measurement facility capable of generating greenhouse gas spectral line data with improved traceability to the SI. The spectral data generated within the project is due to be included in an upcoming revision of the HITRAN database, one of the most widely-used spectral databases in the world.

The project’s contribution will mark a significant increase in the amount of traceable spectral data available to researchers using HITRAN. One of the key users is TCCON, a network of 23 ground-based atmospheric monitoring stations distributed across the globe, which provide performance validation to satellite-borne spectral instruments. The improved data provided by TCCON-validated satellites will make a valuable contribution to reducing the uncertainties involved in climate models and support robust predictions of long-term climate change.



Courtesy of ESA

Confidence in climate data

The UK Met Office generates some of the most comprehensive climate projections ever produced, to help decision-makers assess risk exposure to climate change and inform mitigation and adaptation strategies. These projections are guided by climate data from a number of sources, both historic and current.

The Met Office will use a new uncertainty evaluation method developed within the EMRP project [European metrology for Earth observation and climate](#), to enable the combination of climate data collected on the most recent European Sentinel satellite missions with its existing datasets. This opens up a significant amount of additional climate data to the Met Office for climate monitoring and modelling purposes, improving the quality and range of measurements available to guide its climate projections.

The method and the research it is based on have also been assembled into a course and textbook for Earth observation scientists, which will be freely-available online in the near future. This is a significant step towards improving measurement uncertainty evaluation in the climate research community and will contribute to improved climate models and projections.

Ensuring accuracy in the upper atmosphere

To assess the impact of tiny variations in atmospheric composition on long-term climate change, the Earth observation community needs highly-accurate measurements of atmospheric composition. However, while carefully calibrated on the ground, instruments on board aircraft and satellites can degrade while in flight.

Within the EMRP project [European metrology for Earth observation and climate](#), a new calibration facility was used to provide traceability for airborne spectroradiometers. Two novel, compact black-body radiation sources, developed in collaboration with the University of Wuppertal, were calibrated using the new facility prior to use as transfer standards on board a research aircraft.

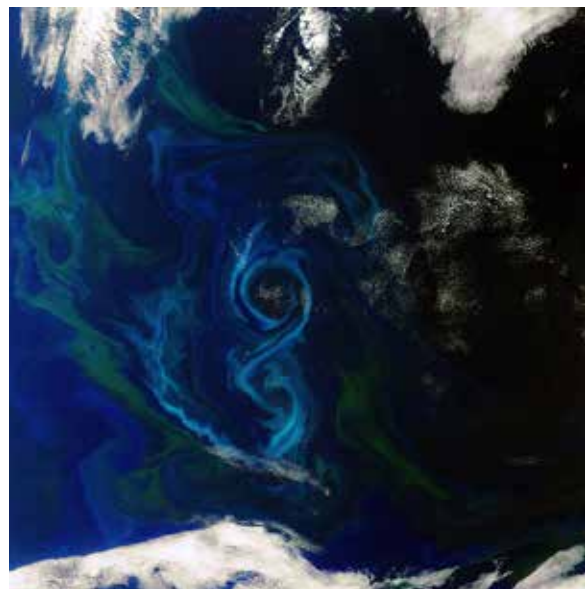
One of the first instruments to benefit was GLORIA, the first of a new generation of spectroradiometers for Earth observation. GLORIA's novel infrared camera measures trace gases in the atmosphere with an unprecedented combination of vertical and horizontal resolution that relies upon highly-accurate calibration. The new transfer standards enabled the first traceable mid-infrared measurements of thermal emissions – a significant step forward in Earth observation research. This newly traceable technology can now be used on board balloons and satellites, plugging the gap in high-quality data needed for robust climate change assessment.

Helping satellites see ocean colour

Research buoys make local measurements of a range of variables essential to climate models, including ocean colour, which can be used as a measure of phytoplankton concentrations and provide vital information for monitoring the global carbon cycle.

The EMRP project [European metrology for Earth observation and climate](#) developed a novel easily-transportable light source, which can be used to calibrate instruments on buoys in situ. This provides traceability to the buoy's measurements, and those provided by satellites, which are compared to the buoy's and corrected when they pass overhead.

One of the first beneficiaries was BOUSSOLE, an international project supported by organisations including the European Space Agency and French space agency, CNES. Instrumentation on the BOUSSOLE buoy has now been calibrated using the new portable standard and is being used to confirm the response of the European Ocean Land Colour Instrument, recently launched on the Copernicus Sentinel 3 satellite. This is just one example of how the new calibration standard is improving the accuracy of ocean colour measurements, and ultimately supporting more robust carbon cycle trend analysis and climate monitoring.



Understanding our oceans

Oceans are the largest active carbon sinks on Earth, absorbing more than a quarter of anthropogenic carbon emissions. The ocean's interaction with the atmosphere, and its ability to absorb carbon dioxide, is strongly influenced by properties of seawater, such as salinity and acidity. Reliable and comparable measurements of these properties are of crucial importance to climate researchers, enabling them to detect small changes in ocean dynamics over decades and even centuries.

Salinity

The EMRP project [Metrology for ocean salinity and acidity](#) provided a reference method for ocean salinity, which makes practical salinity measurements traceable to the SI units through density measurements. Ocean Scientific International Ltd (OSIL) is going to incorporate density measurements into the preparation of its

standard seawater, which is the only internationally-recognised calibration standard for practical salinity. This will provide traceability to ocean salinity measurements across the globe and allow the oceanography community to reliably identify even small changes.

Temperature

Additionally, probes used to measure the speed of sound in seawater can now be traceably calibrated under typical operating conditions at newly-developed facilities at project partners PTB and INRIM. Measurements at sea have also confirmed the performance of a prototype transfer standard developed at INRIM, bringing easily achievable traceability to ship-based probes. Vessels equipped with such sensors could provide a cost-effective, extensive seawater temperature measurement network to supplement satellite data for climate models.

Acidity

The project also helped to establish a traceability chain for seawater pH by developing primary and reference methods for pH measurements. The team contributed validation methods to a new ISO standard (ISO/CD 18191) for pH and is working with the Scripps Institution of Oceanography - the sole provider of a seawater buffer solution used to calibrate field-based oceanographic instrumentation.

The team is also contributing to the two key influential committees that define seawater parameters and methods: the pH subgroup of the Joint Committee on the Properties of Seawater, which is responsible for maintaining and improving the seawater equation of state, a key tool in ocean science; and a new group of the International Union of Pure and Applied Chemists, which is using project outcomes to ensure greater harmonisation of the measurement methods used by the oceanographic community.



Oxygen levels

EHP-Tekniikka, a provider of environmental monitoring services and equipment, took part in a comparison exercise, organised by the University of Tartu and project partner SYKE, to compare the dissolved oxygen measurements provided by commercially-available sensors to those made using the traceable Winkler titration method for the first time. Using a PONSEL OPTOD oxygen sensor - an optical sensor designed with an internal calibration capability - EHP-Tekniikka was able to directly compare the instrument's response using a procedure developed within the project.

The positive results obtained have given confidence in this type of instrument's internal calibration capability and its applicability for high-accuracy measurements of dissolved oxygen concentrations. This validation paves the way to increased use of automated oxygen sensors and will lead to a significant increase in the oceanography community's capacity to produce high-accuracy dissolved oxygen data for robust climate trend analysis.

Building environmental metrology skills

A best practice uncertainty evaluation method, developed by the EMRP project [Metrology for ocean salinity and acidity](#) provided a key component of a new online course developed by project partner, the University of Tartu in Estonia. The best practice method was developed for use with the Winkler titration method, used to determine the concentration of dissolved oxygen in samples in water quality studies.

The online course, Estimation of measurement uncertainty in chemical analysis, has not only been taken by 700 students so far but is also being used by SP, the Technical Research Institute of Sweden, to train environmental testing laboratories working towards Nordtest accreditation. Nordtest is the Nordic area conformity assessment body whose role is to harmonise compliance with standards and remove barriers to trade across the Nordic countries, which includes the accreditation of measurement and testing and conformity assessment laboratories.

The project's outputs are therefore not only contributing to important climate change research but are supporting the development of skills for practical and effective environmental monitoring.



Taking calibration to the extremes

Accurate assessment of climate change relies on a world-wide network of atmospheric monitoring stations that provide high-quality data, which is comparable regardless of where it's collected.

The EMRP project [Metrology for pressure, temperature, humidity and airspeed in the atmosphere](#) is taking traceability to remote monitoring locations through a newly-developed portable calibration chamber for temperature, humidity and pressure sensors, known as EDIE.



EDIE was temporarily installed at Ny-Ålesund, a research community in Svalbard, enabling the island's atmospheric monitoring instruments to benefit from traceable calibration without having to be transported to distant calibration laboratories and unavailable for long periods of time. EDIE has, for the first time, enabled on-site calibration of the ground instruments which contribute to the Global Climate Observing System Reference Upper-Air Network, in conditions closer to those encountered during operation in the harsh Arctic environment.

Further developments to EDIE are underway to make a more robust, compact version suitable for long-term installation in Ny-Ålesund - a first step towards a permanent Arctic calibration laboratory that will support multi-national climate observation and research at Svalbard.

Protecting Europe's water resources

The European Water Framework Directive (WFD) aims to protect and improve water quality through legal limits on a wide range of known pollutants.

The EMRP project [Traceable measurements for monitoring critical pollutants under the European Water Framework Directive](#) developed reference methods, based on different mass spectrometry techniques, for measuring levels of the toxic pollutant TBT in real water samples. This enables testing labs to benchmark their methods, demonstrate compliance with regulation, and perform water monitoring services more accurately, efficiently and economically.

The improved method developed in the project has already been adopted by IPROMA, an organisation contracted for water quality measurements by numerous Spanish Regional Authorities. IPROMA can now offer its clients an improved low-level TBT concentration test, enabling them to demonstrate that TBT levels in the open water systems used to supply cities and towns meet the requirements of the WFD. The new method is more efficient, requiring less time and labour, and costs 20 % less to implement than its predecessor.

The project team also provided well-characterised reference materials to enable CEN to validate test methods in support of the WFD and provided advice to a working group of the CEN Technical Committee on Water Analysis. This work contributed to three draft standards developed by CEN for the analysis of the pollutants TBT, PBDE and PAH, which were published in 2015. The adoption of the CEN standards and traceable measurements will improve pollutant testing across Europe and help keep priority hazardous substances in waters at a safe level.



Tackling nuclear waste

Research carried out within the EMRP project [Metrology for radioactive waste management](#) has enabled the construction of the first dedicated transportable nuclear waste assessment facility, which offers a cost-effective solution to the growing problem of nuclear waste disposal.

Developed by ENVINET, a leading provider of products and services for environmental radiation monitoring, the facility takes new measurement methods developed within the project directly to nuclear decommissioning sites. The improved accuracy and speed of the results enable efficient on-site measurements - in particular, correct identification of waste suitable for free release should avoid the significant costs associated with unnecessary long-term storage.

Within the project, ENVINET was able to both validate the transportable facility and also demonstrate to the Czech authorities it had developed the expertise needed to meet stringent criteria governing the free release of nuclear waste. Subsequently, the first consignments of 150 tonnes of accumulated waste at the ÚJV Řež site in the Czech Republic have been accurately and efficiently sorted prior to release for disposal, and the facility will next be used at a decommissioning site in Italy.



Further information

More detailed information on the EMRP projects' outputs and the contact details for each project can be found at:

www.euramet.org/emrp-industry-environment-2010

Projects in the next EMRP Environment theme can be found at:

www.euramet.org/emrp-energy-environment-2013

More case studies outlining the early impacts of the EMRP Environment projects can be found at:

www.euramet.org/metrology-for-societys-challenges/metrology-for-environment/impact-case-studies-emrp-environment-theme/

Europe's National Measurement Institutes working together

The majority of European countries have a National Measurement Institute (NMI) that ensures national measurement standards are consistent and comparable to international standards. They also investigate new and improved ways to measure, in response to the changing demands of the world. It makes sense for these NMIs to collaborate with one another, and the European Association of National Metrology Institutes (EURAMET) is the body that coordinates collaborative activities in Europe.

The successful European Metrology Research Programme (EMRP) will be followed by the European Metrology Programme for Innovation and Research (EMPIR), both implemented by EURAMET. The programmes are jointly funded by the participating countries and the European Union and have a joint budget of over €1bn for calls between 2009 and 2020. The programmes facilitate the formation of joint research projects between different NMIs and other organisations, including businesses, industry and universities. This accelerates innovation in areas where shared resources and decision-making processes are desirable because of economic factors and the distribution of expertise across countries or industrial sectors.

EURAMET wants to involve European industry and universities at all stages of the programme, from proposing Potential Research Topics to hosting researchers funded by grants to accelerate the adoption of the outputs of the projects.



EURAMET e.V.
Bundesallee 100
38116 Braunschweig
Germany

Phone: +49 531 592 1960
Fax: +49 531 592 1969
Email: secetariat@euramet.org

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