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30 June – 1 July 2015

Report of the BIPM Workshop on Global to Urban Scale Carbon Measurement

Bureau International des Poids et Mesures

Report of the BIPM Workshop on Global to Urban Scale Carbon Measurements
Date: 30 June – 1 July 2015
Venue: BIPM, Sèvres France

Executive Summary

In March 2015, the monthly global average concentration of carbon dioxide surpassed 400 parts per million for the first time since modern records began. With the world's population density highest in cities and metropolitan regions, anthropogenic greenhouse gases (GHG) emissions are largely attributable to urban activity and development. Greenhouse gas emissions from urban areas present unique measurement challenges and requirements for new measurement technologies.

Nations are setting policies to reduce greenhouse gas emissions including reduction target goals, with nationally appropriate mitigation activities (NAMAs). Although these activities have been expected to be of a measurable, reportable, and verifiable (MRV) nature, recent efforts within the UNFCCC have focused on Intended Nationally Determined Contributions, lessening emphasis on verification. Greenhouse gas inventory data, as the most likely metric for gauging reduction policy performance, will continue to be the mainstay of inventorying reporting. Bolstering the data upon which reports are based with scientifically-based measurement methods will add confidence to reported values. GHG concentration and flux measurements are envisioned to provide independent verification of reported emissions. However, advances in a range of emissions measurement methodologies are needed.

The aims of the workshop were to identify requirements for advances in measurements, standards, and reference data; to present instrument comparisons for carbon measurement and related climate variables; and to advance the measurement science base underpinning a comprehensive, global, greenhouse gas monitoring system for routine use as a method for validating greenhouse gas flux and emission data.

Presentations on urban greenhouse gas quantification research efforts currently underway in several countries identified common challenges and practices. Discussions addressed the progression of these efforts from the realm of measurement science research to an operational measurement system capable of providing greenhouse gas concentration and emissions information at a policy relevant scale. Presentations and discussions highlighted the need for a tiered measurement approach comprised of a range of measurement capabilities, e.g., various surface based measurements, aircraft, and remote sensing methods (satellite to surface-based), and the importance of increased geospatial resolution and fidelity. The requirement for a consistent operational measurement system was expected to gain greater acceptance as greenhouse gas emission information is sought at increasingly finer scales in all countries. Capability to better differentiate between anthropogenic emissions and biogenic uptake and emissions in urban settings is also an important area needing further development. Equally evident was the need to establish an overarching framework that builds upon various investigations made within and by cities and that may serve to structure best practices identified for differing types of urban environments. The

workshop emphasized the critical need to demonstrate consistency and comparability of measurement results across the entire framework, from local to global geospatial scales.

The collaboration between atmospheric monitoring and metrology communities for global greenhouse gas measurements and standards was identified as a success and a useful starting point in progressing toward advancing measurement capabilities underpinning future operational urban greenhouse gas measurements and standards. The development of best practice guidelines supporting an urban measurement framework was considered a high priority. Advances in measurement capabilities from emission process-oriented methods, widely used for emissions reporting, to methods independent of emission processes, e.g., atmospheric inversion methods were highlighted. Linking satellite calibration to well-characterized greenhouse gas emission regions, such as large cities, is envisioned as a means of on-orbit observing instrument calibration. This is expected to strengthen the comparability of remote sensing and satellite observations and surface-based observations.

Activities of the metrology community that would benefit city and national emission inventory developers were identified. These included: providing support for developing countries to move away from using default emissions factors in their inventories; producing more specific emission factors that are regionally representative; producing up to date and/or more granular emissions factors for non-CO_2 gases in particular for economic sectors; and improved data on land use, land use change, and forests.

The further development of the Global to Urban Scale Carbon Measurement Framework will require participation by experts in several scientific disciplines, representing expertise from different regions of the world. Organizations such as BIPM and WMO are well positioned to coordinate and conduct joint activities within the metrology and meteorology/climate science communities in developing a standards and measurements framework at the urban scale closely linked to regional, continental, and global scales. This linkage will ensure compatibility and comparability of global monitoring operations. BIPM, WMO and the National Metrology Institutes are well positioned to ensure that mole fraction observation data is properly related to and linked to the WMO Central Calibration Laboratory and supported by direct linkage to the International System of Units. Should urban greenhouse gas measurement systems continue to improve and serve societal needs, there may be a requirement to strengthen the infrastructure for providing these vital measurements standards to meet future global demand.

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Summary report of the BIPM Workshop on Global to Urban Scale Carbon Measurements

Date: 30 June – 1 July 2015

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Steering Committee:

Dr M.J.T. Milton (Chair)	BIPM
Dr J. Whetstone	NIST (United States)
Ms J. Burston	NPL (United Kingdom)
Dr W. Zhang	WMO
Dr O. Tarasova	WMO
Dr A. Samuel	NMIA (Australia)
Dr R.I. Wielgosz	BIPM

1 Introduction and Workshop Aims:

Nations are setting policies to reduce greenhouse gas emissions including reduction target goals. Although international agreements following on from the Kyoto Accords have yet to be concluded, structural needs regarding quantification of nationally appropriate mitigation activities (NAMAs) to mitigate greenhouse gases will likely incorporate the concepts of measurable, reportable, and verifiable (MRV) NAMAs put forth in the Bali Action Plan of COP 13. Greenhouse gas (GHG) inventory data will be the principle metric used to gauge the performance of reduction policies. The quantification requirements needed must be of the required accuracy and consistent with the reduction targets set by national and international bodies and with MRV requirements. Meeting these needs is a multi-faceted challenge to both the metrology and climate observing communities for measuring and reporting inventory data and information and for its verification using independent methods.

Following the development of previous large-scale, emission reduction strategies, it is now clear that success requires consistent, independent, scientifically-recognized measurement methodologies and data to support policy decisions (e.g., ozone depletion, acid rain, air quality in large cities and regions). For greenhouse gases, high quality, and coordinated atmospheric observational information is essential to both ensure success and to inform policy-makers implementing GHG reduction policies. Assessing progress towards and the achievement of reduction targets requires scientifically-sound information based on robust GHG measurement systems having accuracy and performance consistent with reduction target values. The verification of inventory values using independent methods is central to demonstrating their scientific validity.

The aims of the workshop are to identify requirements for advanced measurements, standards, reference data, and instrument comparisons for carbon measurement and other related climate variables to enable a complete global monitoring system for greenhouse gases to be operational and useful for validated greenhouse gas flux and emission calculations and for the verification of emission inventories. Furthermore, approaches to be undertaken for the development of an international roadmap for standards, reference data, and instrument comparisons for global greenhouse gas measurements and other related climate variables and greenhouse gas emission inventories will be elaborated.

The workshop is organized around three themes:

- Carbon measurement and other related climate variables: Global systems, principals and traceability
- Megacities and Metrology Needs for Supporting Greenhouse Gas Mitigation - Urban Greenhouse Gas Domes
- Standards for greenhouse gas emission inventories.

Aims of the Carbon measurement and other related climate variables: Global systems, principals and traceability theme

Concentrating on carbon measurement and other related climate variables, the session will:

- provide an overview of the progress and requirements in standards, reference data and instrument comparisons to enable accurate and validated measurements of global carbon and other related climate variables;
- provide examples of global climate variable monitoring programmes and their approach to incorporate traceable measurements and links to National Metrology Institute (NMI) activities;
- describe novel calibration and standards programmes that have been designed to meet the needs of the climate variable measurement community.

Aims of the Megacities and Metrology Needs for Supporting Greenhouse Gas Mitigation - Urban Greenhouse Gas Domes theme

Managing emissions, especially CO_2, is central to effective mitigation policies. Reduction targets are being set in a number of nations. Emissions inventories will be the metric by which policy compliance is gauged. Assessing progress toward and the achievement of reduction targets requires scientifically-sound and internationally-recognized information based on robust GHG measurement systems. Capability to independently verify inventory values is a significant measurement and standards challenge. Reliable information on greenhouse gas concentration and flux will be required both at national and international levels. Developing the measurements and standards capabilities that will be required is a significant measurement science challenge given the likely target levels. Discussion will focus on existing and planned activities in the megacity context and requirements for the development of measurement methods, standards and comparisons to underpin the accuracy of GHG emission data and calculations.

Aims of the Standards for greenhouse gas emission inventories theme

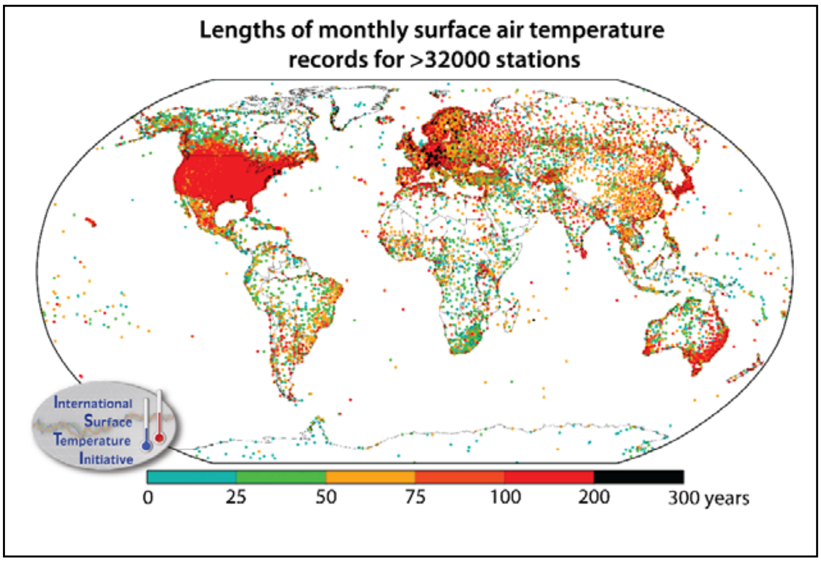
- Summarize the existing position of reporting from all levels (installations, projects, cities, countries)
- Highlight the biggest areas where improvement in measurement capabilities are needed, by answering the following questions:
    - Are uncertainties reported? Where are the uncertainties largest?
    - What new project types should inventory development be focused on?
    - Where are new/more granular/more specific emissions data and factors required?
    - Where is there a need for better consistency?

- Discuss the opportunities and challenges for incorporating forest carbon, soil carbon and land use into inventories of all kinds
- Agree a priority list of Essential Climate Variable (ECVs) based on which could be / are required to cover inventory data needs.

2 Keynote Presentations

Global Measurements of Essential Climate Variables, A. Becker (DWD)

Even without the challenges imposed by global warming and climate change, a comprehensive and, to the best possible extent, complete knowledge of the state of the atmosphere and climate for at least the current and the 20th century is a prerequisite for a reliable assessment and classification of the current observational information comprising mean conditions, extreme events, their variability and trends. It is also needed to validate and properly understand the results of numerical weather prediction-based re-analysis and of climate projections, and to reliably and objectively verify the successful implementation of GHG reduction policies and climate change mitigation in general. However, prior to the detection of global warming and its association to rising GHG concentrations, the demand on geo-temporal homogeneity and climate readiness of observations was basically limited to a subset of mostly surface-based *in situ* measuring systems addressing the observational needs to monitor climate in a narrow sense which is defined in the glossary of the Fifth Assessment Report (AR5) of the IPCC simply as average weather, or more rigorously, as the statistical description in terms of the mean and variability of relevant quantities over a period of time ranging from months to thousands or millions of years. The classical averaging period applied is 30 years as defined by the World Meteorological Organization (WMO) with the view that this does – under stable conditions – reveal characteristic values. The relevant quantities are most often surface variables such as temperature, precipitation and wind. Without a change in the radiative balance imposed by raising GHG concentrations and climate altering pollutants the demands on an in-depth understanding of the climate system affected in all of its five components, i.e. the atmosphere, the hydrosphere, the cryosphere, the lithosphere and the biosphere, including its mutual interaction would have remained a fairly academic question and the demand for an accordingly comprehensive observation extending the scope of the essential climate variables would probably have stayed too low to gather the momentum to establish a Global Climate Observing System (GCOS). In fact it still took until 1992, when the second world climate conference decided to adopt this. To ultimately meet the requirements of the UN Framework Convention on Climate Change (UNFCCC) and other international conventions and agreements mostly related to Climate Change, GCOS addresses the total climate system including physical, chemical and biological properties, and atmospheric, oceanic, terrestrial, hydrologic, and cryosphere components. In doing so, GCOS addresses the need for global coverage and timeliness of data, for example through the promotion of the Essential Climate Variables (ECVs, Bojinski *et al*., 2014) concept and the formulation of the 20 GCOS Climate Monitoring Principles (GCOS, 2013). The choice of over 60 ECV's cover the atmospheric, oceanic and



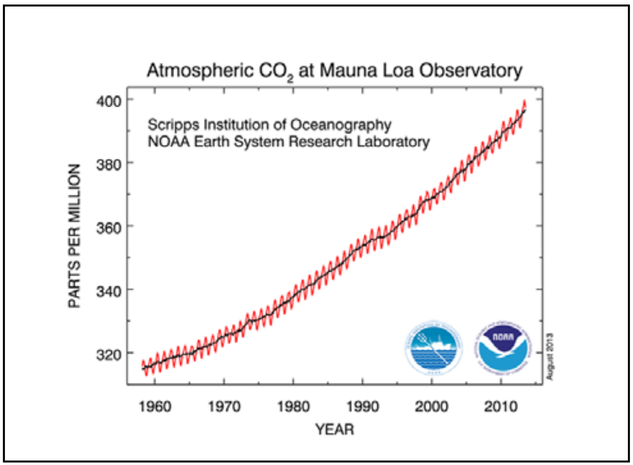
terrestrial domains and have been identified based on their relevance, feasibility and cost effectiveness. With the adoption of the Global Framework for Climate Services at WCC-3 and its implementation thereafter, the importance and demand for an ECV-based observational regime has even grown. One important aspect of the ECV designation lies in the principle of free and unrestricted exchange of ECV datasets, as requested by the state signatories of the UNFCCC. In pursuing its mission GCOS heavily relies on the contributions of the WMO National Hydrological and Meteorological Services in the field of data capture, processing and publication that is organized – *inter alia* - through the World Weather Watch programme including its WMO Information System (WIS). For the ECV precipitation the Global Precipitation Climatology Centre (GPCC) operated by the Deutscher Wetterdienst since 1989 has taken charge of the world-wide collection, quality assurance and processing of *in situ* precipitation data and to generate best quality gridded observational data sets for this ECV. Therefore the presentation will present the ECV concept of Bojinski *et al*. (2014) describing the ultimate goal of a complete Global Climate Observing System and the monitoring requirements that have to be met to reach it, as well as providing some insights into the actual challenges that data centres such as the GPCC face in their day-to-day work on the difficult path to achieving this ideal situation.

References: Bojinski, S., Verstraete, M., Peterson, T. C., Richter, C., Simmons, A., and Zemp, M., 2014: The concept of Essential Climate Variables in support of climate research, applications, and policy. doi: 10.1175/BAMS-D-13-00047.1;

http://www.wmo.int/pages/prog/gcos/documents/bams_ECV_article.pdf

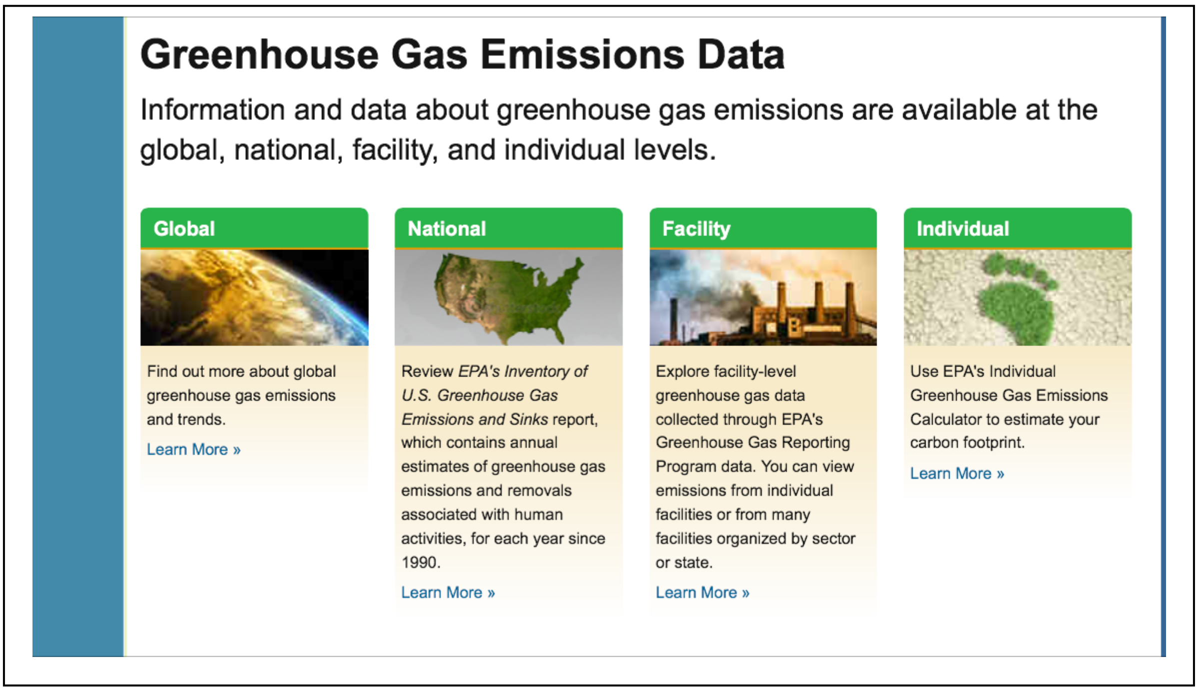
Tracking the World's Carbon, J. Butler (NOAA)

Rapidly rising carbon dioxide (CO_2) in Earth's atmosphere is the primary reason we are facing climate change and ocean acidification today. The amount of atmospheric CO_2 is 43 % higher than it was during the entirety of human civilization and is increasing faster every decade. Over 90 % of this added CO_2 was put there by humans during the past century and what is present in the atmosphere now will remain there for thousands of years, as will most of what is emitted in the future. Given the complex balance among forces maintaining the Earth's energy balance, there is no question that this rapid rise is increasingly affecting climate as we have known it. In an attempt to measure a trend of atmospheric CO_2, Dave Keeling of Scripps Institution of Oceanography began the first reliable, long-term records in 1957 – the International Geophysical Year – in the remote atmosphere of Mauna Loa, Hawaii, and Antarctica. Keeling's measurements were respected then because of his unrelenting attention to detail and his maintenance of a calibration scale that was highly stable over decades. Since then, our measurement system has expanded considerably with evolving scientific questions. At the heart of this system is the World Calibration Scale for CO_2, maintained at first in the Keeling laboratory and later transitioned to NOAA and adopted by the WMO as demand for calibration gases increased. Today, CO_2 is measured at hundreds of sites around the world, with many partners monitoring its trends and distributions in remote and regional areas. These data are critical for us to understand large scale trends and variability of this all-important gas and to be able to evaluate its sources and sinks on the planet. But as society begins to address this issue, measurements will have to increase considerably in number if we are to provide the information needed for successfully reducing, offsetting, or mitigating these emissions. Doing so, while maintaining high levels of compatibility among contributing sites, is challenging. We must continue to address this emerging challenge with the care and attentiveness Dave Keeling gave to the first measurements, with the added complication of the increasing number of players. This presentation will address the history of this measurement record and the emerging challenges of monitoring CO_2 at the increasingly granular levels needed for tomorrow.



Uncertainties and priorities in greenhouse gas inventories, W. Irving (US EPA)

The presentation provided a policy-maker's perspective on national greenhouse gas inventories and facility level reporting of greenhouse gas emissions. For national greenhouse gas inventories the presentation covered compilation methods, international standards for reporting and review through the Intergovernmental Panel on Climate Change (IPCC) National Greenhouse Gas Inventory Programme, and the United Nations Framework Convention on Climate Change (UNFCCC). He emphasized the importance of uncertainty assessment and priority areas for improvement, with a focus on methane, and carbon fluxes in the land sector. He also discussed how inventories are used for setting national goals and for informing international climate change agreements. The presentation presented information on the US facility-level greenhouse gas reporting programmes, which cover approximately 8000 individual facilities representing approximately 80 % of total US greenhouse gas emissions. It focused on the methodological approaches, verification results, data publication, use of data in the national inventory, and use for policy making. The presentation



concluded with some suggestions for how inventory compilers and the research community could collaborate to improve the overall quality of greenhouse gas inventories and facility-level data.

3 Summaries and Outcomes of Workshop Sessions

3.1 Carbon measurement and other related climate variables: Global systems, principals and traceability (Session II)

3.1.1 Session II Aims

Concentrating on carbon measurement and other related climate variables, the session aims were to:

- provide an overview of the progress and requirements in standards, reference data and instrument comparisons to enable accurate and validated measurements of global carbon and other related climate variables;
- provide examples of global climate variable monitoring programmes and their approach to incorporate traceable measurements and links to NMI activities;
- describe novel calibration and standards programmes that have been designed to meet the needs of the climate variable measurement community.

II: Carbon measurements and other related Climate variables: Global systems, principals and traceability

Presentations:

O. Tarasova (WMO)	Background atmospheric carbon measurement and other related ECVs
R. Wielgosz (BIPM)	Gas Metrology for carbon surface measurements and other related ECVs
C. Miller (JPL)	Space-based observations of Megacity GHG emissions
T. Warneke (TCCON)	Validation and calibration of GHG satellite observations by remote sensing measurements
K. Davis (PSU)	Inverse estimates of greenhouse gas sources and sinks using regional ground-based measurements networks
P. Thorne (GRUAN)	Impact of GHGs: Measuring global temperature change

3.1.2 Session II Summary

In March 2015, the monthly global average concentration of carbon dioxide surpassed 400 µmol/mol for the first time since Dave Keeling of Scripps Institution of Oceanography first began recording the value in 1957. In an attempt to measure a trend of atmospheric CO_2, he began the first reliable, long-term records in the remote atmosphere of Mauna Loa, Hawaii, and Antarctica, based on a calibration scale that was highly stable over decades. Since then, the measurement system has expanded considerably with evolving scientific questions. This measurement system is anchored to the World Calibration Scale for CO_2, maintained at first in the Keeling laboratory and later transitioned to NOAA and adopted by the WMO as demand for calibration gases increased.

Long-term global observations and analysis of atmospheric composition change is now coordinated through the World Meteorological Organization's (WMO) Global Atmosphere Watch (GAW) programme. The WMO GAW Programme is a long-term international global programme that coordinates observations and analysis of atmospheric composition and related physical parameter changes. The programme is based on a collaboration of more than 100 countries. Global greenhouse gas (GHG) observations and analysis is one of six focal areas of the GAW. This area includes CO_2, CH_4 and their isotopes as well as N_2O, SF_6 and halocarbons. GAW works towards integrated observations unifying measurements from different platforms (ground-based *in situ* and remote-sensing, balloon, aircraft and satellite) supported by modelling activities. The GAW observational network includes the stations that are not directly impacted by emission sources and that are regionally representative. The stringent requirements to quality of observations are evaluated at the meetings of experts on GHG measurement techniques every two years. The GAW Quality Assurance/Quality Control (QA/QC) system relies on the set of Central Facilities supported by Members. These Central Facilities include in particular Central Calibration Laboratories (that support GAW network primary standard), World and Regional Calibration Centres (that ensure traceability of the station measurements to the network standards and network compatibility) and World Data Centre (that archives and disseminates GHG data and prepares data products).

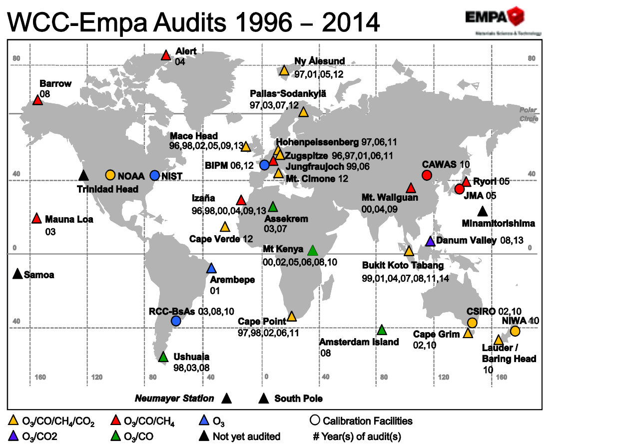


Fig 4: Audits of WMO-GAW sites carried out by EMPA in their role as a WCC (1996-2014)

With the signature of the CIPM MRA by the WMO in 2010, the WMO-GAW CCL for greenhouse gases (NOAA-ESRL) has participated in the Consultative Committee for Amount of Substance (CCQM), Gas Analysis Working Group (GAWG) and participated in the following recent key comparisons: CCQM-K82 (Methane in air at ambient level); CCQM-K83 (Halocarbons in air at ambient levels); and CCQM-K84 (Ambient CO); allowing the compatibility of WMO scale standards to be assessed against other primary standards maintained by National Metrology Institutes. Similar benefits are expected by expanding the comparison to isotope ratio measurements for CO_2 and methane, where measurements of these in the atmosphere are widely used in order to understand complex processes involved in the carbon cycle and to constrain carbon fluxes. The three most urgent issues to be addressed related to a World Scale for carbon isotope ratio measurements are:

- to ensure small measurement uncertainty and long-term stability of Reference Materials (RMs) in use for climate change related measurements and fulfilling associated metrological requirements;
- to introduce replacements of the reference materials that define the World's carbon isotope scale;
- to develop a range of RMs addressing existing and newly emerging analytical techniques (e.g. optical isotopic analysers) in the form of calibrated CO_2 gases with different delta C-13 values.

Cities are the largest and fastest growing sources of anthropogenic carbon, with urbanization having concentrated more than 50 % of the world's population resulting in 70 % of fossil-fuel CO_2 emissions originating from less than 3 % of the world's land surface.

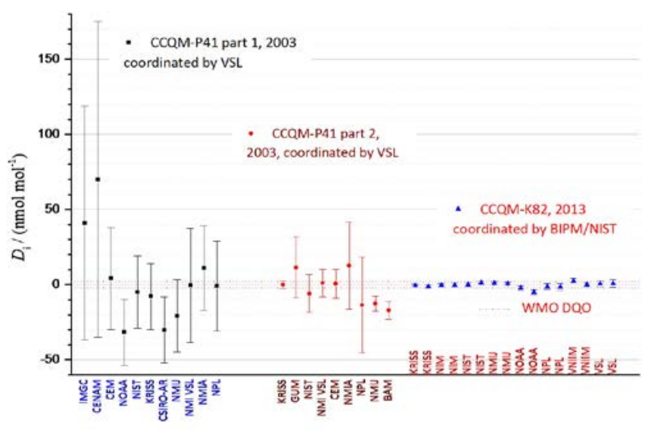


Fig 5: CCQM International comparisons of methane in air primary standards performed in 2003 and 2013, at a nominal mole fraction of 2000 nmol/mol

Greenhouse gas inventories are available for setting national goals and policies and for informing international climate change agreements. Guidelines for their development and reporting are available through the Intergovernmental Panel on Climate Change (IPCC) National Greenhouse Gas Inventory Programme, and the United Nations Framework Convention on Climate Change

(UNFCCC). Verification strategies for the inventories and anthropogenic sources and fluxes of CO_2 into the atmosphere through measurement of concentrations and inverse modelling are in development. Such measurement strategies require both satellite, tall tower, surface measurements as well as validation and calibration measurements for total column CO_2 (as performed by TCCON) and *in situ* measurements through the column via direct sampling (by airplane or AirCore sampling) with traceability of measurements to Primary standards.

Greenhouse gas fluxes can be inferred from atmospheric concentration measurements by inverse modelling. Until recently such inverse modelling studies were solely based on a network of surface *in situ* measurement stations. Remote sensing measurements of atmospheric CO_2 and CH_4 became available 15 years ago. The accuracy and precision of the first greenhouse gas retrievals from these measurements were not sufficient for advancing the understanding the global carbon cycle. However, the situation has changed over the years and several publications have used remote sensing measurements to improve the flux estimates of these gases. It is expected that the quality of the remotely sensed greenhouse gas data will continue to improve and that these data will become increasingly important for constraining greenhouse gas fluxes. A critical point for the future success of the remotely sensed greenhouse gas data is its calibration against the *in situ* reference scale. The ground-based Total Carbon Column Observing Network (TCCON) plays a vital role for the calibration of the column measurements and the validation of satellite retrievals. TCCON records solar absorption spectra and measures the same quantity as the satellites. TCCON measurements can be directly compared to vertical resolved *in situ* measurements and this calibration can be transferred to the satellite retrievals.

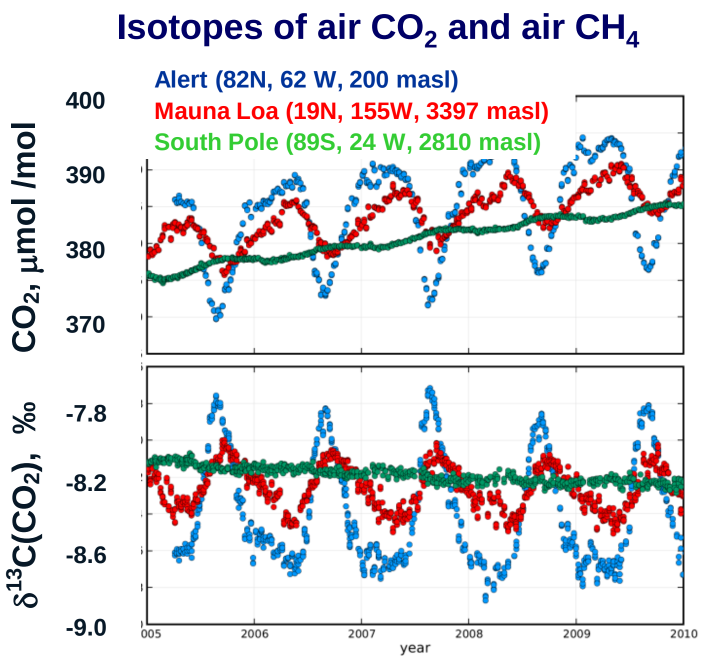


Fig 6: CO_2 Isotope ratio and mole fraction measurements from background sites

At present, inverse analysis of regional greenhouse gas (GHG) measurement networks is proving to be a successful approach to determining GHG total fluxes in addition to their spatial and temporal variability. In general it has been found that the temporal variability in fluxes is relatively easy to detect, followed by net regional fluxes, and that spatial differences in fluxes require the highest fidelity in terms of measurement density and atmospheric transport modelling.

Developing a measurement system that can provide CO_2 concentration and emission information at a policy relevant scale will require the number of measurement sites and measurements to increase considerably. The information provided will be needed for successfully reducing, offsetting, or mitigating these emissions. Doing so, while maintaining high levels of compatibility among contributing sites, is challenging, but will be evermore important as CO_2 emission information is sought at increasingly granular levels in the future, as well as differentiating between biogenic and anthropogenic emissions.

3.1.3 Session II Conclusions and recommendations:

1. The session highlighted the successes following on from the WMO-BIPM workshop in 2010, which had resulted in increased collaborative activities in the field of gas metrology and standards and it was recommended that theses should continue. Among these were:

   a. WMO laboratory participation in CIPM MRA key comparisons, which has led to demonstrated improvements in global compatibility of GHG primary standards;
   b. A CCQM-GAWG workshop on particulates and aerosols organized with WMO-GAW, which had resulted in the formation of task groups in 2015 to deal with metrological and comparison issues activities.

2. It was recommended that work to improve the links between the Satellite Community and Metrology Community should continue. The Metrology community should endeavour to work more closely with the satellite community on radiance measurements but also on quantities and atmospheric concentrations derived from these. NMIs should develop links to agencies actively involved in the development of pre-flight and in-flight calibration/validation strategies for satellite radiance measurements. In addition, there are requirements for:

   a. Solar radiance spectra traceable to radiometric standards over the wavelength range 200 nm to 20 µm;
   b. Lunar reflectance spectrum with +/- 1 % accuracy over the wavelength range 200 nm to 20 µm;
   c. Spectroscopic reference standards for infrared absorption spectra of CO, CO_2 and CH_4, particularly for intensity and line shape parameters with better than 0.1 % accuracy

3. The measurement community needs to be ready to provide policy relevant information, bearing in mind that a large-scale emission reduction plan will require validation to measure its effectiveness. The measurements community should be clear on their role in:
   a. providing better understanding of global to regional scale carbon fluxes to address carbon-climate uncertainties;
   b. “verifying” or validating national inventories;
   c. providing diagnostics to help inventory compilers improve the fidelity of those inventories;
   d. fostering access to other data that directly enables mitigation action by facility operators, regulators, etc.
4. It was recommended that activities that strengthen links between GHG standards developed by NMIs and those maintained by the WMO-GAW CCL, e.g. by encouraging NMI participation in WMO-GAW round robins, complementary to key comparisons, should continue.
5. The session concluded that there is a strong need to develop metrologically robust methods for comparing/combining atmospheric measurements that include the effects of spatial and temporal differences.
6. It was recommended that further consideration should be given to co-locating high quality measurements systems observing many ECVs
7. IAEA, WMO, BIPM, NMIs and other stakeholders were encouraged to work together to strengthen the infrastructure for isotopic standards and traceable measurements for atmospheric applications.

3.2 New Challenges – Metrology and Standard Needs for GHG Emissions from Megacities and Emission Inventories (Session III)

Session aims

III: New Challenges – Metrology and Standard Needs for GHG Emissions from Megacities and Emission Inventories

Presentations

J. Whetstone A Megacity framework for GHG measurements

S. Hamburg Challenges and opportunities in non-CO_2 GHG measurements and standards: Natural gas case study

Managing GHG emissions, especially CO_2, is central to effective mitigation policies. Reduction targets are being set by a number of cities and nations. Emissions inventories will be the metric by which policy compliance is gauged. Assessing progress toward and achievement of reduction targets requires scientifically sound and internationally recognized information based on robust GHG measurement systems. The capability to diagnose reported inventory values independent of primary inventory data development methods, particularly in urban settings, remains a significant standards and measurements challenge. Recognition of such capabilities, and the data and information developed and provided by them on greenhouse gas concentration and flux, will be required both at national and international levels. The session focused on existing best practices and planned activities to develop measurement methods, standards and data analysis, for effective comparisons at a range of the global spatial and seasonal temporal scales.

Presentation Summary

With the world's population density highest in cities and metropolitan regions, anthropogenic greenhouse gases emissions are largely attributable to urban activity and development. Anthropogenic emissions place significant demands on relatively small geographic areas, and reflect rapid changes from land use development, urbanization, energy and water needs, and transportation burden. In the United States, approximately 70 % of emissions are concentrated in metropolitan and suburban areas. The purpose of this workshop session is to address opportunities and metrology challenges for nations to develop measurement capabilities supporting urban greenhouse gas mitigation efforts building upon the global measurement systems and integrated with a comprehensive international framework. Such a global framework is expected to reflect national needs and tiered architecture based on priorities of the local GHG measurement requirements.

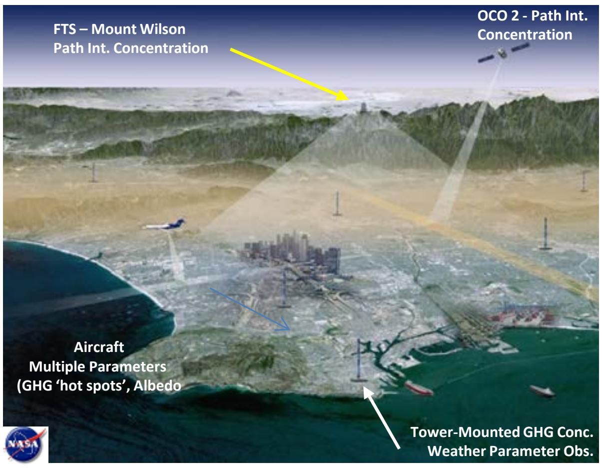


Fig. 7. A tiered or integrated GHG flux measurement system. Data at the urban scale are linked with information from regional and global areas.

Greenhouse gas emissions from urban areas present unique measurement challenges and requirements for new technologies. Two such investigations were presented demonstrating different approaches and objectives. The work being conducted at the U.S. NMI, the National Institute of Standards and Technology (NIST) was presented by J. Whetstone, who gave an overview of NIST's greenhouse gas and climate science measurements programme, emphasizing the research being conducted within the NIST urban greenhouse gas testbed system. The testbed system consists of a dense greenhouse gas observing network located in three U.S. cities, Indianapolis, Indiana (the Indianapolis Flux Experiment, INFLUX), Los Angeles, California (the LA Megacities project), and the most recent, Northeast Corridor greenhouse gas measurement testbed, initiated in the Baltimore, Maryland/Washington, D.C. area with plans for extension to the Corridor's four major metropolitan regions Philadelphia, New York City, and Boston and their surrounding areas. Testbed site characteristics, natural variations, and network design are summarized in Table 1. Important commonalities impacting urban analysis are technical factors such as the high-precision, high-density observational networks for greenhouse gas and meteorological measurements, tiered measurement opportunities, and flexible instrumentation and monitoring campaigns. Figure 7 illustrates a tiered measurement approach composed of surface-based observations, instrumented aircraft campaigns, and remote sensing satellite data.

Table 1. U.S. Urban Greenhouse Gas Measurements Testbed Sites Similarities and Differences

Indianapolis – Estimate Fluxes with Uncertainties of ~10 %	
Geography/Meteorology:	Flat terrain, robust meteorology, atm. dynamics most easily modelled
Population (estimate):	2 Million
Human Emissions:	Transportation, buildings, industry, power generation, landfill, natural gas system (CH_4)
Biosphere Fluxes:	Large seasonal fluxes – agriculture outside the city
Ground-based Observ.:	GHG towers for CO_2, CH_4, CO, and flasks; Doppler lidar; 4 eddy flux measurements for surface energy exchange
Los Angeles – Develop Methods to Diagnose Emission Trends	
Geography/Meteorology:	Atmosphere trapping terrain, ocean effects, difficult meteorology to model
Population (estimate):	16 Million
Human Emissions:	Transportation (land and sea), buildings, power generation, and manufacturing
Biosphere Fluxes:	Investigation of significant dairy production in the eastern Basin – manure management & CH_4 emissions
	Can eddy flux help with surface energy exchange?
NE Corridor – Estimate Fluxes with Uncertainties of ~10 %	
Geography/Meteorology:	Significant influence of Chesapeake Bay, wetlands, and rivers
Population (estimate):	6 Million in Washington/Baltimore Region 40 Million in major cities areas
Human Emissions:	Transportation, buildings, power generation, and manufacturing
Biosphere Fluxes:	Large seasonal fluxes, forest & wetlands influences

Further information on INFLUX was provided by K. Davis and on LA Megacities by C. Miller and R. Duren.

In contrast to the urban GHG measurements, the presentation by S. Hamburg with the Environmental Defense Fund, discussed methane case studies that focused on emissions from the natural gas supply chain. The campaign, Figure 8, was coordinated in major U.S. cities involving wide participation from academia, government, and the private sector.

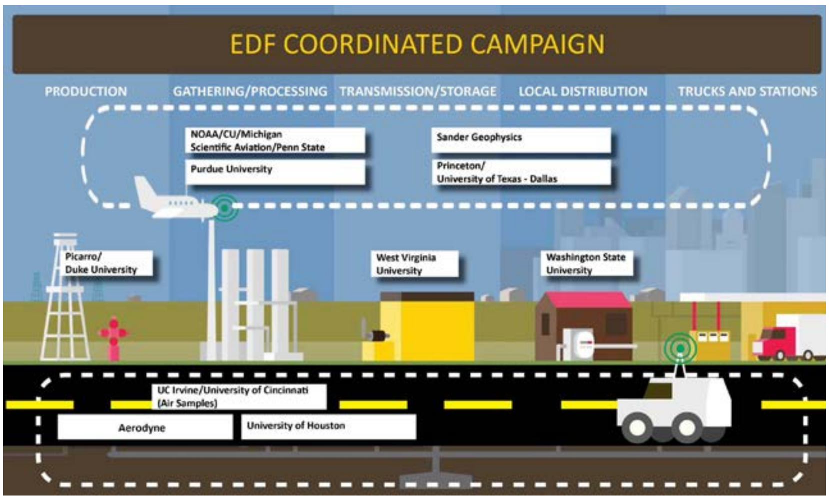


Fig. 8. Coordinated Campaign approach of the Environmental Defense Fund to investigate methane leak characteristics of the U.S. natural gas value chain from well-head to consumption.

Presentations in this session emphasized the global nature of future international mitigation efforts and the need for a consistent greenhouse standards and measurements framework to implement and manage such an effort where emissions data are anticipated to receive more international scrutiny. Figure 7 is illustrative of a tiered and integrated measurement approach and was discussed by several presenters. Accurate and effective emissions measurements at the urban scale and at temporal scales that are significantly below those of current emissions inventory reporting practices, represent measurement challenges using currently available instruments. For maximizing fidelity and minimizing uncertainties, measurements require improved technical capabilities and modelling to achieve accurate atmospheric measurements at these spatial and temporal scales. The expertise needed is relatively broad, requiring participation from a range of technical disciplines, and to support urban networks, a range of technologies are needed, each providing complementary information to cover geospatial scales from the local to the global level.

Technical challenges arise from dense urban regions and complexities of atmospheric dynamics. In particular, higher accuracy simulation of the dynamics of the planetary boundary layer (PBL) and the lower troposphere are a critical need of the atmospheric inversion analysis systems used. These pose additional complexities to the already challenging task of measuring greenhouse gas mole fractions in the field at near state-of-the-art laboratory levels. Progress is evident in many metropolitan regions. Each speaker gave detailed information on major urban programmes being conducted. A robust measurement system will enhance consistency, support transparency and accuracy, and ensure compatibility and comparability. Furthermore, improvements in emissions data quality and measurement methodologies will serve to strengthen national inventories and global GHG emissions data. Equally evident was the need to establish an overarching framework that builds upon various investigations made by cities and that may serve to structure best practices being identified for different urban environments. During the discussions, participants spoke of the importance of a robust framework and detailed technical guidelines for urban GHG metrology.

3.3 Global to Urban GHG Measurements Framework Concept

3.3.1 Megacities and Metrology Needs for Supporting Greenhouse Gas Mitigation: Urban Greenhouse Gas Flux Quantification (Session IIIa)

Session IIIa background

An initial goal statement for this session, with some questions to consider and elaborate upon, were presented to encourage discussion of opportunities and challenges associated with the development of an international greenhouse gas standards and measurements framework concept. Several presentations given on Day 1 of the workshop discussed viewpoints aimed at encouraging nations to participate in a global, integrated–greenhouse gas standards and measurements system to support future international mitigation efforts. This session emphasized the geospatial scales of cities, consistent with the identification of individual emission sources and sinks. Initial discussion focused on urban greenhouse gas measurements testbeds, and approaches to advance measurement capabilities that are robust, scientifically sound, and demonstrated to be useful in urban settings. Such capabilities are currently beginning to reach a level of capability consistent with provision of data, with uncertainty estimates, useful for independent diagnosis of inventory data and information. The global nature of GHG mitigation issues, ranging from global and continental scales to those found in urban settings, emphasizes the need for jointly developed, internationally-recognized advances in measurement science and technology by academic, governmental, and non-governmental contributors.

Session IIIa Summary of Presentations

Session presentations from the first and second day of the workshop described research efforts that are either being planned or are currently operating in urban areas. Presentations began with specific information on three major metropolitan cities, Paris, Los Angeles, and São Paulo. Additionally, greenhouse gas measurement activities in China and the UK were presented to broaden perspectives and provide a better understanding of research efforts in progress. Researchers in these cities have adopted, or are planning, similar approaches, mostly based on atmospheric inversion methods, perhaps augmented by additional approaches that reflect the unique nature of their locations and emission characteristics or of their experimental capabilities. This commonality of approach relies upon real-time mole fraction measurements coupled with meteorological measurements taken in the planetary boundary layer (PBL) to provide the input data for atmospheric inversion analysis. Satellite observations using data from the Orbiting Carbon Observatory 2 have been a component of the LA Megacity research from its conceptualization. It was reported that efforts in Paris will also begin using such data. In Brazil, a strong air quality activity will be allied with greenhouse gas measurements. This joining of usually separate communities may prove to be an important development in future research efforts, and in establishing longer-term monitoring efforts.

IIIa: Megacities and Metrology Needs Supporting Greenhouse Gas Mitigation: Urban Greenhouse Gas Flux Quantification

Presentations:

Phillipe Ciais (LSCE)	CO_2 emissions from Paris using atmospheric measurements
Riley Duren (JPL)	Los Angeles Megacity Project
Fatima Andrade (USP)	Towards a Megacity Project in Brazil
Irène Xueref-Remy	Paris Measurements
Gregoire Broquet	Satellite Imagery to Monitor Large City Emissions
Liang Zhang	Summary of Activities in China
Tom Gardner	Summary of Activities in the UK

Greenhouse gas mole fraction observations are usually obtained from land-based and tower-mounted sampling systems monitoring CO_2, methane, water vapour, and, in some cases, carbon monoxide mole fraction in the atmosphere. Inversion-based methodology is currently the major approach under development for both identifying and quantifying greenhouse gas flux to and from the atmosphere in urban applications. Some utilize a single sampling point altitude on a tower and others utilize multiple sampling points to obtain some measure of mole fraction gradients. Some efforts are augmented with aircraft-based mole fraction observations of greenhouse gas profiles coupled with wind speed/direction measurements. Aircraft-based measurements generally extend through much of the PBL into the lower troposphere. In some cases, a variety of remote sensing approaches are used to augment *in situ* mole fraction measurements.

Atmospheric inversion methods have been applied to geospatial scales ranging from the global atmosphere to those of urban areas and are concerned with the determination of atmospheric flows or fluxes. Pertinent to this discussion are those of atmospheric constituents at low concentration level, e.g., greenhouse gases, particulates, etc. that are trace components of the atmosphere, but have significant impact in such areas as human health and the Earth's climate.

The terminology 'urban dome' is at times used to describe the phenomenon of increased greenhouse gas concentrations found immediately above and around urban areas resulting from increased greenhouse gas concentrations caused by aggregation of emission fluxes found in these areas of high human activity. This terminology is most often used to characterize cities that exhibit meteorological characteristics resulting in the capture and stagnation of the local atmosphere in and above the city. Prominent examples of this are Los Angeles, California and Mexico City which have long been the focus of extensive air quality – related measurement and regulation. By contrast there are many cities of varying sizes that are characterized by terrain where the atmosphere near the city is not captured. These cities aggregate greenhouse gases forming plumes down wind. These are often termed plumes cities. Paris, Indianapolis, and London might be characterized as plume cities, whereas the meteorology of both Los Angeles and São Paulo would be termed dome cities.

Atmospheric inversion analyses applied to global and continental scales require state-of-the-art greenhouse gas mole fraction measurement data and rely on traceability to greenhouse gas mole fraction standards provided by the WMO Central Calibration Laboratory at NOAA's Global Monitoring Division, Boulder, Colorado. These standards are linked to the International System of Units through multiple, frequent comparison with NIST. Inter-comparison efforts administered by the WMO's Global Atmosphere Watch also bolster the consistency of greenhouse mole fraction measurements globally. It was noted that mole fraction measurement requirements in some urban environments may not be as stringent as those for global and continental applications because the GHG variability in urban applications is considerably larger than at the global scale. This is particularly the case for 'dome' or 'capture' cities. In Los Angeles, integrated emission signals have been routinely reported in the range of 400 to 700 µmol/mol, a variability on the order of 200 to

300 µmol/mol. By contrast, in the INFLUX research this variability, out-flow concentration from the city minus in-flow concentration is in the range of a few µmol/mol to approximately 20 µmol/mol.

Discussions provided valuable insight into existing practices and differences of approach. Striking differences between programmes noted were driven by the differing conditions of the urban environment and societal needs, as reflected in existing local legislation. In addition to unique national infrastructure of a city, factors such as geography and climate, population density, extent of urbanization, land use and influence of the local and regional weather played a vital role in assessing GHG emissions and flux.

3.3.2 Session IIIa Discussion

Several topics and questions concerning greenhouse gas emissions and monitoring approaches were discussed in the context of a global to urban measurement system framework similar in concept as discussed in the preceding sections of this report. Subsequent discussions pointed to the importance of GHG flux determination and that flux was the main quantity of interest in many investigations, particularly since inventory data is by its nature that of a flux to or from the atmosphere. It was further stated that flux to or from the atmosphere is the central focus of effective mitigation efforts.

a) Measurement System Framework

For successful development of a measurement system framework, several themes emerged in the discussion.

- The need for compatibility and comparability of results for meaningful integration of scientific investigations to effect mitigation policy. In support of consistency, topics discussed ranged from the greenhouse gas mole fraction standards upon which measurement results are based to the flux estimates themselves and the requirement for uncertainty estimates in those values.
- Global and urban atmospheric monitoring are required as a metric for an effective global mitigation strategy. Effective integration of measurement approaches and results ranging from global to local geospatial scales need to be realized and demonstrated.
- Urban methodologies are focused on emission attribution as a means of identifying entities responsible for emissions or uptake and the attendant responsibilities.

b) Performance Needs

Several issues for such a framework were discussed resulting in the following observations:

- Because many methods independent of source/sink properties are based on observation atmospheric state, there is a need to disentangle, or differentiate, anthropogenic emissions from those of the primarily biogenic, natural background. Both have significant temporal and spatial variability, placing significant constraints on the performance of these measurement systems.
- Since emission credits are often associated with biogenic sinks, accuracy requirements for both sources and sinks are similar.
- Developing a framework that includes methodologies that give consistent and accurate results ranging from the global to the local or urban geospatial scales are central to discussion of an integrated GHG measurements framework supporting mitigation implementation.
- Correct and sufficiently accurate simulation of atmospheric dynamics from the surface to the mid- to upper-troposphere is critical to atmospheric inversion and other source-independent methods. Improvements in the performance of models simulating lower atmospheric dynamics seem to be needed.

- Methods to compare measurement results from different approaches for determination of GHG mole fraction in the atmosphere, e.g., comparison of path integrated techniques (satellite and other remote sensing observation techniques) with the fixed location methods currently used in atmospheric inversion methods;
- The need for operational requirements that are useful for WMO recommendations regarding eventual deployment of GHG observing networks.

During the discussion period, several additional questions were raised related to potential implementation of an observing framework based on cities.

- How many cities would be needed in a measurement framework to have monitoring capability to capture approximately 80 % of anthropogenic GHG emissions?
  How many types of cities should be characterized to capture the range of cities needing monitoring capability?

c) Organizational Issues and challenges for National Metrology Institutions

The following issues were raised:

- Acceptance and recognition by the UNFCCC, nations and other international organizations,
- Host nation participation in and resource allocations supporting an inherently global concept,
- Non-host nation participation, and
- The need for a coordinating organization or organizations.
- Not a traditional metrology issues and most/all NMI's will have limited technical expertise.
- Potentially a new regulatory responsibility role requiring development of significantly new technical expertise.
- Gaining collaboration with governmental agencies and academia in their respective nations.
- Explanation of the role and benefits of the international metrology system.

In the context that a relatively few urban locations will be needed, what constitutes host nation participation, e.g., issues of financial cost and integration and availability of the necessary technical expertise was discussed. Other issues to consider are the development of integrated measurement capabilities supporting an internationally – recognized monitoring system and the organizational issues involved with establishing such a capability.

d) Atmospheric Inversion Methods

Atmospheric inversion methodology seeks to determine GHG flux to and from the atmosphere and has the potential to support emission source/sink attribution. Inversion analysis yields estimates of GHG flux based upon prior estimates, modified by GHG mole fraction measurements at specific points near the surface coupled with simulation of atmospheric dynamics and optimization methods. Because most emission sources and sinks are generally located within 200 to 300 metres of the surface (typical of smokestacks and taller buildings), high fidelity simulation of lower atmosphere dynamics is fundamental to accurate determination of source location and flux in urban applications. The major components of the atmospheric inversion methodology discussed were the following:

1. Emissions data obtained from the GHG emission source/sink source composition of the region of interest.

   Such data is obtained from a range of information sources, a primary one is the national greenhouse gas emissions inventories provided by nations in compliance with UNFCCC emissions reporting requirements. These are submitted yearly to the UNFCCC and include a range of economic sectors for a nation as a whole. Because atmospheric inversions have geospatial and temporal scales that are often considerably smaller than a country or a year, significant effort by primarily the research community has focused on developing and using estimation methodologies that provide emissions estimates at considerably smaller scales. These estimation methods draw upon national inventory information and other sources. [e.g. EDGAR, Vulcan, and Hestia.]

2. Measurements of mole fraction (including isotopic and similar tracers) of the greenhouse gases of interest, primarily CO_2 and methane.

   Mole fraction observing systems are comprised of a combination of primarily airborne and surface-mounted platforms. The latter often on existing communications or similar open lattice-work towers of varying heights. Sampling of the atmosphere occurs at several heights along a tower through a sample line manifold connected to high-accuracy GHG mole fraction measurement instruments housed at the tower base. Mole fraction standards are often employed to frequently calibrate the observation instruments.

   Airborne platforms are generally light aircraft capable of ascending to altitudes of 3000 to 4000 metres and carrying the same type of instruments as those used in surface-mounted platforms. In both cases, cavity ringdown spectroscopy-based instruments have become dominant over the last decade, bringing greater degrees of performance and temporal stability relative to previous generations of instrumentation.

   Accuracy requirements are quite challenging, requiring near state of the art accuracy in a field environment. Accuracy requirements for global atmospheric monitoring are published by the Global Atmosphere Watch (GAW) and rely on working standards linked to the WMO's Central Calibration Laboratory, the Global Monitoring Division of the U.S. National Oceanic and Atmospheric Administration. These in turn are linked to the SI through frequent comparative measurements with NIST, who engages with other NMIs and the GAW in international comparisons. Mole fraction measurement accuracy requirements that are suitable to support atmospheric inversion analysis in urban environments remain a point of discussion, as this is an active research area. Because the range of mole fraction values observed in urban settings is considerably greater than those seen in monitoring of the global atmosphere, mole fraction accuracy requirements in urban settings are thought to be less stringent.

3. Determination of greenhouse gas transport in the lower atmosphere, the planetary boundary layer into the lower- to mid-troposphere.

   Atmospheric dynamics at local scales are typically obtained from weather simulation models, e.g., the Weather Research and Forecasting Model (U.S. National Center for Atmospheric Research), the Integrated Forecasting System (European Centre for Medium-Range Weather Forecasts), or similar models. Accuracy of simulation results are gauged relative to meteorological parameter measurements. These are primarily taken at 1 to 2 metres above ground level consistent with WMO requirements for weather observing stations. In the case of aircraft platforms, some have a means of determining atmospheric velocity local to the plane and are referenced to GPS coordinates.

4. Analysis and modelling methodologies

   Inversion analysis methods are comprised of three main components 1) transport modelling, 2) backward time trajectory analysis, and 3) statistical optimization methods. The various approaches enjoy active research efforts: discussions indicated that to date none exhibited clear advantage over others. This is particularly the case for urban applications, which is a relative new application to that at the global scale.

5. Network design – flexible and applicable to all city types

   Design of observing networks suitable for urban settings relies upon various approaches associated with atmospheric inversion methods. Urban observing networks are considerably denser than those currently used for global monitoring. Global monitoring observation stations are primarily sited at high altitudes to sample the well mixed atmosphere. (Well mixed in the sense that spatial variation in GHG and other trace atmospheric constituent mole fractions are very small and can be considered to be indicative of the atmosphere as a whole). This topic also remains an open area of research. The several research efforts discussed above are expected to improve design methods. It is anticipated that as these gain greater maturity, improved insight into network design will result.

A consistent theme in these discussions was the concept of a tiered and integrated greenhouse gas measurements framework promoting consistency and compatibility of measurement results across the range of geospatial temporal scales. It was noted that advances in such a capability will have a beneficial effect of both advancing understanding of carbon science as well as providing an independent method to assess and diagnose the accuracy of emissions data and, perhaps with a sufficient level of capability, provide a means to produce emissions data in regions where such is not available from alternative means nor is likely to be. Demonstration of compatibility of results across the scales remains an important measurement science research challenge.

3.3.3 Session IIIa Recommendations and Conclusions:

This session examined standards and measurement issues anticipated for the urban portion of a tiered and integrated greenhouse gas measurements framework spanning the global to local geospatial scales. Although several approaches are active lines of research, currently atmospheric inversion methods dominate attempts to utilize atmospheric observations to identify emission sources and estimate their flux to the atmosphere. Urban greenhouse gas quantification research efforts currently under way in several countries were useful in identifying common challenges and practices. Clearly the current state of these efforts places them in the measurement science research category. Although the results of these research efforts continue to show good results and some of these results and practices will quite likely advance further, it is too early in the research effort to develop comprehensive recommendations suitable for operational use.

In summarizing the discussions, several themes emerged.

1. Global to Urban Concept, A tiered, integrated greenhouse gas measurements framework

   Most of the discussion revolved around various aspects of a framework concept that was supported by a number of presentations on the first day of the workshop and of this session. Portions of a tiered greenhouse gas measurements framework concept exist. High accuracy monitoring of the global atmosphere began in the late 1950s. Those capabilities have expanded internationally, involving several nations that operate observing stations around the globe, cooperate under the auspices of the WMO, and provide the atmospheric research community and others with high-quality data. However, these continue to represent a standards and measurement challenge. Global monitoring is an important and foundational part of a tiered concept. Measurement capabilities and support extension of spatial coverage from the global to the local scale and temporal coverage at the daily to monthly level require the development and demonstration of additional capabilities. Such capabilities range from remote sensing approaches, utilizing satellite, airborne, and surface-based methods, to surface-based methodologies capable of measuring emissions at regional and local scales. Demonstration of consistency and comparability of measurement results across the entire framework, from local to global geospatial scales, is a critical component to the successful realization and utilization of such a framework.

2. Best practice guidelines supporting an urban measurement framework

   Measurement approaches should be considered in the following areas:

   - Emissions inventory data at temporal and spatial scales compatible with urban systems that are tied to national inventory information should be developed;
   - Greenhouse gas mole fraction measurements and ancillary tracers/isotopologues, to assist with the disentanglement of anthropogenic and biogenic sources and sinks.

3. Atmospheric inversion methodologies

   Atmospheric inversion methodology was discussed extensively. Clearly there is a need to improve atmospheric transport measurements and modelling capabilities for the lower atmosphere.

   Inversion methodologies are an important component at regional and urban scales. Various aspects of inversion methodologies were identified as needing improvement.

   - Meteorological simulators and models – These provide the atmospheric transport information necessary to obtain flux estimates. Currently, their performance is thought to be a significant contributor to the overall uncertainty of the inversion method.
   - Standardization in the use of these complex model tools is needed to support consistency and comparability. Uniformity of inputs and sub-model/parameter selection are needed.
   - Concurrent wind speed and direction data is needed over a range of atmospheric levels ranging from the boundary layer to the mid-troposphere.
   - Mole fraction measurements and standards are a relatively mature capability. However, urban applications result in higher levels than those seen in global monitoring. Mole fraction standards in these ranges will be needed. Significantly increased demand for these artefacts standards may present a challenge to the international metrology and WMO community.

4. Remote sensing – satellite, airborne, and surface-based

   Remote-sensing capabilities continue to improve. Satellite-based capabilities forecast for the coming decade will quite likely broaden the coverage of these systems that appear to be focused on realization of spatial sensitivity at the few square kilometre level. Should a new generation of less costly satellites operated by many nations become available, comparability of data from these sources will become important. Within the tiered measurement system concept on orbit calibration of satellite instruments will be facilitated by a system of well-characterized greenhouse gas emission regions on the air surface. Large cities, megacities, are an obvious choice for this application. Airborne and surface-based remote sensing capabilities will likely augment atmospheric inversion methodologies applied to urban and similarly-sized regions. The latter has potential to support improved measurement capabilities needed for land use, land change and forestry applications. Furthermore, methods are needed to accomplish synthesis and integrate the results from different measurement methods operating at urban scales, e.g., relating path integrated mole fraction measurements, generally from remote sensing methods such as satellite observations, to surface-based observations.

5. Emission Source Attribution

   The implementation and sustained management of greenhouse gas mitigation activities, particularly the continued management of these, will be greatly aided by the ability to identify those controlling and responsible for emissopms. Additionally, there is a need to substantiate emissions reduction target achievement in an objective and scientifically defensible manner. Identification and estimation of fluxes from previously unknown sources has been and continues to be an important capability. Mitigation efforts will likely utilize forms ranging from market – driven to regulatory – driven approaches. Across such a policy spectrum, fairness of regulation and/or harmonious market function based on confidence in emissions data is an important consideration.

6. Role of Organizations

   Further concept development will require participation by experts in several scientific disciplines, representing expertise from different regions of the world. Organizations such as BIPM and WMO are well position to coordinate and conduct future activities in developing such a standards framework at the urban scale and to ensure compatibility and comparability with global operations.

The BIPM and NMIs are well positioned to ensure that mole fraction observation data is properly related to and linked to the WMO Central Calibration Laboratory and supported by direct linkage to the International System of Units;

Should the urban greenhouse gas measurement system research continue to expanding capability at the very stringent accuracy levels, they may require examination of approaches for providing these vital measurement standards that underpin system measurement consistency.

3.4 Standards for GHG Emission Inventories (Session IIIb)

3.4.1 Session background and aims

The purpose of this session was to:

- Summarize the existing position of reporting from all levels (installations, projects, cities, countries)
- Highlight the biggest areas for improvement, by answering the following questions:
    - Are uncertainties reported? Where are the uncertainties largest?
    - What new project types should inventory development be focused on?
    - Where are new/more granular/more specific emissions factors required?
    - Where is there a need for better consistency?
- Discuss the opportunities and challenges for incorporating forest carbon, soil carbon and land use into inventories of all kinds.

IIIb: Standards for GHG Emission Inventories

Presentations:

M. van Staden (ICLEI)	The Global Protocol for Community-Scale Greenhouse Gas emission inventories (GPC)
M. Linder (EFI)	Monitoring carbon emission from forests and wood products
B. Kofi-Lefeivre (JRC-ISPRA)	MRV GHG Emissions: New challenges when downscaling global to urban inventories

Three separate discussion groups tackled the following issues:

1. City inventories and support urban climate action
2. Forests and land use
3. National inventories

The outputs of these discussions are summarized in the sections below. Each group prioritized three specific areas for action, identified potential barriers to achieving improvement in those areas and recommended actions for the NMI community to progress these areas.

3.4.2 Recommendations: City inventories and support of urban climate action

This work-stream acknowledged the overlap with parallel session IIIa on top down measurements of city emissions and hence did not cover that part of the topic.

The issue: cities are in various stages of developing their own inventories. The city-networks, such as ICLEI and C40, have consolidated their approaches to city inventory compilation into the Global Protocol for Community Scale GHG emissions. The needs now are:

- Activity based inventory
- Local ownership
- Develop action plans
- How to link city inventories to the national inventory

- Measurement at a granular level to help mitigation actions – what policies should be implemented and what are the impact of these policies once they are implemented?

Actions identified for NMIs:

- Engaged to help drive uniformity
- Maintain dialogue with cities and representative bodies to enable NMIs to be reactive to new challenges and needs
- Enable the use of low cost sensors
    - Data quality improvement
    - Network design
    - Characterization
    - Uncertainty on information derived from network's heterogeneous sensors

3.4.3 Recommendations: Forests and land use

i. Improved ground truthing of satellites

The issue: The measurements are not intrinsically difficult, but more ground truthing is required, mainly aimed at deforestation and REDD monitoring. Difficulties around sampling design and difficult terrain.

ii. Impact of disturbances

The issue: How to quantify effects of fire/pests? These things are not included in the inventory. If there is a fire, how can we determine how much carbon is combusted? What are the impacts on soil carbon?

iii. Traceability of *in situ* measurements

The issue:

- Make different sensors/ instruments comparable
- Bringing metrological uncertainty analysis and rigour to the whole chain: ground truth to satellite raw data to algorithms to information supplied in the product

Actions identified for NMIs:

- Reach out to communities: TOPC and MRV
- Provide traceability for service providers e.g. airborne lidar

3.4.4 Recommendations: National inventories

i. Support developing countries to move away from using default emissions factors in their inventories

The issue:

Developing countries use default emissions factors provided by the IPCC guidelines. These are often not representative of their emissions profile as they are usually based on the emissions factors that have been developed for use in developed countries with different conditions. The particular areas in which default emissions factors are deemed to be least appropriate for local conditions are: livestock, non-livestock based agriculture (e.g. N_2O from fertilizer use), and N_2O and CH_4 emissions from combustion. Fuel quality data may also be difficult for developing countries to obtain, which will affect all combustion emissions factors.

Actions identified for NMIs:

- Produce more specific factors that are regionally representative
- Document the research so that (a) countries that want to prove that these factors are more relevant to them than the default factors have evidence to do so and (b) so that the factors can be added to the database of factors the IPCC guidelines points to, so they can be used by a wider range of countries
- Capacity building with local institutions
- [BIPM] communicate with policy makers in countries that do not have NMIs about the importance of measurement and the availability of expertise in the NMI community
- Liaise with international aid agencies for funding for this activity

Barriers:

- Even if they have the specific emissions factors, can developing countries get the activity data? Is this more of an issue for them (larger contributor to the uncertainty)?

ii. Produce up to date and/or more granular emissions factors for non-CO_2 gases in particular sectors

The issue:

Some areas of developed country inventories are lacking sufficient emission factors to support policies to reduce emissions. Specific areas of note include: landfill emissions factors and oxidation rates in different climatic zones, waste water (although this is a small source of emissions), gas distribution (this will be very specific to each country), domestic gas leaks at the householder side of the meter (this could be very small but no one knows).

Actions identified for NMIs:

- Review UNFCCC inventory reports from various countries to determine priority areas (high uncertainty + large percentage of inventory)
- Speak to the local inventory agency (usually a government body) to identify their priorities and make them aware of NMI expertise
- Write best available technique guidelines and include instrument manufacturers in the formulation of these
- Work with NGOs (like EDF in the US) and funding agencies to highlight where measurement campaigns would add the most value

Barriers:

- NMI awareness of the issues and priorities
- Funding for development of new emissions factors
- The need in some sectors for companies to volunteer sites which leads to data confidentiality issues

iii. Complete cost-benefit analyses for climate-related interventions to enable prioritization of action areas

The issue:

Many people who would benefit from better measurement or calibration practices are resistant to implementing them due to costs.

Actions identified for NMIs:

- Compile examples of how poor measurement practices can result in bad consequences (inability to implement regulation, inability to measure the impact of policies or changes to process etc) and how good practice leads to beneficial impacts (support for increased quality of life and economic benefit)
- Articulate methods of doing cost-benefit analysis for measurement projects so that the community can learn from one another
- Get stakeholder input at the source of funding to ensure real world challenges are being worked on and that the projects will have an impact

Barriers:

- Lack of knowledge in stakeholder organizations about what NMIs have expertise in and where they could help, along with lack of NMI knowledge of stakeholder challenges – general lack of interaction
- Temptation to listen just to the people who shout the loudest
- Suspicion of business interests.

4 Appendix 1: Workshop Agenda

Day 1 (Tuesday 30.06.2015) : Pavillon du Mail

9:00	***Session I: Introduction and Keynote Presentations***	
	Chair: M. Milton (BIPM)	
	Registration	
	Opening address by the BIPM Director	*M. Milton (BIPM)*
	Global Measurements of Essential Climate Variables	*A.Becker (DWD)*
	Tracking the World's Carbon	*J. Butler (NOAA)*
	Uncertainties and priorities in greenhouse gas inventories	*W. Irving (US EPA)*
11:00	**Coffee and Tea**	
11:30	**Session II: Carbon measurement and other related climate variables: Global systems, principals and traceability**	
	Chair: M. Milton (BIPM)	
	Background atmospheric carbon measurement and other related ECVs in WMO-GAW	*O.Tarasova (WMO)*
	Gas metrology for carbon surface measurements and other related ECVs	*R. Wielgosz (BIPM)*
	Space-based observations of Megacity GHG emissions	*C. Miller (JPL)*
12:30	**Lunch**	
14:00	**Reconvene**	
	Validation and calibration of GHG satellite observations by remote sensing measurements	*T. Warneke (TCCON)*
	Inverse estimates of greenhouse gas sources and sinks using regional ground-based measurement networks	*K. Davis (PSU)*
	Impact of GHGs: Measuring global temperature change	*P. Thorne (GRUAN)*
	Presentation of presubmitted abstracts and discussion identifying:	
	Priority of issue; timescale for action; groups best placed to act	
16:00	**Coffee and Tea**	
	Chair: J. Burston (NPL)	
16:30	**Session III: New Challenges - Metrology and Standard needs for GHG Emissions from Megacities and Emission Inventories**	
	A Megacity framework for GHG measurements	*J. Whetstone (NIST)*
	Challenges and opportunities in non-CO_2 GHG measurements and standards: Natural gas case study	*S. Hamburg (EDF)*
	Introduction to Day 2 of meeting	*J. Whetsone/J.*

Burston

17:45 Closure of Day 1

18:30 Leave for Workshop Dinner

Day 2 (Wednesday 01.07.2015)

Chair. J. Whetstone (NIST)

9:00 Session IIIa: Megacities and Metrology Needs for Supporting Greenhouse Gas Mitigation - Urban Greenhouse Domes (Break-out session: Pavillon du Mail)

Introduction to breakout session	*J. Whetstone (NIST)*
A first estimate of CO_2 emissions from the Paris city using an array of atmospheric CO_2 measurement sensors	*P. Ciais (LSCE)*
The Megacities Carbon Project	*R. Duren (JPL)*
Towards a Megacity project in São Paulo, Brazil	*M.F. Andrade (USP)*

10:30 Coffee and Tea

11:00 Reconvene

Presentation of presubmitted abstracts and discussion identifying:

Priority of issue; timescale for action; groups best placed to act

12:00 Lunch

13:00 Reconvene

Discussion on: future role of NMIs; potential barriers; recommendations

14:30 Closure of the session

Day 2 (Wednesday 01.07.2015)

Chair: J. Burston (NPL)

9:00 Session IIIb: Standards for GHG Emission Inventories (Break-out session: Pavillon de Breteuil)

Introduction to breakout session	*J. Burston (NPL)*
The Global Protocol for Community-Scale Greenhouse Gas emission inventories (GPC)	*M. van Staden (ICLEI)*
Monitoring carbon emissions from forests and wood products	*M. Lindner (EFI)*
Measurable, Reportable and Verifiable Greenhouse Gas Emissions: New Challenges when Downscaling Global to Urban Inventories	*B. Koffi-Lefeivre (JRC-ISPRA)*

10:30 Coffee and Tea

11:00 Reconvene

Presentation of presubmitted abstracts and discussion identifying:

Priority of issue; timescale for action; groups best placed to act

12:00 Lunch / Déjeuner

13:00 Reconvene

Discussion on: future role of NMIs; potential barriers; recommendations

14:30 Closure of the session

Coffee and Tea (Change meeting room)

Chair: M. Milton (BIPM)

15:00 Session IV: Report Back (Pavillon du Mail)

Global systems, principals and traceability- report back	*R. Wielgosz (BIPM)*
Megacities, Mitigation, Metrology - report back	*T. Wong (NIST)*
Standards for Emission Inventories - report back	*M. Sene(NPL)*

Chair: M. Milton (BIPM), with J. Burston (NPL) and J. Whetstone (NIST)

15:30 Session V: Engaging with key stakeholders in low carbon activity

Working with key stakeholders on metrological issues	*J. Whetstone (NIST)*
Using a carbon themed Centre as a mechanism for interacting with government	*J. Burston (NPL)*
Grouped issues and questions discussion (requested at the end of Day 1)	*J. Burston (NPL)*

16:45 Closure of the meeting

5 Appendix II: Abstracts of Presentations

Title: Background atmospheric carbon measurement and other related ECVs in WMO/GAW

Speaker: Oksana Tarasova

Institute: WMO

Session II: Carbon measurement and other related climate variables: Global systems, principals and traceability

Abstract:

The Global Atmosphere Watch (GAW) Programme of the World Meteorological Organization is a long-term international global programme that coordinates observations and analysis of atmospheric composition and related physical parameters changes. The programme is based on a collaboration of more than 100 countries and it relies fundamentally on contributions of its Members to help build a single coordinated global understanding of atmospheric composition and its change. Global greenhouse gas (GHG) observations and analysis is one of six focal areas of GAW. This area includes CO_2, CH_4 and their isotopes as well as N_2O, SF_6 and halocarbons. GHG observations and research within GAW are contributing to observational and research pillars of the Global Framework for Climate Services (GFCS). GHG observations are also required for implementation of the Integrated Global Greenhouse Gas Information System (IG3IS). GAW works towards integrated observations unifying measurements from different platforms (ground based *in situ* and remote-sensing, balloon, aircraft and satellite) supported by modelling activities. GAW observational network includes the stations that are not directly impacted by emission sources and that are regionally representative. The stringent requirements to quality of observations are evaluated at the meetings of experts on GHG measurement techniques every two years. GAW Quality Assurance/Quality Control (QA/QC) system relies on the set of Central Facilities supported by Members. These Central Facilities include in particular Central Calibration Laboratories (that support GAW network primary standard), World and Regional Calibration Centres (that ensure traceability of the station measurements to the network standards and network compatibility) and World Data Centre (that archives and disseminates GHG data and prepares data products). WMO/GAW collaborates with the Bureau International des Poids et Mesures (BIPM). NOAA, in the framework of an agreement signed between WMO and BIPM, participates in a number of BIPM key comparisons to establish a link of the GAW network standard to the other existing standards. Global Climate Observing System (GCOS) recognizes GAW coordinated observational networks for CO_2, CH_4 and N_2O as comprehensive (and their subset as a baseline) networks for these Essential Climate Variables.

Title: Gas Metrology for carbon surface measurements and other related ECVs

Speaker: R.I. Wielgosz (BIPM), JS. Kim (KRISS), P. Brewer (NPL), G. Rhoderick (NIST)

Institute: BIPM

Session II: Carbon measurement and other related climate variables: Global systems, principals and traceability

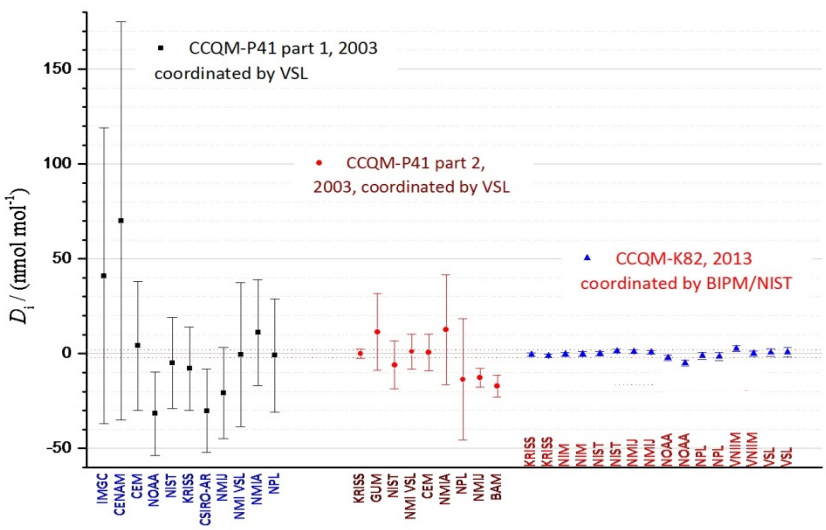
Abstract:

National Metrology Institutes (NMIs) provide gas standards for measurements at both ambient and emission levels, demonstrating their international equivalence through comparisons organized by the Gas Analysis Working Group (GAWG) of the BIPM's Consultative Committee in Metrology in Chemistry and Biology (CCQM).

These comparison activities, which have been running for 20 years, have allowed the equivalence of standards and improvements in reported uncertainties to be demonstrated both for long–lived greenhouse gases (GHG), including CO_2, CH_4, N_2O and SF_6, as well as precursors for ozone and aerosol formation including NO_2, SO_2, HCHO and CO. Since 2010, the WMO's Central Calibration Laboratory for the long-lived greenhouse gases, has participated in these comparisons, and joined the GAWG with its membership of thirty-three NMIs. At the same time a number of NMIs have agreed to take on the role of a Central Calibration Laboratory for other priority gases with the WMO's Global Atmosphere Watch (WMO-GAW).

The presentation will focus on research underway to reduce uncertainties for primary gas standards, notably for CO_2 CH_4, and N_2O. The result of these activities is that the uncertainties on primary standards from different institutes are approaching levels of uncertainty that meet the needs of even the most stringent long term monitoring requirements. This will be demonstrated with data from completed comparisons, where uncertainties in comparison measurements have also improved. The future CCQM GAWG programme of GHG standard comparisons will also be presented.

Results of CCQM GAWG Comparisons of Methane in air at nominally 2 µmol/mol over the last 10 years



Title: Space-based Observations of Megacity GHG Emissions

Speaker: Charles Miller

Institute: Jet Propulsion Laboratory, California Institute of Technology

Session II: Carbon measurement and other related climate variables: Global systems, principals and traceability

Abstract:

Over the last decade there has been tremendous progress in space-based observations of greenhouse gases (GHGs), and methodologies have been developed to disentangle natural and anthropogenic fluxes. Sampling strategies focused on megacity emissions monitoring have emerged as one of the primary ways to quantify and monitor anthropogenic GHG emissions. We will summarize the current state-of-the-art in space-based monitoring of megacity GHG emissions, and present an architecture for a global, integrated carbon observing system with traceability to international metrology standards.

Title: Validation and calibration of greenhouse gas satellite observations by ground-based remote sensing measurements

Speaker: Thorsten Warneke

Institute: University of Bremen

Session II: Carbon measurement and other related climate variables: Global systems, principals and traceability

Abstract:

Greenhouse gas fluxes can be inferred from atmospheric concentration measurements by inverse modelling. Until recently such inverse modelling studies were solely based on a network of surface *in situ* measurement stations. This approach is limited by the sensitivity of the flux estimates to vertical transport and by the sparse spatial coverage of the sampling sites. Remote sensing measurements overcome some of the limitations of the *in situ* network. Remote sensing measurements provide a column integral, a different kind of information than the *in situ* measurements. The column is not sensitive to vertical transport and space-borne sensors provide global coverage. Remote sensing measurements of the atmospheric CO_2 and CH_4 became available only 15 years ago. The accuracy and precision of the first greenhouse gas retrievals from these measurements were not sufficient for advancing the understanding the global carbon cycle. However, the situation has changed over the years and several publications have used remote sensing measurements to improve the flux estimates of these gases. It is expected that the quality of the remotely sensed greenhouse gas data will continue to improve and that these data will become increasingly important for constraining greenhouse gas fluxes. A critical point for the future success of the remotely sensed greenhouse gas data is its calibration against the *in situ* reference scale. The ground-based Total Carbon Column Observing Network (TCCON) plays a vital role for the calibration of the column measurements and the validation of satellite retrievals. TCCON records solar absorption spectra and measures the same quantity as the satellites. TCCON measurements can be directly compared to vertical resolved *in situ* measurements and this calibration can be transferred to the satellite retrievals.

Title: Inverse estimates of greenhouse gas sources and sinks using regional measurement networks

Speaker: Kenneth J. Davis

Institute: The Pennsylvania State University

Session II: Carbon measurement and other related climate variables: Global systems, principals and traceability

Abstract:

Inverse analysis of regional greenhouse gas (GHG) measurement networks have proven to be a successful approach to determining GHG total fluxes in addition to their spatial and temporal variability. Regional networks have been deployed in the U.S. for the North American Carbon Program Midcontinent Intensive (MCI) regional study, the state of California, the Indianapolis Flux Experiment (INFLUX), the LA Megacities project, the city of Boston, the Gulf Coast Intensive and the Marcellus Shale regional experiment, in addition to the background North American tower and aircraft monitoring network. I will present a brief review of the state of this field of research in addition to more detailed results from the MCI and INFLUX. I will discuss the methods used in these inverse flux estimates with careful attention to the uncertainties in the estimates, and the causes of these uncertainties. In both cases I will also present comparisons to detailed inventory estimates constructed specifically for these experiments. We find in general that the temporal variability in fluxes is relatively easy to detect, followed by net regional fluxes, and that spatial differences in fluxes require the highest fidelity in terms of measurement density and atmospheric transport modeling. I will also discuss ongoing efforts to introduce sector-specific GHG source estimates into our inversion system, and efforts to quantify and reduce atmospheric transport errors.

Title: Impact of GHGs: Measuring global temperature change

Speaker: Peter Thorne

Institute: Maynooth University

Session II: Carbon measurement and other related climate variables: Global systems, principals and traceability

Abstract:

If we are to understand climate changes and their causes then robust monitoring of the climate system changes is required. Historical measurements of the climate system have been undertaken for a variety of reasons by a broad range of public and private entities, groups and individuals. Early measurements were at the surface. Since the mid twentieth Century column measures using weather balloons have been undertaken and since the late 1970s sustained satellite measurements programs have been in operation. All of these observing systems have undergone substantive changes over time such that the record is not a homogeneous estimate of the true climate system evolution. Aspects such as change management, measurement characterisation and calibration / validation have either been missing entirely or grossly inadequate. The Global Climate Observing System (GCOS) Reference Upper Air Network (GRUAN) was instigated in 2005 by a diverse range of climate scientists. This network aims to create a long-term network of measurements of the column characteristics at a number of sites around the world that are well characterised and understood. Working with instrument manufacturers and metrologists in the intervening decade the network has transformed from an aspiration to a reality. This talk will summarize the rationale, guiding principles and progress to date before touching upon the work yet to come.

Session II: Carbon measurement and other related climate variables: Global systems, principals and traceability

Title: The Role of WMO in Developing a Space-Based Architecture for Climate Monitoring

Speaker: Wenjian Zhang, Jérôme Lafeuille and Stephan Bojinski

Institute: WMO

Abstract:

The development of an architecture for climate monitoring from space, formally initiated by the 16th World Meteorological Congress (Geneva 2011) received immediate response and strong support from space communities, including the Committee on Earth Observation Satellites (CEOS), the Coordination Group for Meteorological Satellites (CGMS), national space agencies, satellite operators. The architecture, respond to WMO Members' requirements and the requirements from WMO sponsored climate programmes and initiative like the Global Framework for Climate Services (GFCS), Global Atmosphere Watch (GAW), Global Climate Observing System (GCOS), and the World Climate Research Programme (WCRP), as well as broader user community (for example, Global Earth Observation Systems of Systems (GEOSS)) requirements on climate monitoring, calls for strengthening and enhancing international collaboration that ensures delivery of these observations over the time frames required for both: analysis of the Earth's climate system variables (including major GHG: CO_2, CH_4, H_2O, N_2O, O_3, etc.) over long-term , and monitoring climate extreme events in near real time. The architecture will initially build upon a constellation of research and operational satellites currently existing or planned programmes by space agencies, supported by open data-sharing policies, contingency planning, surface observations for validations and user interface seeking feedback, monitoring deliverables and meeting user-service needs. The task of climate monitoring, however, has requirements that must extend beyond the capabilities of one-time research missions and operational satellite systems in existence today. The role of WMO in developing the space architecture for climate monitoring will mainly the following:

1) Requirements Analysis and Consolidation: to set broader requirements for climate monitoring by consolidating the requirements from climate programmes and initiatives like IPCC, GFCS, GCOS and WCRP;

2) Promotion of climate data and products policy: The WMO 66th Executive Council (June 2014), adopted a resolution on "Exchange of data and products to support the implementation of the GFCS" with an annex defining climate relevant "essential data" for the purposes of implementing Resolution 40 (Cg-XII) and Resolution 25 (Cg-XIII);

3) Coordination on Space capability assessment, planning and implementation: WMO Space Programme will work together with CEOS and CGMS to define future CGMS baseline and CEOS Virtual Constellation meeting the needs of climate monitoring requirements, detailing missions and instrumentations, and coordinating the implementation; (iii) Fostering the collaboration with broader international partners and stakeholders, like BIPM, GEO etc., for building synergies of different technologies, including the integration of the surface-based with space-based observations by taking the advantages of the comprehensive surface observing networks from WMO Members, partners new technological development, and on-going as well as future space activities.

4) Data management, access and dissemination: The role of WMO Information System (WIS) in the space architecture development is to ensure timely accessibility of observations and products in compliance with agreed interoperability standards. Metadata, catalogue interfacing, and formats should be standardized in compliance with the WIS standards for WMO Members.

5) User interface and Feedback: WMO as an organization will be a natural user interface with its Members as the key end users community for climate monitoring and services should be maintained in order to seek feedback, monitor deliverables and use the products from the architecture for climate monitoring services. All WMO Members, relevant WMO Programmes, relevant UN agencies, international agencies & organizations and the general public, will benefit from the development of the architecture by using more timely products and information of climate monitoring from space.

Title: Overview of the 'Metrology for Climate' Workshop

Speaker: Nigel Fox

Institute: NPL

Abstract:

By the time of the BIPM conference, NPL will have run a workshop on 'Metrology for Climate' and I can update delegates on the outcomes of this workshop. The concept of 'Essential Climate Variables' (ECVs) provides a crucial systematic framework of variables to facilitate the monitoring and understanding of climate change. The ability to reliably detect trends from a background of natural variability requires decades of measurements, each with robust uncertainty estimates to enable the necessary long term Climate Data Records (CDRs) to be established. To generate trustable and robust climate data, it is essential that the metrology community develops a work programme to ensure its research outputs address the highest priorities in a timely manner. Early cross community dialogue is needed so that resources can be coordinated and allocated appropriately. There is, therefore, a need to prioritise each ECV based on its current level of focus from the metrology community and its potential impact to our understanding of climate change. The presentation will discuss the outcomes of an ECV prioritisation exercise with stakeholders. It will also suggest how this output can help the Earth Observation community to steer new research activities, prioritise investment and establish mechanisms for future interactions.

Title: Coordination of U.S. Civil Earth Observations: Assessing Earth Observations for Societal Benefit and Greenhouse Gas Monitoring

Speaker: Christopher Clavin, Jason Gallo

Institute: IDA

Abstract:

Globally, the United States Government is the largest provider of environmental and Earth-system data. These data support and provide numerous societal benefits to the U.S. and its international partners. The U.S. Federal Government is responsible for generating, curating, and rapidly disseminating Earth observations data for decision support by a wide range of stakeholders, from local community planners through international climate change researchers. In July 2014, the White House Office of Science and Technology Policy released the first-ever National Plan for Civil Earth Observations. The Plan describes the U.S. Federal Government's approach and priorities for

developing sustained and experimental observations for a multiple societal benefits including long-term climate monitoring. Earth observations supporting scientific understanding and the development of operational products that help identify the sources and sinks of greenhouse gases, including changes in short- and long-lived greenhouse gas emissions and concentrations over time are identified in the plan as a sustained Earth observation priority. In developing the U.S. National Plan for Civil Earth Observations, a U.S. Government-wide assessment of Earth observations was conducted in 2012. This Earth Observations Assessment (EOA) provided an objective and analytical basis for identifying the various societal priorities, including greenhouse gas monitoring, of the U.S. Earth Observation enterprise. The 2012 EOA reviewed the impact of 362 observing systems over 13 societal benefit areas spanning priorities such as agriculture and forestry, climate, disasters, terrestrial and freshwater ecosystems, energy and mineral resources, weather, and reference measurements and their associated standards that provide an underpinning for other societal benefit areas. U.S. Federal agencies are currently undertaking efforts to improve upon the EOA 2012 and develop a new EOA that will further identify the role that Earth observations play in supporting societal benefits. This session will provide a detailed overview of the greenhouse gas monitoring priorities described in the U.S. National Plan for Civil Earth Observations, a description of the current status and review of the process for conducing the on-going second Earth Observations Assessment, and provide a integrative review of the multiple types of Earth observations, including non-climate observations, that support greenhouse gas monitoring that identified by this comprehensive assessment approach.

Title: METROLOGY ISSUES IN ESTABLISHING A CLIMATE REFERENCE UPPER AIR NETWORK

Speaker: Tom Gardiner

Institute: NPL

Abstract:

The GCOS Reference Upper Air Network (GRUAN) is an international reference observing network, designed to meet climate requirements and to fill a major void in the current global observing system. Upper air observations within the GRUAN network aim to provide high-quality reference data to establish long-term climate records; improve the quality of data for numerical weather predictions; constrain and validate data from satellite remote sensors; and provide data for the study of atmospheric processes. The network covers measurements of a range of key climate variables. One of the primary goals for the GRUAN measurements is that all data is provided to users with traceable uncertainties. Establishing rigorous uncertainties for measurements in the upper atmosphere presents a significant challenge, particularly given the range of different measurement techniques involved, which include radiosondes, lidars, microwave radiometers, GNSS water vapour and FTIR spectrometers. The presentation will review some of the research activities being undertaken within GRUAN to address this metrological challenge.

Title: IAEA stable isotope reference materials: addressing the needs of atmospheric monitoring,

Speaker: S.Assonov, M.Groening, A. Fajgelj

Institute: IAEA

Abstract:

Stable isotope analyses of atmospheric CO_2 and methane are widely used in order to understand complex processes involved in the carbon cycle and to constrain carbon fluxes. To get reliable data supporting meaningful interpretation, all data of atmospheric monitoring have to be on the same scale and compatible within established limits. Presently compatibility goals for delta C-13 data of air CO_2 and air methane have been set at the level of 0.01 per mil and 0.02 per mil respectively. These challenging limits can only be achieved through the proper use of reference materials (RMs). Delta C-13 measurements are traditionally based on isotope ratio mass-spectrometry. Recently, optical laser analysers (both for CO_2 concentration and isotopic measurements) become available. Optical CO_2 concentration analysers being more and more in use for atmospheric measurements require a correction for CO_2 isotope difference between reference gases and samples. Therefore all reference gases in use have to be characterised for CO_2 isotopic composition, thus increasing the demand for suitable C-13 RMs.

For practical reasons all isotope measurements are performed on relative delta scales realized through the use of international, scale-defining RMs; in fact all these RMs are artificially chosen selected materials. The VPDB C-13 scale is realised via two international RMs (carbonates NBS19 and LSVEC) maintained and distributed by IAEA. The priority task is to maintain these highest-level RMs at the required level of low uncertainty, ensuring the long term scale consistency. The second complex task is to introduce replacement RMs when needed (currently needed for NBS19 being exhausted), and to do so with the lowest achievable uncertainty. The next task is to produce lower level international RMs (secondary, tertiary) being calibrated via the highest level RMs, and to determine their total uncertainty being traceable to the delta C-13 VPDB scale. There are three most urgent issues to be addressed at IAEA related to delta C-13 reference materials:

• ensuring small measurement uncertainty and long term stability of RMs in use for climate change related measurements and fulfilling associated metrological requirements;

• urgent need for introducing the replacement of NBS19 (delta C-13 scale defining RM), potentially also for LSVEC;

• the need for a range of RMs addressing existing and newly emerging analytical techniques (e.g. optical isotopic analysers) in form of calibrated CO_2 gases with different delta C-13 values.

The presentation will give an overview of the current status of the delta C-13 reference materials, the strategic plan of developments and steps for the near future.

Title: Traceability of Greenhouse Gas Measurements within the Global Atmosphere Watch Programme: Results from the World Calibration Centre WCC-Empa,

Speaker: Christoph Zellweger, Martin Steinbacher, Lukas Emmenegger, Brigitte Buchmann

Institute: Empa

Abstract:

Empa operates the World Calibration Centre for Surface Ozone, Carbon Monoxide, Methane and Carbon Dioxide (WCC-Empa) since 1996 as a Swiss contribution to the Global Atmosphere Watch (GAW) programme. WCC-Empa has conducted over 70 system- and performance audits over the past 20 years. This activity significantly contributes to sustain and improve the data quality required for climate and environmental research. The concept of the performance audits was recently expanded by the addition of parallel measurements with a travelling instrument using an entirely independent inlet system and calibration scheme. This presentation will give an overview of the results obtained during these audits with a focus on measurement capabilities. It will further highlight the advantages of the new performance audit approach based on recent CO_2 and CH_4 comparisons. Results from various stations acquired with different analytical techniques will be compared, and instrumental aspects such as water vapour interference as well as the influence of the calibration interval, data coverage, and aggregation times will be addressed.

References:

Rella, C. W., Chen, H., Andrews, A. E., Filges, A., Gerbig, C., Hatakka, J., Karion, A., Miles, N. L., Richardson, S. J., Steinbacher, M., Sweeney, C., Wastine, B., and Zellweger, C.: High accuracy measurements of dry mole fractions of carbon dioxide and methane in humid air, Atmos. Meas. Tech., 6, 837-860, 2013.

Zellweger, C., Steinbacher, M., and Buchmann, B.: Evaluation of new laser spectrometer techniques for in-situ carbon monoxide measurements, Atmos. Meas. Tech., 5, 2555-2567, 2012.

Title: Metrology for well-established and innovative isotopic measurements in climate change research

Speaker: Franz Josef Maringer

Institute: BEV

Abstract:

Stable and radioactive isotopes are increasingly measured to assess the causes and effects of climate change. The accurate measurement of environmental stable and radioactive isotopes advances in climate monitoring, modelling, prediction and management. The metrological resources for these isotopic applications have been weakly developed so far. Measuring and modelling water flow in the oceans and atmospheric transport models on a global scale by radionuclide tracer applications will contribute to the understanding of possible climate change scenarios. Radionuclide dating techniques are useful tools in the investigation of geological materials, where stable isotope ratios and the relative levels of uranium, thorium and lead isotopes reveal information about climate conditions prevalent at the time of deposition and dating of such materials. Measurements of ice cores reveal data about climate in the more recent past, especially where such cores contain ancient dissolved air. Again, stable isotope ratios are of key importance, but radionuclides arising from cosmic ray irradiation also reveal data concerned with both climate conditions and solar output. At present much data is collected from the Pacific Ocean, where traces of radionuclides from Fukushima reveal the paths of ocean currents (at different depths), which are crucial to understand for climate studies and the radiotracers also help the understanding of uptake in the food chain. The list of other possible measurements is long, but ^{210}Pb:^{210}Po, ^{81}Kr:^{85}Kr and ^{39}Ar are examples of radionuclides that can yield important information. Using ^{39}Ar for dating ancient underground water reservoirs would have implications for water resource management. Fossil CO_2 emissions can be monitored by ^{14}C measurements. The same technique can be applied to distinguish between the use of fossil or biofuel which benefit the European guidelines where CO_2 emissions from fossil fuel must be paid for to an increasing extent.

The measurement of radionuclides in environment (i.e. atmosphere, soils, oceans and sediments) provides valuable information on the study of climate change at short, medium and long-term scale. Some key topics are the following:

- The fallout of anthropogenic radionuclides as ^{3}H, ^{14}C, ^{90}Sr, ^{137}Cs and Pu isotopes can serve to date a number of short-term processes.

- ^{137}Cs/^{90}Sr ratios can be used to check for seasonal changes. - The radiotracers ^{41}Ca and ^{45}Ca are used to study calcifying rates in corals and other organisms.

- Cosmogenic radionuclides as ^{7}Be, ^{10}Be and ^{14}C can help to trace seasonal and long-term atmospheric processes but also to study the influence of solar activity in earth's atmosphere.

- The activity ratio ^{234}Th/^{238}U is used to assess the organic carbon flow in oceans and sediments. - Disequilibrium between ^{210}Pb and ^{226}Ra can be used as a chronometric indicator in several processes as rate of marsh accretion.

- The isotopes ^{230}Th and ^{231}Pa produced from the decay of uranium give important information on several key oceanic processes that have affected global climate in the past.

- The isotope hydrology of quaternary climate change can be estimated from the decay of the radioisotopes ^{14}C, ^{36}Cl and ^{81}Kr over timescales comparable to the ice core record.

To support the international climate change research with reliable and traceable measurements, there is an increasing need on metrologically sound reference data, standards, procedures, instrumentation and traceable calibration methods for isotopes important for climate control that require extremely low detection limits. Mass spectrometry, low-level activity measurement techniques and atom trap trace analysis (ATTA) should be also developed based on demonstrated superior selectivity and detection efficiency.

This contribution is based on the submission of a potential research topic PRT in the EMRP call 2013 'Environment II - global metrological challenges for climate control' submitted by 8 European research partners.

Title: Metrology for High Impact Greenhouse Gases

Speaker: Paul Brewer

Institute: NPL

Abstract:

Understanding the chemistry of the atmosphere and the mechanisms that control the levels of the gases involved in radiative forcing are of major global concern. Consequently, there is substantial demand from policy makers to improve our understanding, control the increasing influence of human activity on it and address the effects of climate change. There is a requirement for long-term observations based on accurate and stable standards of the highest impact greenhouse gases to ensure that the data meets the requirements of WMO DQOs compatibility goals, environmental policy makers as well as academic and regulatory users.

We have made significant advances in preparing high accuracy, SI traceable and fully- synthetic gaseous reference standards of carbon dioxide and methane in a whole air matrix. Current research aims to improve the uncertainty and stability of these reference materials by optimising passivation chemistry used in cylinder treatment, making high-accuracy quantification of target impurities in the matrix gas, characterising the isotopic composition of the target component and understanding its influence on measurements made in the field.

Title: A Megacity Framework for GHG Measurements

Speaker: J. Whetstone

Institute: NIST

Session III: New Challenges – Metrology and Standard needs for GHG Emissions from Megacities and Emission Inventories

Abstract:

Nations across the world are evaluating options for achieving energy security and limiting the potentially crippling impacts of climate change. Managing GHG emissions will be central to effective mitigation policies for all nations. Demonstrating the effectiveness of mitigation policies requires the ability to measure progress toward those targets with quantifiable measurements uncertainty smaller than the target values. Urban areas and megacities have localized energy needs and concentrated emissions sources that present challenges that differ somewhat from measurements of the global atmosphere. Thus, collective action and focus on cities has the potential benefit of leveraging resources and maximizing impact on much of a nation's population. Recent studies have shown significant differences among the various methods used to quantify greenhouse gas emissions in cities and urban areas through the NIST urban dome project. This initiative seeks to investigate the sources of these differences to identify approaches that can reduce or eliminate ambiguities and to use this knowledge as the means for developing measurements and standard methodologies of sufficient accuracy to diagnose the most commonly used methods for obtaining greenhouse gas emissions data.

Greater understanding of the underlying mechanisms controlling measurement and estimation approaches has additional potential to reduce uncertainty of emissions data. The levels of accuracy needed for these methodologies should be consistent with reduction targets set by individual nations. As centers of commerce, and communications, cities and urban areas intensify energy utilization and magnify climate variability in relatively small geographical regions. Thus, urban greenhouse gas concentrations will remain a significant issue for the remainder of this century. Emissions quantification, both spatially and temporally, will continue to be a significant technological challenge for these compact geospatial regions for years to come. Measurement issues and needs relevant to megacities will be discussed in the context of an international framework for greenhouse gas measurements and national standards coordination.

Title: Challenges and opportunities in non-CO_2 greenhouse gas measurements and standards: Natural gas case study

Speaker: Steven P. Hamburg

Institute: Environmental Defense Fund

Session III: New Challenges – Metrology and Standard needs for GHG Emissions from Megacities and Emission Inventories

Abstract:

The challenges of greenhouse gas measurement and standards are perhaps at their greatest when the spotlight is clearly focused on emissions monitoring. Over the past three years Environmental Defense Fund has coordinated a large measurement campaign involving 100 institutions – academic, government and private sector – focused on methane emissions from the natural gas supply chain in the United States. I will address

the challenges of making accurate and effective emissions measurements at a diversity of spatial and temporal scales, as required for effective regulation and mitigation. I will also review efforts to bridge the measurement and standards gaps that were required for affecting rapid improvements in emissions profiles. We believe this effort can serve as a model for both understanding associated impacts of the oil and gas industry and greenhouse gas emissions more broadly, as well as more broadly for innovative civil society collaborations.

Title: A first estimate of CO_2 emissions from the Paris city using an array of atmospheric CO_2 measurement sensors

Speaker: Philippe Ciais

Institute: LSCE

Session IIIa: Megacities and Metrology Needs for Supporting Greenhouse Gas Mitigation- Urban Greenhouse Domes

Abstract:

A pilot network of five CO_2 mole fraction atmospheric measurements sensors was established around the Paris city since 2010, and operated on a discontinuous basis until 2015 as part of research and innovation projects CO_2-megaparis and Carbocount-City. Hourly time series of atmospheric CO_2 mole fraction measurements are used to adjust daily to monthly fossil fuel CO_2 emissions of the Paris urban area, using a Bayesian inversion with priors. The ingredients of the inversion are

1) a first guess map of CO_2 anthropogenic emissions established from the emission inventory of the Airparif air quality agency with an a priori error estimate, and a first guess map of the biogenic flux of CO_2 exchanged between vegetated areas and the atmosphere, which can be a source or a sink of CO_2 with respect to the atmosphere,

2) observed CO_2 mole fraction atmospheric measurements and their uncertainties, arising from various sources, and

3) a 2-km horizontal resolution atmospheric tracer transport model over the Paris area that converts the signal of emissions into simulated mole fractions, this mesoscale model being nested into a global coarser grid transport model to obtain CO_2 atmospheric boundary conditions from outside the Paris area.

The inversion adjusts CO_2 fluxes (anthropogenic and biogenic) with a temporal resolution of 6 hours, assuming temporal correlation of emissions uncertainties within the daily cycle, and from day to day, while keeping the a priori spatial distribution from the first guess emission inventory. The inversion significantly improves the agreement between measured and modelled concentrations. However, the residual misfits between the measurements and the model are sometimes large compared to the measured CO_2 gradients between the sites that are used to estimate the fluxes, in particular for the CO_2 sensor located on top of the Eiffel tower station. These results suggest that the inversion has better performances when we use the measured upwind-downwind CO_2 gradients rather than the individual mole fraction measurements at each station. With such setup, realistic emissions are retrieved for a one year period. The uncertainty reduction on emissions obtained by the inversion will be discussed, together with the different uncertainty terms entering in the error budget of the approach, separating random errors and systematic errors that lead to biased emission estimates.

Title: The Megacities Carbon Project

Speaker: Riley Duren

Institute: JPL

Session IIIa: Megacities and Metrology Needs for Supporting Greenhouse Gas Mitigation- Urban Greenhouse Domes

Abstract:

Anthropogenic carbon emissions from cities and the demands they place on broader infrastructure represent the single largest human contribution to climate change. Many small areas with large fossil-fuel CO_2 and CH_4 fluxes are undergoing rapid change due to development, urbanization, energy sector transformations and/or climate mitigation actions. Meanwhile, flux estimation uncertainties at these finer spatial scales remain significantly larger than those at the continental and national scales addressed by traditional carbon estimation techniques. Improved quantification and understanding of underlying processes at the urban scale will not only provide policy-relevant information and improve the understanding of urban dynamics and future scenarios, but will translate into better global-scale anthropogenic flux estimates, and advance our understanding of carbon cycle and climate feedbacks across multiple scales. An observing system including a tiered set of surface, airborne, and satellite sensors can be focused spatially and sectorally to address these challenges. A thoughtfully crafted research program that is grounded in sustained, dense observations relevant to estimating urban carbon fluxes and their controlling processes and is focused on a statistically significant sample of cities will advance our understanding of the carbon cycle and support decision making. We describe the Megacities Carbon Project in Los Angeles as an example for developing and validating the integrated application of atmospheric observations from localized surface networks, aircraft campaigns, and satellites with an analytical construct for linking atmospheric information with the human activities that drive emissions. We present examples of preliminary observations from surface and satellite assets, space-time resolved emission data sets and describe challenges and future plans.

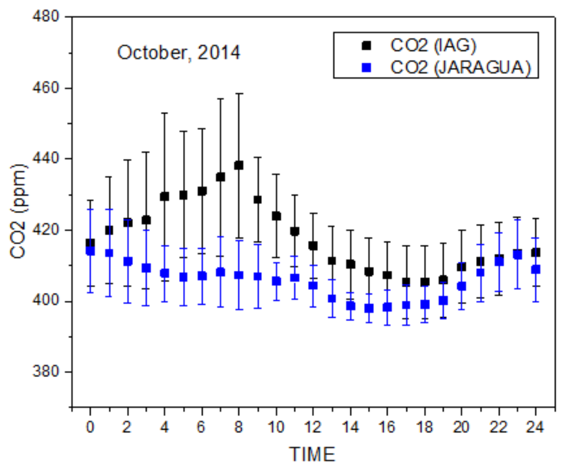
Speaker: Maria de Fatima Andrade

Institute: Institute of Astronomy, Geophysics and Atmospheric Sciences, University of São Paulo

Session IIIa: Megacities and Metrology Needs for Supporting Greenhouse Gas Mitigation- Urban Greenhouse Domes

Abstract:

The Metropolitan Area of São Paulo (MASP) has grown since the 50`s becoming the most important region concerning the economy for the country. The city is characterized since its foundation by economic activities as commerce and services. In the last ten years, many industries have moved away from São Paulo. The most important source of air pollution is the vehicular emission that is responsible for more than 80 % of the CO and VOC (Volatile Organic Compound) and more than 70 % of NO_x emissions. The most important pollutants regarding events of high concentrations are Ozone and Fine Particles (MP2.5). These regulated pollutants have been studied for many years and their time and spatial distributions are well described. But the long-lived species have been addressed based on estimative of emissions from the burning of fuels and biomass (forested and agricultural areas). Since 2013, the Atmospheric Sciences Department started the regular measurements of CO_2, CH_4 and NH_3 to address the following aspects: formation of fine particles and ozone, temporal variation of CO_2 and the evaluation of the emission inventory of short and long-lived species in the atmosphere. The São Paulo Megacity Project (SPMP) will address the gaps of measuring long-lived and short-lived species at the area and its related to the emission by the urban sources and the transport. Four components will be considered: measurements of ambient concentration, flux of CO_2 and CH_4, short-lived species and meteorological parameters; modeling of emissions in regional and local scale with satellite data evaluation of the emission data; modeling of dispersion and concentration; evaluation of impacts and risks. The MASP is impacted by the emission of 7 million vehicles, being 85 % light-duty vehicles (LDV), 3 % heavy-duty diesel vehicles (HDV)s, and 12 % motorcycles. About 55 % of LDVs burn a mixture of 78 % gasoline and 22 % ethanol (gasohol), 4 % use hydrous ethanol (95 % ethanol and 5 % water), 38 % are flex-fuel vehicles that are capable of burning both gasohol and hydrous ethanol and 3 % use diesel (diesel + 5 % bio-diesel). The use of ethanol as vehicular fuel has to be analyzed considering the whole process of production and consumption. The emission of ozone precursors and the impact to human health consist in one aspect of the question, and the balance of CO_2 due to the growth of sugar-cane plantation is another aspect. Due to the large emissions of CO_2 and other GHG gases by the transport sector, its contribution is important in a regional and global scale. Measurements of CO_2 were performed with a Picarro monitor based on WS-CRDS (wavelength-scanned cavity ringdown spectroscopy) for the years 2012-2013. The sampling site was on the University of São Paulo campus (22°34´S, 46°44´W), situated in the west area of the city, surrounded by important traffic roads. The average data showed two peaks, one in the morning and the other in the afternoon, both associated with the traffic. Correlation analysis was performed between the concentrations and the number of vehicles, as a proxy for the temporal variation of the CO_2 emission. The highest concentration was 430 ppm at 8:00am, associated to the morning peak hour of vehicles and the stable condition of the atmosphere. The average concentration was 406 ±12 ppm, considering all measured data. The measured data of CO_2 and co-pollutants will be compared with retrieved data from satellite observations. It is presented one example of measurements performed at two sites in MASP, one downtown (IAG) and the other downwind of the central part of the city, in the Northwest region (Jaragua).



Title: Global Protocol for Community-Scale Greenhouse Gas Emission Inventories (GPC)

Speaker: Maryke Van Staden

Institute: ICLEI

Session IIIb: Standards for GHG Emission Inventories

Abstract:

Cities are an integral part of the global effort to tackle climate change, but they have been lacking a consistent and transparent way to measure and report emissions. However, inventory methods that cities have used to date vary significantly, raising questions around data quality, and limiting the ability to aggregate local and subnational GHG emissions data. With the GPC, however, cities are required to measure and report a comprehensive inventory of GHG emissions following the same accounting principles established by the 2006 IPCC Guidelines for National Greenhouse Gas Inventories.

In this sesssion, Ms Maryke Van Staden, Head of Low Carbon Cities Program and Director of the Carbon Center (Bonn Center for Local Climate Action and Reporting (Carbon Center) in ICLEI World Secretariat, will introduce you The **Global Protocol for Community-Scale Greenhouse Gas Emission Inventories** (GPC). A newly launched city level GHG protocol, which uses a robust and clear framework to establish credible emissions accounting and reporting practices, thereby helping cities develop an emissions baseline, set mitigation goals, create more targeted climate action plans and track progress over time. With the GPC, cities are required to measure and report a comprehensive inventory of GHG emissions following the same accounting principles established by the 2006 IPCC Guidelines for National Greenhouse Gas Inventories. By using the GPC, cities will also strengthen vertical integration of data reporting to other levels of government, and should gain improved access to local and international climate financing.

The GPC also underpins the global Compact of Mayors, the world's largest cooperative effort among cities to reduce GHG emissions, track progress and prepare for the impacts of climate change. The Compact – endorsed by preeminent global city networks – has adopted the GPC as part of its core activities to raise the level of ambition and quality of city GHG inventory reporting. Using GPC, cities can report emissions through the carbon Climate Registry, the Compact's designated central repository, as well as through existing city reporting platforms such as CDP.

Title: Monitoring carbon emissions from forests and wood products

Speaker: Marcus Lindner

Institute: European Forest Institute

Session IIIb: Standards for GHG Emission Inventories

Abstract:

The measurement of forest carbon stock is most commonly derived from forest inventory data, but not all countries have established regular plot based inventory systems. Remote sensing products are also becoming more commonly available and these are increasingly used in combination with ground based sampling. They are especially useful for monitoring, reporting and verification of efforts to reduce deforestation, and forest degradation (REDD). Both forest inventories and remote sensing are supported by well-established research

communities and GHG emission inventories from forests have steadily improved in coverage and quality over recent years. A new challenge is arising with new obligations for countries to inventory carbon in harvested wood products. Storing carbon in harvested wood products is one of several strategies of using forests and their products for climate change mitigation. The IPCC Good Practice Guidance presents three alternative accounting practices for carbon in Harvested Wood Products with increasing information demands. In order to report carbon pool changes with proper consideration of trade flows, substantial information is needed that goes far beyond the data on wood removals from forests that are available from statistics. This presentation summarizes some established inventory practices and outlines perspectives on how to improve forest sector carbon balances including the carbon pool changes in harvested wood products and the quantification of fossil fuel substitution effects.

Title: Measurable, Reportable and Verifiable Greenhouse Gas Emissions: New Challenges when Downscaling Global to Urban Inventories

Speaker: B. Koffi, G. Janssens-Maenhout, A. Iancu, S. Martelli, G. Melica, S. Rivas-Calvete, A. Kona, P. Zancanella, P. Bertoldi

Institute: European Commission, Joint Research Centre

Session IIIb: Standards for GHG Emission Inventories

Abstract:

Urban areas, which emit up to 70 % of global greenhouse gases, can greatly contribute to climate change mitigation policies and sustainable energy use. Comparable emission inventories at city level are needed to better understand the relation between emissions and institutional, socio-economic and demographic characteristics and to allow for the definition and implementation of efficient local policies for emission reduction. Global greenhouse gas emission grid maps from the EDGARv4.3 (Emissions Database for Global Atmospheric Research) dataset and the resulting urban totals per sector, as calculated bottom-up (with activity data and emission factors in a consistent way for all world countries) will be presented. They will be compared at national level to a review of city inventories collected in Europe in the frame of the Covenant of Mayors (CoM) initiative. The CoM initiative is the mainstream European movement involving local authorities voluntarily committing to meet and exceed the European Union 20 % CO_2 reduction objective by 2020. In order to demonstrate such commitment, the Covenant signatories (towns, cities and regions) must prepare and submit a Sustainable Energy Action Plan which is based on the results of baseline energy consumption and CO_2 emission inventories. The “CoM sample 2013” collection of harmonized inventories, including small to very large cities, has been carefully checked to ensure its internal consistency and its congruity with respect to internationally accepted guide values for emission factors. It will be compared, at per capita level, to EDGAR emission (and IEA energy) global data, for the buildings and the transport sectors. The analysis of the consistency and heterogeneity of the results with respect to the applied methodologies, as well as the potential of CoM derived-indicators for the downscaling of global to urban inventories will be discussed.

Title: Working with key stakeholders on metrological issues

Speaker: J. Whetstone

Institute: NIST

Session V: Engaging with key stakeholders in low carbon activity

Abstract:

Stakeholders concerned with low carbon activities are concerned about the impacts of increasing levels of greenhouse gases in the atmosphere. Stakeholder communities involved range from the climate science to the economic and policy development and implementation communities. All have a stake in development of and access to emissions and uptake information of accuracy sufficient to support implementation of greenhouse mitigation efforts. Although the metrology community has contributions to make, developing effective relationships across the range of stakeholders is a critical issue that the community must address both nationally and internationally. Discussions in this session will focus on stakeholder involvement approaches

Title: Using a carbon themed centre as a mechanism for interacting with government

Speaker: Jane Burston

Institute: NPL

Session V: Engaging with key stakeholders in low carbon activity

Abstract:

National Measurement Institutes are a critical part of the science and technology infrastructure of a country, but often find it hard to get profile with government colleagues and influence policy in their areas of expertise. One means of raising the profile of an NMI's work with stakeholders in government (and beyond), is to establish centres of excellence around particular themes or sectors. The Centre for Carbon Measurement at NPL in the UK was established three years ago. Jane Burston will talk about how and why it was set up, what the challenges were and what benefits NPL has gained as a result.