

## Conserving the environment

A summary of the outputs and impact of the EMRP joint research projects in the Environmental Data Calls I and II.

The aim of these themes was to improve environmental data quality for policy making, underpinning climate research activities and stimulating 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 Union, EURAMET's European Metrology Research Programme (EMRP) brought together National Measurement Institutes in 23 countries to pool scientific and financial resources to address key measurement challenges at a European level.

The programme was designed to ensure that measurement science meets the future needs of industry as well as wider societal challenges. Research was structured around 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 Environmental Data

A key challenge facing Europe is the need to protect the environment and safeguard our quality of life, whilst ensuring sustainable economic growth. Managing and protecting the environment requires robust and reliable data to assess and monitor environmental parameters whether for assessing climate change or pollution emission trends. Scientists studying climate change base their findings on data gathered from satellite borne instruments, and terrestrial networks for monitoring air quality. National and international agencies rely on this data to ensure that environment treaties and regulations are both well-designed and enforced effectively.

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) supported 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).

EURAMET's two EMRP Environment themes provided the funding to support 19 collaborative research projects that brought together 44 NMIs and Designated Institutes (DI) with industry and academia to address some of the measurement challenges associated with the better quantification of the parameters that affect climate change and the measurement of emissions hazardous to our quality of life.

This report presents the key technical achievements of these research projects and highlights examples of the impact generated within the climate and environmental monitoring community. Projects are grouped into two sub-themes:

- Increasing our understanding and the assessment of climate change
- Upgrading the measurement infrastructure used to monitor environmental pollution

Research continues in the European Metrology Programme for Innovation and Research's (EMPIR) Environment theme projects.





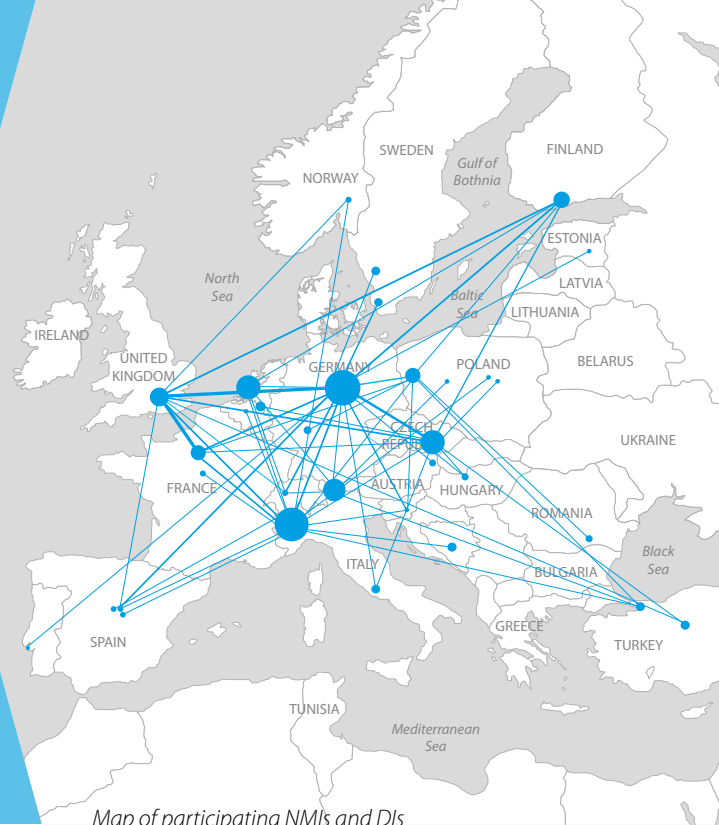




# Highlights

EURAMET's interdisciplinary Environment Task Group brings together metrology experts from a range of measurement areas with the organisations that collect and use environmental data to ensure the relevance of the EMRP research projects to user communities. The two EMRP Environmental themes enabled the European metrology community to work collectively to improve the measurement methods which are important for environmental monitoring and climate change trend identification.

The European Commission and national governments invested €77M in collaborative environmental research projects involving research groups in 44 European National Measurement Institutes and Designated Institutes, along with 25 academic groups, and 7 businesses.



Map of participating NMs and DIs

## Greater accuracy for climate data from satellite measurements

To meet the demands for greater accuracy in earth observation measurements that are made by satellite borne instrumentation new high altitude and ground based confirmatory measurements, with rigorous SI traceability, are required.

EMRP research has produced methods to confirm the performance of orbiting instrumentation using transfer standards and a spectroradiometer which are carried high into the atmosphere on an aircraft. This has increased the measurement accuracy of satellite-borne instruments by a factor of 10.

In addition, EMRP research has enabled the accurate characterisation of two new desert test-sites for use in confirming the performance of satellite-based radiance instrumentation. This is supporting the Committee on Earth Observation Satellites (CEOS) RadCalNet network, whilst careful radiance measurements of leaf reflections at Wytham Woods in the UK have resulted in its designation as a CEOS super-site. In addition, EMRP research developed traceable protocols for calibrating satellite borne ocean surface radiance instrumentation. This is a key measurement parameter for detecting climate change trends based on measuring the colour of phytoplankton blooms.



## Improved data for essential climate variables

Detecting trends in the weather, as global warming creates more severe storms and droughts, relies on accurately monitoring key parameters such as temperature and humidity using land-, sea- and air-based instrumentation. Automatic weather stations provide data for short-term weather prediction, with increased accuracy these could significantly increase data availability for climate trend determination. EMRP research introduced improved links to the SI units for the calibration of sensors used to detect temperature changes deep in the ocean and for those used high in the atmosphere to monitor humidity. EURAMET funded research has also improved the accuracy of the temperature data generated by automated weather stations, thus making it more suitable for use by climatologists when predicting global warming trends.

## Improving air quality – reducing NO<sub>2</sub> emissions

Improving air quality requires accurate measurements of pollutants at the low concentrations which are permitted by European regulation. EMRP research developed preparation methods for the following calibration gases SO<sub>2</sub>, NO and NO<sub>2</sub> at or near the limit values specified in the regulations. A practical portable NO<sub>2</sub> generator was also developed for the cost-effective calibration of air quality sensors in the field.

The NO<sub>2</sub> 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.



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## Monitoring harmful pollutants and gas traces in the atmosphere

Monitoring and reducing industrial pollution is essential for preserving our environment. Harmful gases from a variety of industries are contributing to climate change or damaging our health. EMRP research has targeted a number of these emissions resulting in greater monitoring accuracy under real conditions and supporting improved assessments of industrial emission release reduction strategies.

EMRP research has developed increased calibration rigor for a variety of reactive pollutant gases, including the ammonia that is released by intensive farming, the fluorocarbons released from air conditioning systems and the volatile organic compounds emitted outdoors by the oil and gas industry and indoors from construction products and furnishings. EU Directives regulate these emissions and require users to robustly demonstrate compliance as emission limits tighten.

To address pollution from industrial plants, EMRP research developed facilities which mimic stack discharges. These were used to compare the performance of optically based monitoring techniques against methods authorised for regulatory compliance. Evaluation of test methods under near site conditions enabled in-the-field measurement protocols to be determined. A revised CEN standard now incorporates these protocols – a first step towards their implementation in industrial plant, and use for demonstrating EU Directive compliance.



## Meeting the Water Framework Directive requirements

The European Water Framework Directive specifies very low permitted levels for pollutants that present a significant risk to, or via, the aquatic environment. Toxic pollutants such as tributyltin, polybrominated diphenylether and selected polycyclic aromatic hydrocarbons are particularly harmful as they are liable to accumulate in the food chain. EMRP research developed validated SI traceable reference methods based on isotope dilution for the analysis of these pollutants in water 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 they are already being deployed in several European regions.



# EMRP Environment projects at a glance



Pooling expertise of

**44** NMIs and DIs from

**23** European countries



businesses





271

articles  
in peer-reviewed  
journals



training courses  
delivered to over

850

presentations at  
conferences



211

contributions  
to

55

technical  
committees and  
working groups  
of standards  
organisations



Supported the  
development of improved  
instrumentation with  
projected sales of

€15.3 M



32

number of  
articles in  
trade and  
popular press



46

contributions to draft standards  
and published standards





# Understanding climate change



## Measurement challenges

Metrology has a critical role to play in understanding, modelling and monitoring climate change. European policies aimed at mitigating greenhouse gas induced climate change and the implementation of adaptation measures need to be based on 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, academia and monitoring communities make the necessary advances in measurement quality to underpin reliable climate assessments, models and predictions.

Monitoring and modelling the Earth's climate requires the measurement of a wide range of climate parameters – the Global Climate Observing System 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 the improved accuracy of measurement data for Essential Climate Variables and the development of new measurement methods and technologies for improving the:

- Spectral line data used in many earth observation spectrometric measurement techniques
- Post-launch performance confirmation of satellite borne instrumentation for earth observation data
- Weather station data for use in essential climate variable trend analysis
- Detection of ozone layer trends using Solar UV data
- Measurements of ocean parameters generating data for climate and circulation studies.



# Key technical achievements

## Improving atmospheric spectrometry measurements

The EMRP project **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.

<b>More information is available at</b>	ENV06 Spectral Reference Data for Atmospheric Monitoring (EUMETRISPEC) <a href="http://www.euramet.org/project-ENV06">http://www.euramet.org/project-ENV06</a>
<b>Contact</b>	Volker Ebert (PTB) <a href="mailto:volker.ebert@ptb.de">volker.ebert@ptb.de</a>



## 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 European metrology for **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 endeavor 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) 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

<b>More information is available at</b>	ENV04 European metrology for Earth observation and climate (MetEOC) <a href="http://www.euramet.org/project-ENV04">http://www.euramet.org/project-ENV04</a> Follow-on EMRP project: ENV53 Metrology for Earth observation and climate (MetEOC2)	
<b>Contact</b>	Nigel Fox (NPL)	nigel.fox@npl.co.uk

## Earth observation for climate studies

The world has already warmed by 1 °C since pre-industrial times, due to human activity and this is expected to increase to 1.5 °C by 2040. Understanding global warming requires measurements of incoming and outgoing radiation and information on the effect of greenhouse gases on temperature rises. Calculating this radiative balance depends on the Earth observation data generated from satellite-borne instrumentation. Ensuring that this data is reliable relies on confirming instrument performance post launch.

The effects of ocean colour changes near shorelines and plant cover characteristics on satellite-based radiance measurements need better assessment to improve radiative balance data. Confirming the in-flight performance of radiometric instruments, relies on overflying well-characterised terrestrial- and ocean-based sites, the range and number of which must be increased in order to achieve more accurate measurements for climate change predictions.



Courtesy of ESA

The EMRP project **Metrology for earth observation and climate** developed methods to improve the accuracy of the land-, sea-, air- and satellite-based radiance measurements that are used for climate change monitoring. This project follows on from the EMRP project **European metrology for Earth observation and climate**.

The Project:

- **Improved the performance of an existing lab-based cryogenic solar radiometer (CSAR)**, by reducing window-induced noise by a factor of 100 and successfully demonstrated in-the-field performance against reference radiometers at the World Radiation Centre (Davos)
- **Developed portable, SI-traceable reference standards for radiometer calibration**, for use with ground-based instruments and the aircraft-based GLORIA spectroradiometer
- **Established two new well-characterised desert test-sites**, for confirming satellite-based radiance instrumentation performance in support of the RadCalNet network
- **Characterised Wytham woods (UK) as a reference site for leaf area index measurements**. This location has been recognised as a CEOS super-site for land product validation
- **Developed traceable protocols for greater accuracy in measuring ocean surface radiance**, enabling calibration of satellite-based instruments for ocean colour, a key Essential Climate Variable.

This project has successfully developed improved SI-traceable methods to monitor the performance of both the Earth-based and satellite-borne radiance measuring instrumentation that is used for climate measurements. European instrument manufacturers have been able to improve their Earth observation data, such as that collected on European Space Agency (ESA) Sentinel missions, by adopting methods and overflying the RadCalNet site characterised during this project. The information generated has supported new collaborative projects through ESA and H2020 QA4ECV. Based on implementing the measurement methods derived in this EMRP project, the QA4ECV research team were able to assemble a prototype quality assurance component more rapidly than would have previously been possible. This is now being further developed as part of the EU Copernicus Climate Change service. Improving the quality of the radiance data used in estimating how rapidly global warming is occurring is essential for trend identification and determining the success of remediation strategies. Measurement science research for earth observation continues in the EMPIR project MetEOC 3.

<p><b>More information is available at</b></p>	<p>ENV53 Metrology for earth observation and climate (MetEOC2)  <a href="http://www.euramet.org/project-ENV53">http://www.euramet.org/project-ENV53</a>            Follow on project: 16ENV03 Metrology for earth observation and climate (MetEOC 3)</p>	
<p><b>Contact</b></p>	<p>Nigel Fox (NPL)</p>	<p><a href="mailto:nigel.fox@npl.co.uk">nigel.fox@npl.co.uk</a></p>



## Measuring Essential Climate Variables

The EMRP project **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 the World Meteorological Organisation 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 WMO, 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.

<b>More information is available at</b>	ENV07 Metrology for pressure, temperature, humidity and airspeed in the atmosphere (MeteoMet) <a href="http://www.euramet.org/project-ENV07">http://www.euramet.org/project-ENV07</a> Follow-on project: ENV58 Metrology for essential climate variables (MeteoMet2)
<b>Contact</b>	Andrea Merlone (INRIM)      a.merlone@inrim.it

## Improvements for climate change monitoring

As weather extremes become more frequent due to climate change, society will have to respond to challenges that include threats to human habitation and food supply security. To prepare for such risks, climatologists draw upon disciplines ranging from oceanography to atmospheric physics to make long-term predictions. Identifying climate trends, however, depends on land-, sea- and air-based monitoring instrumentation for measuring key parameters such as temperature and humidity. By improving the SI-traceability and measurement accuracy of weather station instrumentation, the data quality can be raised to a level suitable for long-term climate change monitoring.

The EMRP project **Metrology for Essential Climate Variables** investigated the performance of various climate-monitoring instruments under the extreme conditions likely to be encountered in the upper atmosphere, deep sea, or mountain environments.

This project builds upon the previous EMRP project **Metrology for pressure, temperature, humidity and airspeed in the atmosphere**.



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The Project:

- **Developed a humidity calibration chamber for radiosonde instrumentation**, which is used to monitor water vapour in the upper atmosphere, thereby improving measurement accuracy
- **Developed a high-pressure testing facility** for the calibration of temperature sensors for use in deep sea environments
- **Investigated the contribution to recorded temperature readings of snow-reflected solar radiation and weather station surroundings** leading to the introduction of improved corrections for ambient temperature measurements
- **Devised a protocol for confirming the equivalence of calibrations performed on temperature, pressure and humidity instrumentation used at weather stations.** This has been adopted by the World Meteorological Organisation Commission for Instruments and Methods of Observation for use in large scale laboratory performance comparisons.

This project assessed a range of instrumentation for long-term climate monitoring and this led to the development of methods for improving the measurement accuracy for humidity and temperature, both essential climate variables. The calibration technique developed for radiosonde humidity probes has been adopted by the Global Climate Observing System (GCOS) Reference Upper-Air Network (GRUAN), a leading international network of climate-monitoring stations. Now that facilities are available for the validation of precision temperature probes at high pressures, it will be possible to measure changes at the millikelvin (mK) scale in deep sea environments. Although these are very small temperature changes these equate to huge changes in the energy stored by the world's oceans. The project derived protocol for confirming equivalence between routine weather station temperature, pressure and humidity instrumentation calibrations has been adopted by the World Meteorological Organisation Commission for Instruments and Methods of Observation for use in large scale laboratory performance comparisons.

By bringing together measurement science and user communities, this project has successfully delivered a range of improvements for greater accuracy in long-term climate change monitoring.

<b>More information is available at</b>	ENV58 Metrology for Essential Climate Variables (MeteoMet II) <a href="http://www.euramet.org/project-ENV58">http://www.euramet.org/project-ENV58</a>	
<b>Contact</b>	Andrea Merlone (INRIM)	<a href="mailto:a.merlone@inrim.it">a.merlone@inrim.it</a>



## 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 **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.



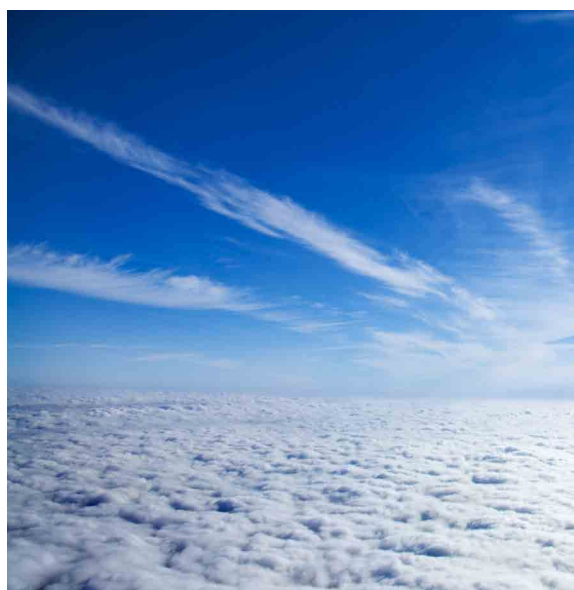
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<b>More information is available at</b>	ENV03 Traceability for surface spectral solar ultraviolet radiation <a href="http://www.euramet.org/project-ENV03">http://www.euramet.org/project-ENV03</a> Follow on project: ENV59 Traceability for atmospheric total column ozone (ATMOZ)
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## Detecting ozone layer trends

About 90 % of all ozone is found in a layer high up in the stratosphere. Detecting trends in this layer and the atmosphere's total ozone content requires confidence in the characteristics of monitoring instruments, assurance in their performance and robust calibration methods to ensure data accuracy. Precise measurements over many years will be needed to detect ozone recovery processes, which are expected to occur after restrictions in the use of chlorine and bromine compounds were imposed by the 1987 Montreal Protocol.

Established networks for monitoring total column ozone, which is the ozone in an imaginary column between ground level and the top of the atmosphere, rely on bulky, ageing, or proprietary instruments. Each network operates one or more master instruments to which all other network instruments are referred to ensure measurements inter-relate. However different instrument types yield small, but significant, differences in output data, hampering this process and impeding the merging of results from different networks, which is critical for reliably detecting future ozone layer recovery.



The EMRP project **Traceability for atmospheric total column ozone** evaluated differences between the reference Dobson and Brewer spectrophotometers that are used by networks, generated corrections to improve their performance and developed tools to ensure greater accuracy in the field. Building on the developments from the previous EMRP project **Traceability for surface spectral solar UV**.

The project:

- **Investigated and characterised Dobson and Brewer reference spectrophotometers at NMI facilities** and identified causes of measurement uncertainty. This has produced greater comparability between networks
- **Developed and validated a tuneable radiation source (TuPS)** for use in confirming the performance and operational stability of Dobson spectrophotometers
- **Generated new reference data sets and uncertainty budgets** for ozone measurements made at network monitoring station
- **Developed a prototype high-resolution array spectroradiometer system** and evaluated its ability to measure total column ozone in the atmosphere.

This project has provided greater certainty for networks measuring total column ozone using Dobson and Brewer spectrophotometers. By introducing increased agreement between data sets from different instruments, and tools to confirm on-site performance, users of ozone data will be able to have increased confidence in ground-based measurements of atmospheric ozone. These developments offer new capabilities for spotting trends in the state of the Earth's protective ozone layer, which over the next decades is expected to begin to replenish as strategies introduced under the Vienna Convention and Montreal Protocol begin to take effect.

<b>More information is available at</b>	ENV59 Traceability for atmospheric total column ozone (ATMOZ) <a href="http://www.euramet.org/project-ENV59">http://www.euramet.org/project-ENV59</a>
<b>Contact</b>	Julian Gröbner (PMOD/WRC) <a href="mailto:julian.groebner@pmodwrc.ch">julian.groebner@pmodwrc.ch</a>



## Greater accuracy for Ocean status monitoring

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.



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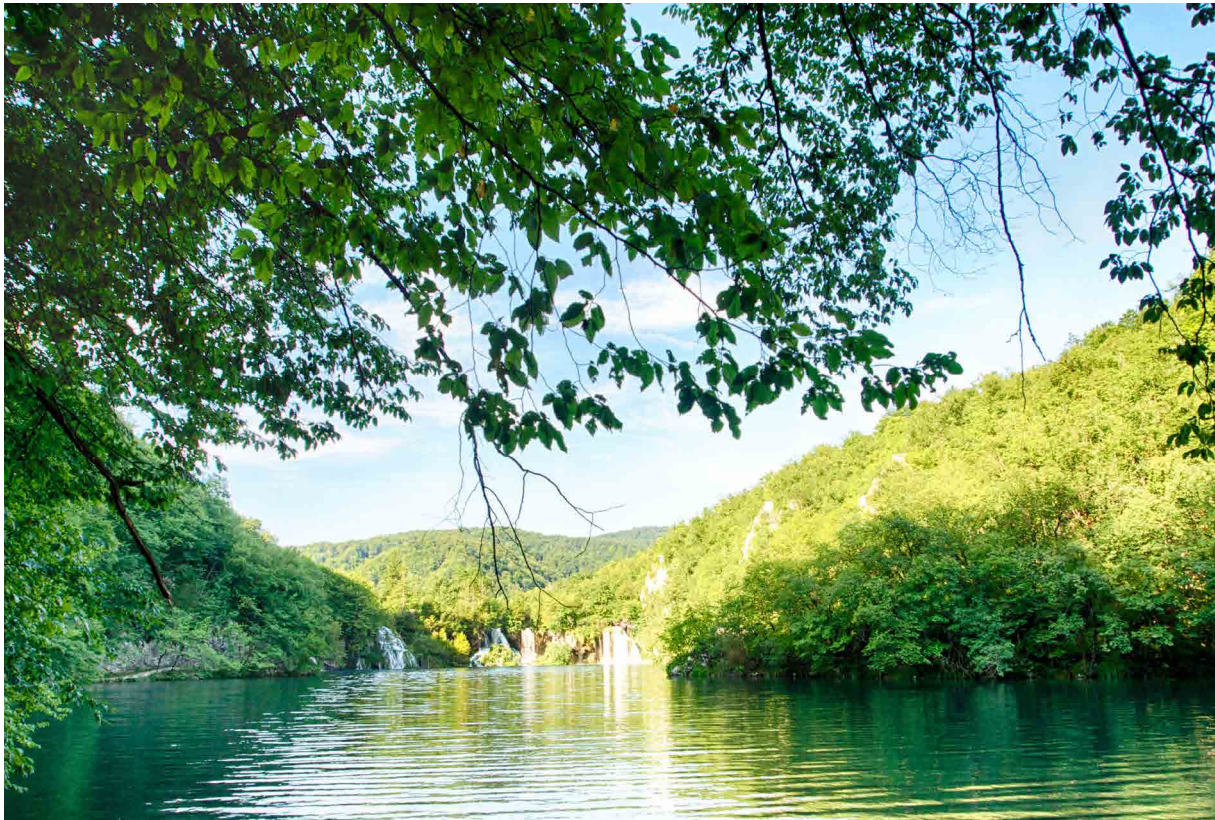
The EMRP project **Metrology for ocean salinity and acidity** developed:

- **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 a 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.

<b>More information is available at</b>	ENV05 Metrology for ocean salinity and acidity (Ocean) <a href="http://www.euramet.org/project-ENV05">http://www.euramet.org/project-ENV05</a>	
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# Creating a clean, safe environment



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## Measurement challenges

Accurate data is essential for 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.

Environmental regulation evolves over time as our understanding of the effects of pollutants on human health and the wider environment increases. 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 has improved the quality of the environmental monitoring data which is important for compliance with European environmental regulations and the measurements of hazardous emissions and releases that affect public health. Research focused on:

- Water and air quality monitoring
- Industrial pollution and trace gas air monitoring
- Vehicle exhaust and mercury monitoring
- Early warnings for ionising radiation during a nuclear incident
- Ensuring accurate identification and segregation of high activity nuclear decommissioning waste.



# Key technical achievements

## 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.



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The EMRP project **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.

<b>More information is available at</b>	ENV08 Traceable measurements for monitoring critical pollutants under the European Water Framework Directive (WFD) <a href="http://www.euramet.org/project-ENV08">http://www.euramet.org/project-ENV08</a>	
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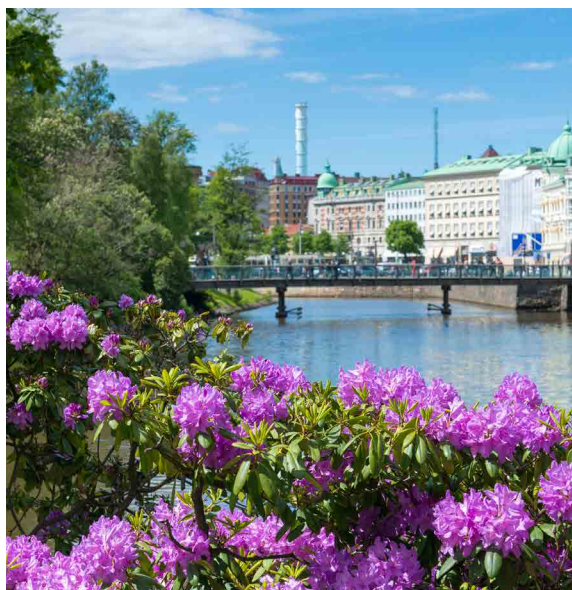
## Air quality

The EMRP project **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 SO<sub>2</sub>, NO and NO<sub>2</sub>** 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 NO<sub>2</sub> 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.



Martin Wahlberg

<b>More information is available at</b>	ENV01 Metrology for Chemical Pollutants in Air (MACPoll) <a href="http://www.euramet.org/project-ENV01">http://www.euramet.org/project-ENV01</a> Follow on project: ENV56 Metrology for VOC indicators in air pollution and climate change (key-VOC)	
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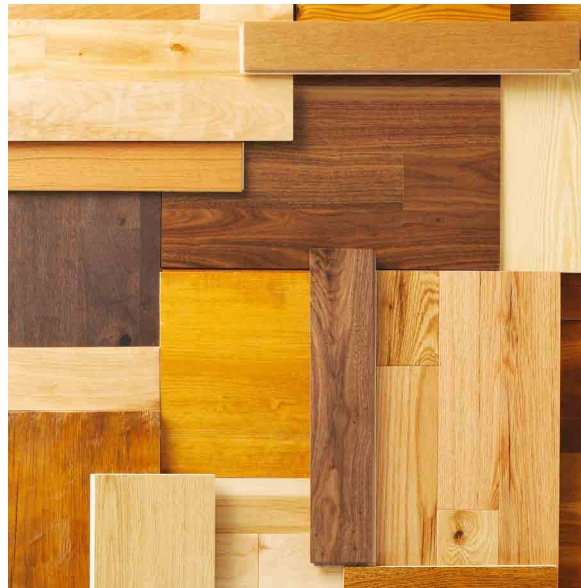


## Improved air quality monitoring

Volatile Organic Compounds (VOCs) released from wood and plastics create indoor health hazards, whilst others such as benzene and oxygenated species like methanol and formaldehyde play a part in atmospheric chemistry. These reactive and short-lived compounds present at trace levels in the atmosphere interact to produce greenhouse gases and very small particles in smog that can create breathing problems.

The EU's Air Quality directive and the Construction Products Regulation provide a framework for controlling exposure to these compounds. To enable decorative material manufacturers to demonstrate compliance and air quality networks tracking atmospheric trends to produce accurate data, improved reference materials and calibration methods are needed at the low concentrations encountered during routine VOC measurements.

The EMRP project **Metrology for VOC indicators in air pollution and climate change** developed new reference materials and gas standards at the low concentrations required by users and the project used these to evaluate the performance of the low-cost gas sensors which are used in environmental monitoring. This work builds on outcomes from the EMRP project **Metrology for Chemical Pollutants in Air**.



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The project:

- **Investigated the proprietary treatments used for preventing interactions between VOCs and a gas cylinder's walls.** This is important for stabilising low-concentration reference gas mixtures in the high pressure cylinders that are used in instrument calibrations
- **Developed new VOC emission reference materials and techniques for in-situ gas mixture preparation**
- **Investigated the VOC adsorption properties of the materials and coatings that are used in air monitoring systems** to quantify potential losses between the sampling point and gas analysis
- **Evaluated portable, low cost sensors for VOC detection using both lab and field testing** leading to the derivation of best practice measurement procedures.

This project has developed new VOC gas reference standards, enabling the test labs in Europe-wide and global environmental monitoring networks such as the WMO Global Atmosphere Watch programme, to calibrate instrumentation and harmonise measurement methods. Upgrades to sampling lines, through recommendations to use inert coatings, is supporting improved trace VOC measurement accuracy and this has been adopted during the IAGOS-CARIBIC climate-monitoring project. The dynamic gas generators developed for reactive VOC gases have been used for a range of climate monitoring calibration applications and for breath analysis in hospitals. Project developed reference materials have enabled accredited labs, which perform assessments of emissions from decorative materials, to better demonstrate proficiency across a broader spectrum of VOC species, whilst best measurement practice recorded in peer reviewed papers from this and the preceding project have been cited as key references in a WMO publication on benzene and other VOC data. Improvements in the accuracy of measuring VOC traces in the atmosphere, resulting from this project, will support robust data generation and early trend identification of VOC changes in the environment.

<b>More information is available at</b>	ENV56 Metrology for VOC indicators in air pollution and climate change (key-VOC) <a href="http://www.euramet.org/project-ENV56">http://www.euramet.org/project-ENV56</a>	
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## Accurate monitoring of greenhouse gases

Industrial gas emissions of carbon dioxide (CO<sub>2</sub>) and methane contribute to the Greenhouse Effect, whilst gases containing halogens, such as sulphur hexafluoride (SF<sub>6</sub>), banned from use, except in electrical switchgear, are far more damaging greenhouse gases, but have lower concentrations in the atmosphere. It has been estimated that mitigating climate change will cost the EU 4 % of GDP by 2100.

Sensitive instruments are used to monitor trends in greenhouse gas concentrations and to identify sources of halogenated emissions. These rely on extremely low level and very specific gas calibration standards to confirm their performance. Increasing the accuracy of atmospheric monitoring, and identifying gas emission sources, relies on the production of reference gas standards or complex halogenated gas mixtures with robust links to SI units.



The EMRP project **Metrology for High-Impact Greenhouse Gases** developed SI-traceable gas cylinder standards and point-of-use reference gas standards, including CO<sub>2</sub> standards isotopically matched to the ratio of <sup>13</sup>CO<sub>2</sub> to <sup>12</sup>CO<sub>2</sub> in the atmosphere.

The Project:

- **Developed synthetic “zero” air gas standards with quantified amounts of the traces of gases to be measured.** These are used in the production of reference gas standards and for setting instrument background responses
- **Developed stable gas cylinder based and point-of-use reference gas standards** for CO<sub>2</sub>, CO, N<sub>2</sub>O, and halogenated gases to enable low uncertainty instrument calibration at the levels present in the atmosphere
- **Developed an optical transfer standard based on spectral line data** with traceability to the SI for characterising laser-based spectroscopic instrumentation that is used for atmospheric measurements of CO and CO<sub>2</sub>
- **Evaluated the use of Optical Isotopic Ratio Spectroscopy for determining the effects of different isotope abundance in analysis samples.** This is important for increasing the accuracy of calibration standards and determining the sources of greenhouse gases.

This project has successfully developed a range of traceable reference gas and optical transfer standards for the improved calibration of greenhouse gas-monitoring instrumentation. Newly developed standards, for example, have significantly improved the accuracy of atmospheric CO<sub>2</sub> measurements made by the UK’s national and international greenhouse gas-monitoring networks. Trace level reference gas standards containing complex mixtures of fluorinated gases have been used in system testing at the EMPA Dübendorf monitoring site (Switzerland) introducing robust traceability to the SI for their measurements. Project results will help climate-monitoring networks to achieve the target measurement accuracies set by the WMO as well as supporting the implementation of industrial emissions regulations and directives, including the EU’s F-gas legislation and air quality directive (2008/50/EC).

<b>More information is available at</b>	ENV52 Metrology for High Impact Greenhouse Gases (HIGHGAS) <a href="http://www.euramet.org/project-ENV52">http://www.euramet.org/project-ENV52</a>
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## Measuring ammonia in air

Intensive livestock farming and widespread fertilizer usage have increased ammonia pollution levels in Europe, reducing biodiversity and generating secondary particles hazardous to human health. An EU Directive on reducing atmospheric pollutants will, from 2020, impose strict limits on ammonia emissions, obliging member states to introduce reduction strategies. National monitoring networks are being set-up to collect ammonia data, by air sampling using low-cost trapping methods, requiring chemical analysis. Automated continuous analysers are also used for real-time measurements. Both require improved calibration methods with robust links to SI units and new ways to assess performance in-the-field. Additionally, optimisation of materials based on inertness to ammonia – a reactive gas – could help reduce measurement losses before gas analysis.



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The EMRP project **Metrology for Ammonia in Ambient Air** developed ammonia reference gas standards for use in calibrations and in-the-field device performance assessments, and commissioned, then used, a facility for evaluating material/ammonia interactions to help inform user selection decisions.

The project:

- **Developed ammonia gas cylinder standards and point-of-use generation methods** to improve calibrations and in-the-field performance assessments of measuring devices
- **Used these reference gas standards to calibrate** laser-based cavity ring-down spectroscopy and quantum cascade laser technologies showing potential for use as SI transfer standards
- **Upgraded a lab-based Controlled Atmosphere Test Facility (CATFAC)** for use with ammonia, and used it to assess the performance of ammonia sampler trapping media
- **Investigated interactions between ammonia and the materials used in measurement devices** to optimise the selection of inert materials throughout the measurement chain.

The upgraded CATFAC facility was used for a comparison of 16 ammonia measuring devices in the lab followed by a pioneering field study. The project's new reference gas standards enabled the assessment of their performance and the generation of an improved understanding of ammonia trapping efficiencies which when implemented by manufacturers has increased measurement accuracy. Studies performed using the CATFAC facility, have supported laser-based spectrometry instrument manufacturers by identifying inert materials and determining ways to correct for water vapour interferences that hamper ammonia detection. These developments have been taken up by Picarro Inc, a manufacturer of cavity ring-down spectrometers and Mirico, a developer of laser-based spectrometry technologies. Another early adopter of the project's developments has been the Swiss national air pollution monitoring network who have invested in the project's point-of-use generation method for field tests of ammonia sampling devices.

Closer agreement between ammonia measurement devices and new tools to determine the efficiency of samplers will enable European air quality monitoring networks to produce validated data of suitable accuracy for identifying successful ammonia emission reduction strategies. This will be vital for achieving compliance with the EU's National Emission Ceilings Directive on reducing atmospheric pollutants.

<b>More information is available at</b>	ENV55 Metrology for Ammonia in Ambient Air (MetNH3) <a href="http://www.euramet.org/project-ENV55">http://www.euramet.org/project-ENV55</a>
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## Accuracy for emissions monitoring

A principal instrument of Europe's drive for cleaner, healthier air is the Industrial Emissions Directive, that limits emissions of polluting and greenhouse gases, and tightens requirements for regulatory reporting. However, emission measurement is difficult for point sources (such as stacks) and for assessing releases from large area sources like methane from landfill or 'fugitive gases' from oil refinery pipework.

Improving the reliability of installed stack emission monitoring systems by introducing calibrations based on spectrographic techniques, such as Fourier transform infrared (FTIR) cameras and tuneable diode laser absorption spectroscopy (TDLAS) and reducing the measurement errors associated with stack flow measurements would significantly improve accuracy. Open path optical techniques based on Differential Absorption Lidar (DIAL), FTIR and TDLAS are available for determining large area emissions, but standardised operational procedures for their use must be developed before they can be used for regulatory compliance monitoring.



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The EMRP project **Metrology to underpin future regulation of industrial emissions** developed new reference materials and stack simulation facilities. The project also developed improved stack flow monitoring and calibration methods, to enable plant operators to comply with the Industrial Emissions Directive.

The Project:

- **Validated FTIR and TDLAS techniques for calibrating stack emission monitoring instrumentation** for CO, NO, SO<sub>2</sub>, HCl, H<sub>2</sub>O, industrial process emissions and produced protocols for their use
- **Developed computational fluid dynamic modelling methods** and used these to reduce stack flow measurement errors leading to new guidance on determining annual plant emissions
- **Validated the use of open path optical techniques and generated measurement protocols for the remote sensing of fugitive emissions** to aid compliance with the EU's Refining of Mineral Oil Best Available Technique Reference Document
- **Designed, constructed and validated facilities that simulate industrial emissions** thus enabling, for the first time, accurate assessments of the emissions monitoring community's performance.

This project provided an improved measurement infrastructure for point and area emission monitoring and methods which have been incorporated into CEN standards, for example EN14181 Stationary Source Emissions - Quality Assurance of Automated Measuring Systems. These have enabled environmental regulatory authorities, such as the UK Environment Agency, to allow the use of portable FTIR techniques for emissions monitoring for the first time. Manufacturers of remote sensing devices are benefiting from new measurement calibration methods, standards and protocols; and process plant operators, test laboratories, and national regulators are using project derived uncertainties that have been incorporated into the new guidance document *Framework for determining uncertainty sources and the propagation of uncertainty contributions in reported annualised mass emission*.

The follow-on project **Metrology for sampling and conditioning SO<sub>2</sub> emissions from stacks** is developing Standard Reference Methods for monitoring sulphur dioxide emissions from industrial processes; and the project **Metrology for air pollutant emissions** is developing measurement methods for newly regulated pollutants, including ammonia and hydrogen fluoride.

<b>More information is available at</b>	ENV60 Metrology to underpin future regulation of industrial emissions (IMPRESS) <a href="http://www.euramet.org/project-ENV60">http://www.euramet.org/project-ENV60</a> Follow on projects: 15NRM01 Metrology for sampling and conditioning SO <sub>2</sub> emissions from stacks (Sulf-Norm) and 16ENV08 Metrology for air pollutant emissions IMPRESS 2	
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## Exhaust emissions

The EMRP project **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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<b>More information is available at</b>	ENV02 Emerging requirements for measuring pollutants from automotive exhaust emissions (PartEmission) <a href="http://www.euramet.org/project-ENV02">http://www.euramet.org/project-ENV02</a>	
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## Monitoring mercury in the environment

Highly toxic mercury is released into the atmosphere in several forms - elemental mercury, particle-bound mercury, or oxidised mercury - from burning fossil fuels, forest fires or energy efficient compact fluorescent lights. Its form governs the distance it travels and its ability to accumulate in biological systems. To control and reduce mercury emissions the EU has introduced a raft of legislation supporting the goals of the Minamata Convention.

Mercury is reactive, volatile, difficult to store and handle, making it extremely challenging to measure as it sticks to many surfaces. Existing measurement methods need better links to the SI units and increased accuracy to enable improved monitoring of abatement effectiveness and mercury trends in the environment.

The EMRP project **Traceability for mercury measurements** developed, a calibration system for mercury in air and used this to calibrate environmental monitoring sensors, and optimised biota analysis procedures to remove biases from inter-species fat content variation. This project builds on the outcomes of EMRP project **Emerging requirements for measuring pollutants from automotive exhaust emissions**.



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The project:

- **Developed an SI traceable mercury-in-air calibration system** based on accurately determining mercury vapourisation weight loss to provide a potential replacement for currently used equations
- **Compared NMI calibration methods using an SI traceable transfer instrument** as a first step towards international measurement equivalence
- **Optimised and validated procedures for determining the mercury content in fish** and used these to establish inter-species differences resulting from variations in fat content or habitat
- **Evaluated the performance of innovative low-cost mercury-in-air monitoring sensors**, demonstrating their suitability for use in determining atmospheric traces of mercury.

This project made significant progress towards the introduction of a measurement infrastructure based on the SI units for measurements of mercury, thus providing a potential alternative to the current use of equations of state. New measurement methods and procedures are now available for determining mercury traces in atmospheric precipitation and seawater, whilst a project derived digestion method for mercury in particulate matter has removed reliance on hazardous hydrofluoric acid. This has been included as an annex to a European Normative standard. The project's low-cost yet highly sensitive prototype sensor, based on nanostructured materials, has been trialled at 5 Global Mercury Observation System monitoring sites, successfully demonstrating its potential for greater adoption in environmental mercury monitoring.

Collaborations between the project and the IAEA Marine Environmental Studies Laboratory, providers of technical support to several UN agencies, have enabled the uptake of accurate production procedures for mercury containing biota reference materials, whilst a constant interaction with NIST and the US EPA has achieved an international consensus for mercury measurement standards in air. These are important steps in the generation of a greater international harmonisation for mercury measurements.

<b>More information is available at</b>	ENV51 Traceability for mercury measurements (MeTra) <a href="http://www.euramet.org/project-ENV51">http://www.euramet.org/project-ENV51</a> Follow on project: 16ENV01 Metrology for oxidised mercury (MercOx)	
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## Greater accuracy for radiation monitoring networks

Decisive and proportionate action is essential for protecting public health in the event of a nuclear incident. This depends on early and accurate contamination identification and the reliable estimation of the radiological dose associated with it. Rapid, accurate, and harmonised measurement data from monitoring networks is required for this purpose. Currently, dose measurements are mainly made using Geiger Müller (GM) counters, supplemented by air sampling systems. While GM devices are robust, no data is generated on radiation type; air samplers are accurate concerning the monitoring of airborne radioactivity concentrations, but many do not provide live nuclide specific data. New spectrometric sensor technologies can generate both information on dose rates as well as on radioactive contamination levels but these require robust characterisation to demonstrate reliability. An improved understanding of background radiation from naturally occurring radon gas and siting effects are also needed to improve dose rate and radionuclide specific contamination information availability for rapid public safety decisions and appropriate countermeasures.



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The EMRP project **Metrology for radiological early warning networks in Europe** characterised a range of prototype spectrometric detectors to test suitability for dose rate and airborne monitoring use by Europe's radioactive early warning networks. Measured dose rate data from monitoring systems installed in network stations were also harmonised to ensure increased comparability. The project:

- **Characterised new scintillation-based spectrometric detectors** using radioactive sources that simulated released nuclear contamination, demonstrating the instrument's response and suitability for dose rate networks and air monitoring
- **Investigated the effects of detector positioning and other radiation background effects** to generate improved individual site corrections, for increased accuracy of dose rate measurements
- **Developed sophisticated data analysis protocols and databases** leading to increased radiological data quality for aiding authority decision making
- **Developed and tested instrumentation for airborne-radioactivity monitoring** using simulated contamination filter sources to confirm their likely performance in an emergency.

This project interacted with user communities, including the European Radiological Data Exchange Platform, and created databases of spectra provided by early warning networks. The partners worked with radiological monitoring networks in Spain, Belgium, Germany and Poland on upgrading instrumentation and the project experts have given information to a UK parliamentary committee considering preparedness. New instrumentation and procedures are being promoted to regulatory bodies, environmental agencies and international standards organisations to promote the uptake of spectrometric detectors based on scintillation-based technologies. These efforts will help support the introduction of new technologies and practices for improved networked dose rate and contamination monitoring, enabling faster, and better coordinated emergency action based on more harmonised data to protect public health and the environment. The EMPIR research project **Metrology for mobile detection of ionising radiation following a nuclear or radiological incident** is building on this project's developments with an increased focus on unmanned mobile systems such as drones.

<b>More information is available at</b>	ENV57 Metrology for radiological early warning networks in Europe (MetroERM) <a href="http://www.euramet.org/project-ENV57">http://www.euramet.org/project-ENV57</a> Follow on project: 16ENV04 Metrology for mobile detection of ionising radiation following a nuclear or radiological incident (Preparedness)	
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## 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 **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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<b>More information is available at</b>	ENV09 Metrology for radioactive waste management (MetroRWM) <a href="http://www.euramet.org/project-ENV09">http://www.euramet.org/project-ENV09</a> Follow-on project: ENV54 Metrology for decommissioning nuclear facilities (MetroDecom)	
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## Technologies for nuclear decommissioning

The first generation of nuclear power plants are due for decommissioning, a process that is expected to cost 150 billion Euro and will generate large volumes of highly radioactive waste. Highly contaminated graphite, concrete, and steel require in-situ identification followed by removal and accurate segregation to ensure safe and appropriate waste storage in underground concrete lined repositories – potentially for hundreds of years. Ensuring the containers used can withstand the heat generated by their contents and monitoring the store for environmental releases of radioactive gases pose long term challenges for current measurement techniques. New waste handling facilities and measurement methods need to be developed to address nuclear site decommissioning requirements.



The EMRP project **Metrology for decommissioning nuclear facilities** investigated methods

and sampling regimes for in-situ radioactive contamination mapping, developed and characterised a waste segregation measurement system and devised new methods for assessing waste drum and large concrete structure integrity. It also developed systems for determining radioactive gas releases from high level nuclear waste storage facilities. This project builds upon the outcomes of **Metrology for radioactive waste management**.

The Project:

- **Investigated methods for mapping radioactivity at nuclear facilities**, including a newly developed gamma ray camera and a geostatistical modelling technique for depth-profiling contamination in building structures
- **Developed a materials segregation facility for waste package characterisation** for on-site installation, that is configurable for a range of radiation detection modes
- **Developed radioactive gas monitoring systems for nuclear sites and radioactive waste repositories**, for the detection of hazardous emissions containing tritium or carbon-14
- **Developed waste package temperature-monitoring systems**, to help identify container “hot spots” early and before thermally-induced damage can create the potential for radioactivity release.

This project has successfully developed methods for the safe and cost-effective decommissioning of nuclear facilities, ensuring waste materials are managed according to their identified hazards. A range of detection systems – for monitoring radioactive and thermal emissions – have also been assessed for nuclear sites and waste repository use. Both EDF and ANDRA are installing fibre optic distributed temperature sensing technologies to monitor the integrity of large concrete structures supported by a test facility commissioned during the project for evaluating the performance of electro-optical control instrumentation. The testing of prototype radiation detection instrumentation during the project has resulted in several companies developing commercial devices which are suitable for use at long-term high activity nuclear waste storage facilities.

In the long-term, project results will help provide measurement methods to enable the accurate consignment of decommissioning waste streams as nuclear sites are retired across Europe. The follow-on EMPIR project **In-situ metrology for decommissioning nuclear facilities** (MetroDECOM II) will continue EURAMET funded research in this area.

<b>More information is available at</b>	ENV54 Metrology for decommissioning nuclear facilities (MetroDECOM) <a href="http://www.euramet.org/project-ENV54">http://www.euramet.org/project-ENV54</a> Follow on project: 16ENV09 In-situ metrology for decommissioning nuclear facilities (MetroDECOM II)	
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# 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 NO<sub>2</sub>, 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 NO<sub>2</sub> 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 NO<sub>2</sub> 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 NO<sub>2</sub> 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 NO<sub>2</sub> 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 NO<sub>2</sub> 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.

## 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.



© dlib

## 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.



## Traceability for mercury measurements

Mercury, a highly toxic metal, can be released into the environment from human sources. European and international treaties are in force to limit its emission, introducing the need for reliable mercury monitoring. Cheap and easy to use sensors that can be deployed anywhere in the world and that are capable of operating without power supplies are needed for monitoring atmospheric mercury levels.

The EMRP project **Traceability for mercury measurements** developed a prototype “passive sensor” for determining mercury in air. As well as being low cost, these sensors are re-usable and designed to determine ultra-trace amounts of mercury, with robust links to the international system of units.

The United Nations Environment Programme and the World Health Organisation in collaboration with project researchers at the Institute of Atmospheric Pollution Research, Italy have used these sensors at 10 sites worldwide in a pilot study. The aim is to develop a global monitoring system to meet the requirements of European and international regulations. Increasing mercury measurement coverage globally will lead to improved knowledge of the scale of this problem and this will help to identify where efforts should be concentrated to have the greatest effect on reducing mercury releases to the environment.



© B&M Noskowski

## Better digestion for mercury analysis

Highly toxic mercury, which is present in the environment, bioaccumulates into fish and seafood which has led to the introduction of EU Directives that compel industrial polluters to monitor emissions. A robust measurement hierarchy underpinned by rigorous links to the SI, coupled with improved sample preparation procedures, is needed to help overcome reference data discrepancies.

The EMRP project **Traceability for mercury measurements** developed an aqua regia based digestion method for preparing mercury containing analysis samples, thus removing the need to use hazardous hydrofluoric acid. It produces a solution that is interference free and easy to transfer to analytical instruments without instrument fouling. It is now incorporated into an annex of the relevant mercury CEN measurement standard, which is the initial step needed for its use in regulatory compliance.



© Marchcattle

The NMI community is proposing that the BIPM - the International Bureau of Weights and Measures - could become the arbiter for data quality. This would solve an increasing problem in that the accuracy of reference data sources based on empirical equations has become hard to judge, hampering measurement accuracy. The BIPM maintains a materials database of reference data and this could be extended to include NMI derived mercury data with robust links to the SI. The introduction of a robust measurement hierarchy with authenticated data will help compliance with Directives on mercury emissions.

## Monitoring ammonia

Ammonia is a harmful pollutant, which damages ecosystems, harms human health and contributes to global warming. The EU has set targets for its reduction and introduced Directives for its regulation, but compliance verification requires accurate ammonia sensors that do not interact with the gas they measure. Improved material testing facilities and calibration standards are needed to support the development of sensors based on ammonia inert materials with robust links to the SI units.

The EMRP project, **Metrology for ammonia in ambient air**, extended the capabilities of CATFAC, an existing testing facility to enable its use for the evaluation of materials and coatings that are inert to ammonia. The proprietary coating made by SilcoTec™ was found to be the most suitable and has been used by the project team to prepare stable ammonia standards for use in sensor calibrations.



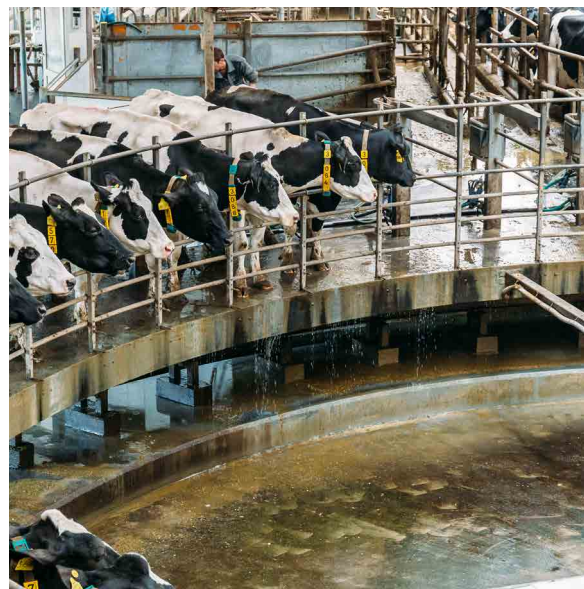
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MIRICO, a manufacturer of high-performance gas sensing instruments, used project developed ammonia standards to identify inert materials for use in a prototype ammonia sensor. This sensor is being developed for standalone use and for inclusion into MIRICO's air quality monitoring platform. Having confidence in the performance of sensors based on improved knowledge of ammonia/material interactions will increase the accuracy of environmental ammonia measurements and this will assist in assessing reduction strategies.

## Greater accuracy for ammonia monitors

Ammonia is a harmful pollutant produced by intensive farming which damages ecosystems. Monitoring networks have been created to assess ammonia levels and the success of strategies for meeting EU emissions targets. Performing spot checks and ensuring test exercises supply specified ammonia concentrations to samplers requires accurate real-time measurements. Optical gas measurement technologies could provide these, but ways to compensate for spectroscopic cross interference effects created by water vapour in the sample are needed.

The EMRP project **Metrology for ammonia in ambient air**, used the upgraded CATFAC environmental gas testing facility to create compositions of ammonia gas with defined humidity levels and these were used to assess how water vapour effects the performance of laser-based techniques. Results were combined with modelling to reduce this effect.



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Picarro, a manufacturer of gas measurement technologies, used the CATFAC facility to evaluate its Cavity Ring Down Spectrometer, a laser-based ammonia monitoring instrument. As a result, Picarro have improved new and existing production models to reduce interferences from water vapour. These instruments can now operate at higher accuracies, making them viable for comparing, calibrating and checking ammonia measurement instruments in the field. This brings greater accuracy to the ammonia monitoring networks that assess the success of ammonia reduction strategies.

## Detecting new pollutants in the air

International treaties regulate greenhouse gases containing fluorine and other halogens that damage the atmosphere. These are frequently used in car air-conditioning units. Networks of instruments are being commissioned at remote locations and require appropriate calibration gas standards based on new halogenated compounds to detect halogenated gases.

The EMRP project **Metrology for High-Impact Greenhouse Gases** developed a new method for making fluorinated gas mixture calibration standards in a single cylinder that are suitable for use by halogenated gas monitoring networks. These standards are many times more accurate than those previously available from National Metrology Institutes.

Empa, the Swiss Federal Laboratories for Materials Science and Technology, is a research institute which performs air quality research and operates the high-altitude AGAGE halogenated gases monitoring station at Jungfraujoch. Using the project's new gas standard with their own dilution system, Empa produced a reference gas mixture for calibrating their instruments. Once its suitability has been confirmed, an increased number of institutes will be able to share the responsibility for producing these essential standards that underpin networks detecting atmospheric halogenated gas trends and pollution sources.



© KevinHyde

## Accurately monitoring pollution traces

Traces of man-made and naturally occurring volatile organic compounds (VOC) and oxygenated VOC (OVOCs), such as methanol or acetone, affect air quality and climate by the formation of ozone and aerosols. Monitoring networks track these trace pollutants to generate data for climate change prediction. Having confidence in data accuracy relies on robust SI links between lab-based calibrations and network monitoring instruments.

The EMRP project **Metrology for VOC indicators in air pollution and climate change** developed methods to quantify the metal surface adsorption of gases such as methanol and acetone which is important for preventing changes to gas calibration standard concentrations during storage. The project found that a proprietary coating manufactured by the company SilcoTek™ significantly improved their long-term stability and therefore increases calibration accuracy.

The German meteorological service (DWD) organised a performance assessment exercise for European Global Atmosphere Watch network calibration laboratories using the project's gas standards. This exercise enabled these labs to demonstrate proficiency in detecting VOC traces and the distribution of new VOC gas standards.



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## Improving gas plant leak detection

Supporting efforts to reduce polluting gas emissions, the EU's Industrial Emissions Directive introduces new limits and reporting rules. Europe's gas plant operators must identify and measure leaks to tougher limits that require greater measurement accuracy than are achievable using current authorised methods. Advanced optical measurement techniques exist, but these need robust performance evaluation and protocols for use before they can be authorised for use by plants required to demonstrate Directive compliance.

The EMRP project **Metrology to underpin future regulation of industrial emissions** validated new test and controlled-release facilities, that simulate leaks from industrial plants and used these to verify the performance of optical technologies including optical gas imaging in trials at a former gas plant. Operating procedures, developed for each technology, are being incorporated into a European Draft CEN standard - an important step towards future adoption for regulatory compliance.

FLIR, a manufacturer of optical gas imaging cameras used the project's controlled-release facility to demonstrate that a new optical gas imaging camera meets the required standards for use on American gas plants. Once the CEN standard is finalised, robust procedures for using highly accurate optical measurement techniques, such as that developed by FLIR, will give gas plant operators improved tools for monitoring leaks and emissions for regulatory compliance.



© zablowski

## Industrial emissions mapping

The EU's Industrial Emissions Directive sets increasingly stringent emissions limits for industrial polluters. Corresponding standards are being established for emissions monitoring approaches, but current techniques for determining releases from entire facilities lack the required accuracy for meeting these stricter limits. New optical techniques based on how chemicals absorb different wavelengths of light, offer a solution. Solar Occultation Flux (SOF), for example, generates information from the sun's spectrum to map the chemicals present.

The EMRP project **Metrology to underpin future regulation of industrial emissions** investigated and characterised optical emissions monitoring techniques, including SOF by releasing defined pollutants on a plant site where the wind has a significant effect on measurement accuracy. The best measurement practice that resulted is being incorporated into a CEN standard – a first step towards inclusion as Best Available Technologies for regulatory compliance.

FluxSense AB, a Swedish SME which manufactures innovative SOF instruments, expects to be an early beneficiary from the imposition of lower emission limits and the introduction of SOF for industrial regulatory compliance monitoring. Plant operators will also benefit from the increased availability of accurate techniques, such as SOF, to help them demonstrate compliance with stricter emissions standards.



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## Formaldehyde emissions monitoring

Formaldehyde, emitted from furnishing and construction materials and from the combustion of organic materials, can cause health problems. Regulations govern safe limits, and monitoring systems check these are not exceeded. Gas standards – cylinders with accurate formaldehyde amount fractions – are used to calibrate such systems, but as limits become stricter, new methods are required for producing standards with lower amount fractions and increased stability to confirm the performance of monitoring instrumentation.

The EMRP project **Metrology for VOC indicators in air pollution and climate change**, investigated formaldehyde/material interactions that reduce calibration standard stability and identified the best inert materials for use. These were included in a new point-of-use production facility for the low-amount fraction formaldehyde gas standards that were developed in the project.

Air Liquide, the world's largest supplier of industrial gases, was one of the first to use this facility during the calibration of its own in-house formaldehyde standards. The company aims to be amongst the first gas suppliers to provide low amount fraction formaldehyde standards, in anticipation of increasingly stringent regulations that impose more rigorous testing using gas standards.

Access to more accurate standards will help industry and government monitor and reduce formaldehyde emissions, improving health and ensuring compliance with increasingly strict regulations.



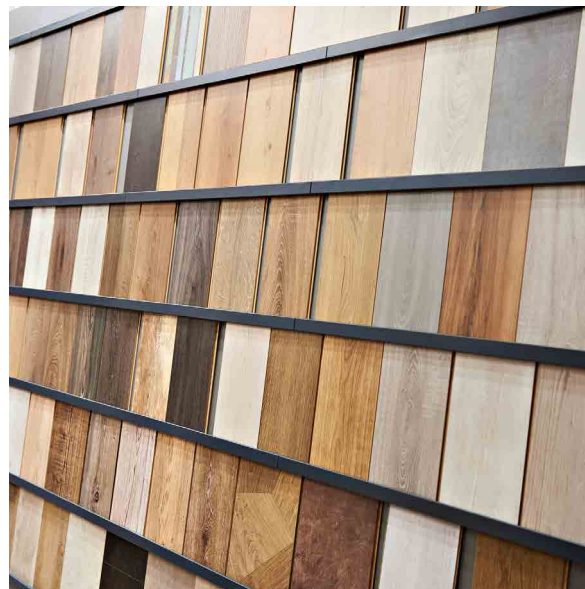
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## Accurately measuring indoor pollutants

Building materials, construction products and furnishings can emit volatile organic compounds (VOCs) which make people feel ill. Under the EU Construction Products Directive, their manufacturers must send samples to be tested at accreditation laboratories to ensure VOCs are within safe limits. Here, vapours are collected in tubes, and the VOCs within them are measured. To ensure these instruments are measuring correctly, laboratories must periodically check them against gas reference standards.

The EMRP project **Metrology for VOC indicators in air pollution and climate change**, developed improved gas reference materials for a wider range of VOCs. A previous project produced sorbent tube reference materials containing higher boiling point VOCs, which are released more readily on hot days. These can now be used with a large spectrum of the VOCs routinely analysed by testing laboratories, for instrument calibration.

DTI which provides VOC testing to e.g. construction product manufacturers, confirmed its measurement accuracy by participating in a comparison exercise. Reliable test results provide valuable knowledge to manufacturers for the design of safer products, and thereby making the indoor environment of homes and offices healthier.



© serelyzhov

## 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-INSTITUT 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-INSTITUT'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.



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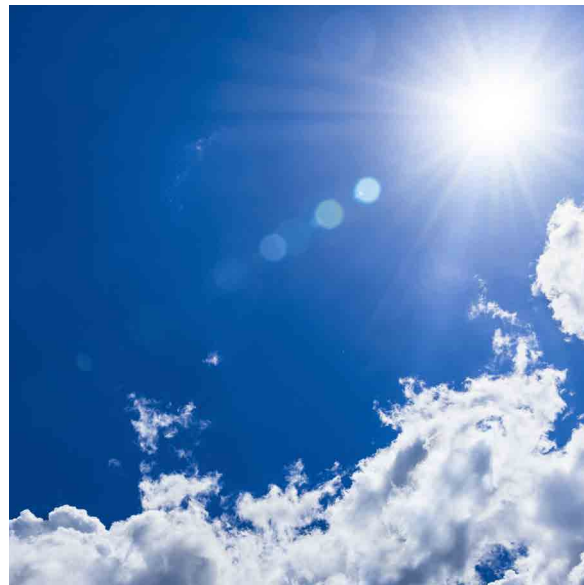
## Better UV monitoring to protect public health

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 these have 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 that 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 which is part 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.



© Zoran Kolundzija



## Advanced optics for atmospheric research

As part of the EMRP project **Traceability for surface spectral solar ultraviolet radiation**, the project partner Aalto University, working with industrial partners Kipp & Zonen and CMS Ing Dr Schreder GmbH, has designed new type of optical component for Brewer spectrophotometers, the sophisticated instruments that are 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 which 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 the project's outputs. Products incorporating the new optics will soon be commercially-available to customers that require 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 this is 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 that are 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 that is 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 it will support robust predictions of long-term climate change.



Courtesy 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, thus 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 it 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.

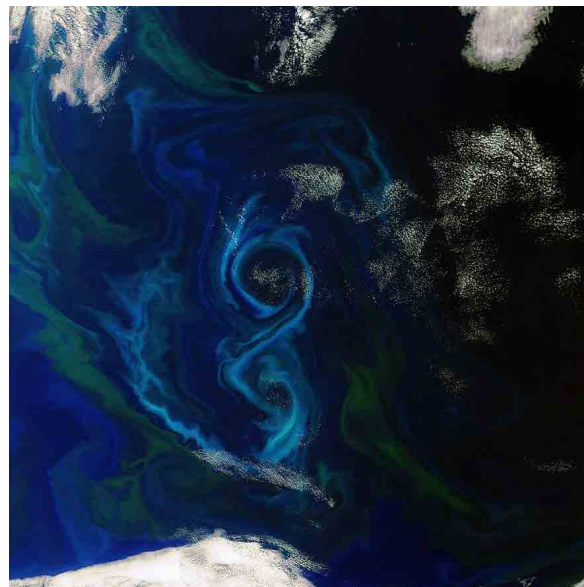
One of the first instruments to benefit was GLORIA, the first of a new generation of spectroradiometers for Earth observation. GLORIA's novel infrared camera measures trace gases in the atmosphere with an unprecedented combination of vertical and horizontal resolution that relies on highly-accurate calibration. 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 the high-quality data that is needed for robust climate change assessment.

## Helping satellites see ocean colour

Research buoys make local measurements of a range of variables that are essential for use in climate models, this includes ocean colour, which can be used as a measure of phytoplankton concentrations. This provides 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, as these 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 the French space agency, CNES. Instrumentation on the BOUSSOLE buoy has now been calibrated using the new portable standard and it 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 the 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 it will 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 the satellite data that is used in climate models.

## Acidity

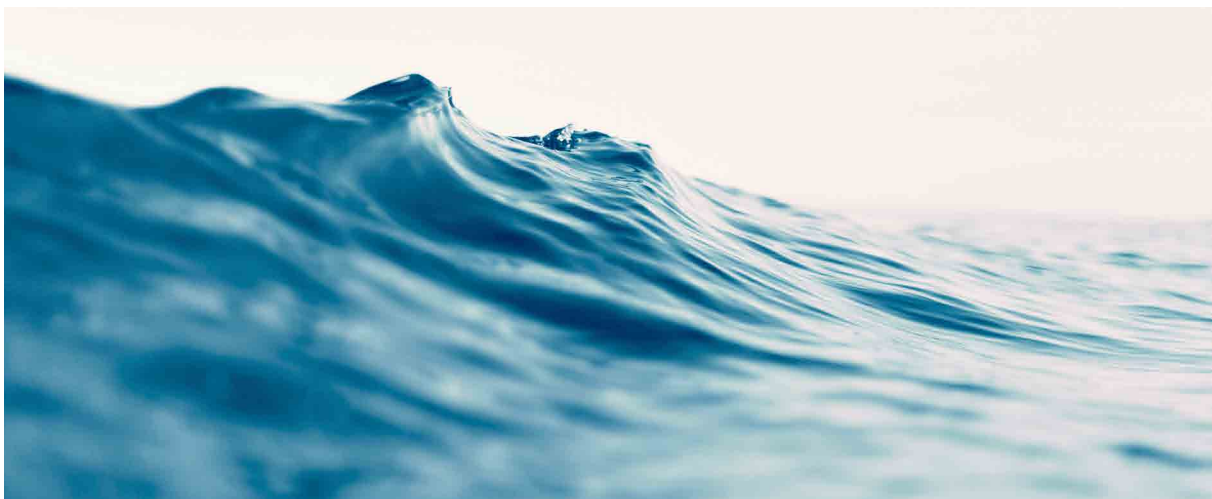
The project also helped to establish a traceability chain for seawater pH by developing primary and reference methods for pH measurements. The team contributed validation methods to a new ISO standard (ISO/CD 18191) for pH and is working with the Scripps Institution of Oceanography - the sole provider of a seawater buffer solution that is 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 that are 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 for the increased use of automated oxygen sensors and it will lead to a significant increase in the oceanography community's capacity to produce high-accuracy dissolved oxygen data for robust climate trend analysis.



© danilovi



## 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, which is 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 it is also being used by RISE, 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 these are also 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 is 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.

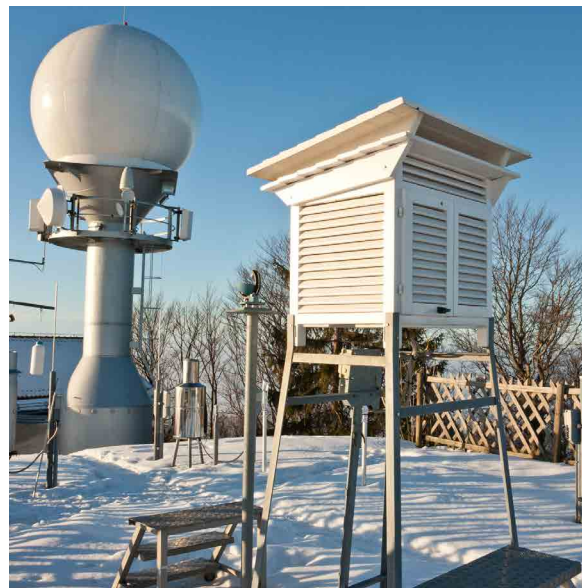
Further developments to EDIE are underway to make a more robust, compact version that is suitable for long-term installation in Ny-Ålesund - a first step towards a permanent Arctic calibration laboratory that will support multi-national climate observation and research at Svalbard.



## Weather data for climate change

Data on temperature, humidity and pressure, captured by Automatic Weather Stations (AWS) for weather forecasting, could provide data for monitoring climate change. However, these stations are managed and calibrated independently by different networks around the world. To use this data reliably for global monitoring, climate scientists need confidence that measurements are comparable and can be robustly linked to the SI.

The EMRP Project **Metrology for Essential Climate Variables**, identified instruments that are suitable for confirming the calibration of weather station instruments and a protocol for using these that matched World Meteorological Organisation (WMO) testing requirements for their AWS networks. At WMO's request, the project used the protocol to confirm the performance of European AWS calibration labs.



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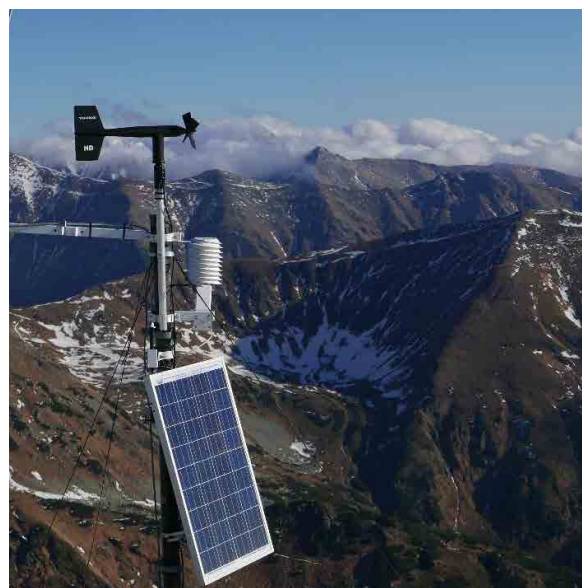
Now the protocol has been included in a WMO Guide on meteorological instruments and methods of observation that outlines measurement procedures for AWS networks around the world. Using this Asian calibration lab, proficiency has been confirmed and an exercise for American labs is planned. These comparison exercises will help harmonise global AWS network measurements for temperature, humidity and pressure. An essential step for increasing the use of AWS data in the climate models used by governments making decisions on strategies for mitigation and adaptation to climate change.

## Improved climate change monitoring

To achieve more accurate air temperature measurement, addressing sources of error, such as those caused by weather station siting and poor housing design need to be better understood.

The EMRP project **Metrology for Essential Climate Variables** investigated the performance of the various climate-monitoring instruments that are used in automatic weather stations where poor shielding design can create temperature measurement errors. Results demonstrated that up to 3 °C in temperature variation was attributable to back reflected solar radiation compounded by poor air flow inside the shielding.

Barani Design, an SME producing weather station sensors, had a novel prototype sensor shield independently validated during the project. This new shielding design has a helical structure that improves air flow whilst minimising back-reflected radiation influences and this is being used in a new Barani product to be launched in 2019. This affordable automatic weather station will introduce a cost-effective variant, which will be attractive to regions currently lacking a developed meteorological infrastructure, such as Africa and south-east Asia.



© Slovak Mountain Rescue Service

## Forecasting snow-related hazards

The extreme environments of high mountain regions cause a range of natural hazards. Weather conditions introduce risks, creating avalanches from snow cover or downstream river floods from meltwaters. To help assess these risks, networks of weather stations monitor local conditions. Temperature data is a key input for hazard forecasting, but measurement errors resulting from poor sensor shielding design need reduction to improve both measurement accuracy and risk assessment.

The EMRP project **Metrology for essential climate variables** investigated the effect of radiation shielding design on temperature measurements and established an inaccuracy of up to 3 °C due to heating inside the shielding itself caused by snow-reflected solar energy compounded by a lack of air flow.

CAE SPA, supplies multi-hazard monitoring and early warning systems, including weather stations.

It had a prototype shielding design and new sensors independently evaluated during the project which demonstrated their superior performance. These are now commercially available and one of the first customers has been the Regional Authority for the Environmental Protection of Piedmont (ARPA), Italy. Currently operating alongside existing instrumentation to provide comparison data, ARPA eventually intends to upgrade its network using CAE weather stations. Improved temperature data accuracy will aid the prediction of snow related risks in the Piedmont region.



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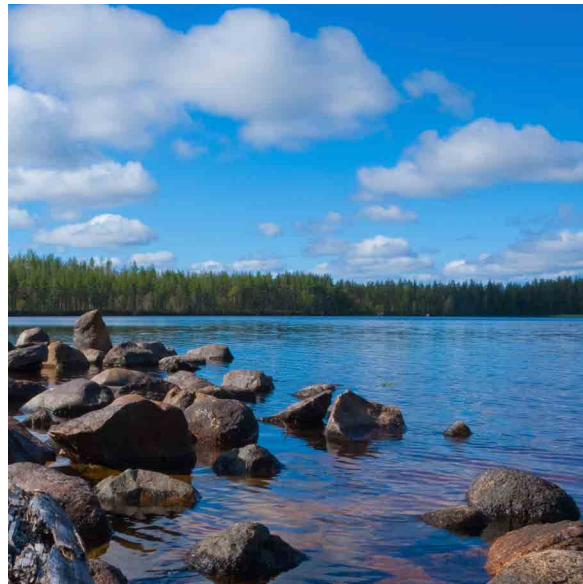
## Protecting Europe's water resources

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 it 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 also 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 this will help keep priority hazardous substances in waters at a safe level.



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## 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, the correct identification of waste which is suitable for free release and this 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 that 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.



## Reducing the nuclear decommissioning bill

The EU is facing a € 150 billion bill for decommissioning outdated nuclear facilities. Accurate on-site waste segregation of the hundreds of thousands of tonnes generated during clearance of a single nuclear unit is required to ensure that only the most radioactive is sent for long-term repository storage. Making accurate assessments of radioactivity in waste requires facilities which are capable of determining individual radionuclide activities in inhomogeneous and complex material mixes, ideally on the site undergoing decommissioning, to help reduce costs and speed consignment decisions.

The EMRP project **Metrology for decommissioning nuclear facilities** has adapted and extended a novel transportable free release waste facility developed in a previous EMRP project to enable its use for segregating nuclear waste streams on site. The facility is designed for using a range of detector types and operating configurations, thus enabling its adaptation for various waste assays in the decommissioning process. Further validation and upgrades to the facility's performance are continuing in the follow on EMPIR project In situ metrology for decommissioning nuclear facilities where evaluation against an existing operational decommissioning facility is planned.

A commercially available system is envisaged that will enable decommissioning operators and radiation protection regulators to optimise on-site waste management processes by speeding site clearance and reducing the associated costs.



## Nuclear incident alerts

A pan-European monitoring network of over 5000 stations mainly using Geiger-Mueller counters, stands ready to detect sudden increases in ionising radiation that may indicate a major nuclear incident, so that governments can respond appropriately. These counters accurately measure radiation levels but cannot distinguish between individual radionuclides that pose different dangers. Instruments using scintillation materials, which produce light in proportion to incoming radiation energies, could identify specific radionuclides. However, these require performance validation before networks can benefit from faster accurate data on airborne radioactive contamination.

The EMRP Project **Metrology for radiological early warning networks in Europe** compared a range of scintillation detectors, using radioactive sources to simulate radioactive contamination and this demonstrated that scintillation-based instruments are suitable for use by radiation monitoring networks.

As a result, the Polish National Atomic Energy Agency, the operator of the national monitoring network, gained knowledge and experience which helped them to develop and test a new compact spectrodosimetric probe that is planned to be installed in 30 new locations and to replace the old detectors in 13 monitoring sites. Germany's 1850 radiological monitoring stations, the largest European network, operated by BfS, is being upgraded with a project validated scintillation-based detection system, capable of issuing automated alerts for elevated dose rate levels. These new systems will support effective responses in the event of a nuclear incident, whilst reducing the risk of unnecessary interventions.



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## Fibre optics for structural integrity

Ensuring the integrity of large nuclear structures, such as waterways supplying vital power plant coolant or underground repository facilities for long-term radioactive waste, is important for our safety and that of the environment. Temperature measurements based on optical sensing could provide key information on their long-term integrity but generating confidence in a monitoring system that will operate for decades relies on rigorous testing of all its constituent parts.

The EMRP project **Metrology for decommissioning nuclear facilities** developed a facility for studying the performance of key sensing components in distributed temperature sensing systems. To simulate in-service conditions, optical fibres in a 25 m long heater are used to create test signals for assessing the performance of detection and interpretation instrumentation. Procedures for operating this facility are being incorporated into a new IEC standard that will enable greater test uniformity for temperature monitoring using optical sensing.

Early facility users Andra, the French national authority for radioactive waste management, and EDF were keen to benefit from this independent testing capability. Having confidence that commercially available distributed temperature sensing system components perform to specifications is essential for systems that monitor the safety of critical nuclear structures that must retain integrity over long time periods.



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## Further information

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

<https://www.euramet.org/emrp-energy-environment-2013>

Other projects in the EMPIR Environment Theme can be found at:

<https://www.euramet.org/research-innovation/empir/empir-calls-and-projects/>

## Europe's National Measurement Institutes working together

The majority of European countries have a National Metrology 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.

While traditional metrology stakeholders in manufacturing demand ever-increasing scope and greater accuracy, there is also a greater demand for accurate measurement in areas which support food safety, clinical medicine and environmental quality, as well as emerging areas such as biotechnology and nanotechnology. This requires resources beyond the scope of most national metrology systems and therefore it makes sense for NMIs to significantly increase the level of collaboration with each other. **The European Association of National Metrology Institutes (EURAMET)** is the body that coordinates collaborative activities in Europe.

EURAMET has implemented the European Metrology Research Programme (EMRP), a project programme organised by 23 NMIs and supported by the European Union, with a value of over €400 million. The EMRP facilitates the formation of joint research projects between different NMIs and other organisations, including businesses, industry and universities.





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**EMRP**

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