

# The Greenhouse Gas and Climate Science Measurements Program at NIST

APEC Regional Workshop  
on  
Measurement Challenges in  
Renewable Energy and Climate Science

October 29, 2015  
National Institute of Metrology, Beijing, China

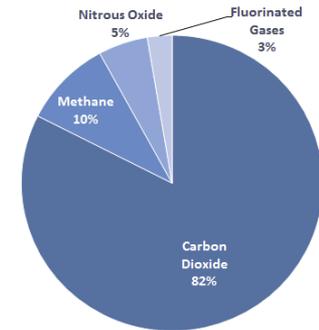
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# NIST's Greenhouse Gas and Climate Science Measurements Program

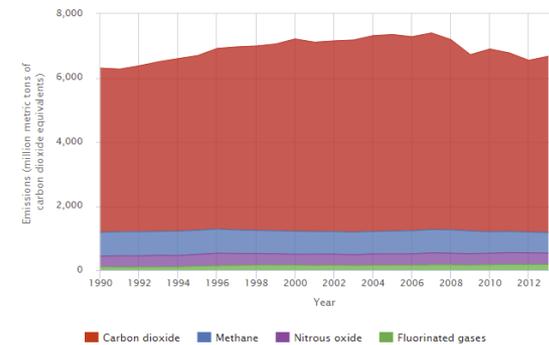
## Objectives:

- **Develop advanced measurement tools and standards that improve accuracy of:**
  - **Greenhouse gas emissions inventory data by**
    - Advancing emissions measurement capabilities for emissions reporting,
    - Developing methodologies focused on urban areas to independently diagnose emissions data discrepancies and identify unknown sources,
  - **Remote observations, both satellite and surface-based**
    - Extend measurement science and tools underpinning advances in understanding and description of Earth's climate trends and its change drivers



**U.S. Emissions in 2013 - 6,673M  
Metric Tons CO<sub>2</sub> equivalent**

U.S. Greenhouse Gas Emissions by Gas, 1990-2013



Source: U.S. EPA's Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2013.  
<http://www.epa.gov/climatechange/ghgemissions/usinventoryreport.html>

# NIST Greenhouse Gas and Climate Science Measurements Program Components

- **Stationary/Point Source Metrology**
  - Increase accuracy of Continuous Emission Monitoring technology
    - Flow Test Beds - smoke stack simulators
- **Tools for Quantification of Urban Emissions & Urban Testbeds**
  - Measurement Tools Characterizing Emission in Urban GHG Concentration Domes
    - Improve the accuracy of GHG data supporting inventory reporting
  - Urban GHG Testbeds
    - Indianapolis Flux Experiment (INFLUX)
    - Los Angeles Megacity Carbon Project
    - Northeast Corridor Project
  - An International GHG Metrology Framework Supporting Inventory Diagnosis Based on Cities and Megacities

- **Measurement Tools, Standards, and Ref. Data**
  - GHG Concentration Standards
  - Spectroscopic Reference Data
  - Surface Air Temperature Assessment
  - Atmospheric Flux Measurement Tools
- **Advanced Satellite Calibration Standards**
  - Microwave Observations
  - Advanced Optical Radiometric Methods
  - TOA and Surface Solar Irradiance
  - Surface Albedo Standards
- **Carbonaceous Aerosol Measurements**
  - Advanced Optical Property Measurements
  - Development of Reference Materials

# Stationary Source Measurements

- Develop and disseminate measurement standards for continuous emissions monitoring technologies and seeks to increase accuracy of emission source measurements.
- Establish testbeds and simulators to advance research on flow measurements in smoke stacks.



## Metrology for Electrical Generation and Power Plant Emissions Monitoring

Advance measurement technology for accurate, SI-traceable measurements for Continuous Emissions Monitoring the CO<sub>2</sub> emitted from the stacks of electrical and power generation plants to improve the accuracy of emission inventory data



## Test Beds to Advance Greenhouse Gas Stack Emissions Metrology

Establish a well-characterized and highly accurate reference measurement system at near industrial scale to serve as a test bed for carbon dioxide emissions measurements...

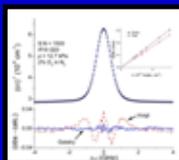


## Greenhouse Gas Emissions and Atmospheric Transport Modeling

Develop and demonstrate a measurement capability and methodology to accurately locate greenhouse gas sources and measure their flux to the atmosphere at urban and regional scales...

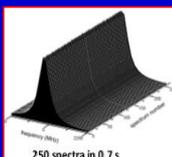
# Measurement Tools, Standards, & Reference Data

- **Spectroscopic Reference Data and Advanced Metrology Tool Development**
- **Greenhouse Gas Concentration Standards – atmospheric to stack effluent levels**



## Reference Data for GHG Sensing

Enable SI-traceable, absolute, laser-spectroscopic-based amount-of-substance measurements of greenhouse gases and atmospheric pollutants



## Sensor Development: Metrology Tools for Climate Science

Develop ultra-sensitive, SI-traceable laser measurement techniques for measuring the amount-of-substance of greenhouse gases



## Reference Materials and Gas Metrology

Develop suites of SI-traceable, amount-of-substance, primary gas standard mixtures (PSM) for the key greenhouse gas species at state-of-the-art accuracy levels.  
Provide linkage to the SI for WMO Central Calibration Lab (NOAA) for GHGs.



## Seawater Chemistry and Defining pH

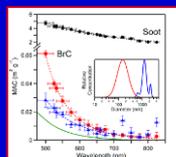
Establish traceable seawater pH and associated seawater chemical parameters, extend pH reference standards in artificial seawater to spectrophotometric pH measurements of natural seawaters. Provide certified pH sensitive dyes as field standards.

# Measurement Science of Carbonaceous Aerosols

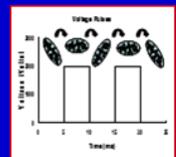
Improve predictability of direct and indirect radiative forcing by carbonaceous (black & brown carbon) and organic aerosol particles.

## Program goals:

- Advance measurement capabilities for optical property determination – Black Carbon
- Improve methods for reference material development and dissemination
- Explore new instrumentation and characterization methods

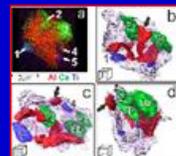


**Methods and Standards for Measurement of Atmospheric Aerosol Radiative Properties**  
Develop methods that facilitate the measurement of aerosol optical properties, apply these measurements to relevant atmospheric systems that improve models of radiative forcing, and develop a transferrable aerosol with known optical properties



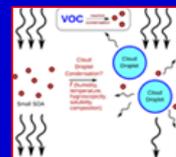
## Carbonaceous Aerosol Measurements

Develop methods to decrease the uncertainty in the measurement of particle size, size distribution and shape to enable higher fidelity field measurements. Particularly improve accuracy of nanoparticle measurement standards, & extend capability to provide on-the-fly shape and chemical information



## Heterogeneous Atmospheric Dust: Individual Particles Microanalysis Optical Property Modeling and Lab-Generated Particle Analogs

Determine the natural variation in optical properties of heterogeneous based on microanalysis of selected individual particles



## Secondary Organic Aerosols

Identify and characterize chemical processes that affect the interaction of atmospheric organic aerosols with incoming solar radiation

# Advanced Satellite Calibration Standards

Advancing measurement science for calibration of earth observing satellites relies strongly on advances in radiometric measurements and standards. NIST works with other U.S. Federal agencies to ensure and improve the accuracy of satellite instruments and calibration procedures.



## Calibration of Earth-Viewing Satellite Sensors

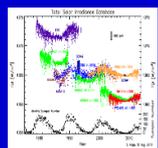
Develop the metrology infrastructure enabling SI-traceable satellite sensor radiometric calibration at relative uncertainty levels for Earth climate monitoring.

Advance NIST primary standards, develop & disseminate calibration methods and tools, and transfer the fundamental units & standards to satellite calibration facilities.



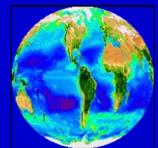
## Reflectance/BRDF Standards for Surface and Atmospheric Albedo Measurements

For reflective and scattering materials, facilitate climate monitoring through reflectance scale dissemination and improved characterization capabilities and theoretical understanding of reflective and scattering materials.



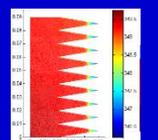
## Surface and Exo-Atmospheric Solar Measurements

Provide state-of-the-art, high-accuracy radiometric standards and measurement capabilities from 2 nm to 2500 nm to better quantify surface and exo-atmospheric solar radiation, the main drivers for the Earth's climate and weather.



## Ocean Color Measurements

Provide standards for color remote sensing of the world's oceans, for improved understanding of ocean ecology, biogeochemistry, and acidification.

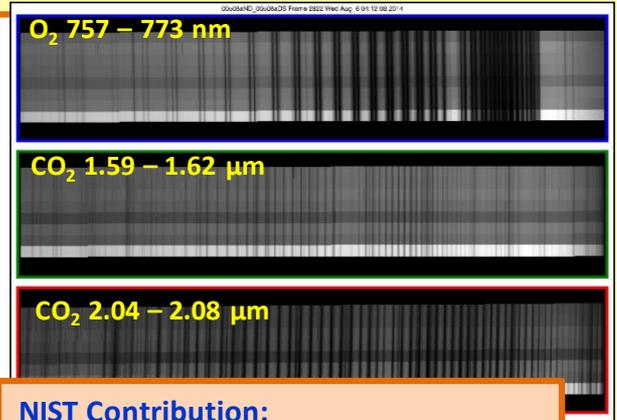
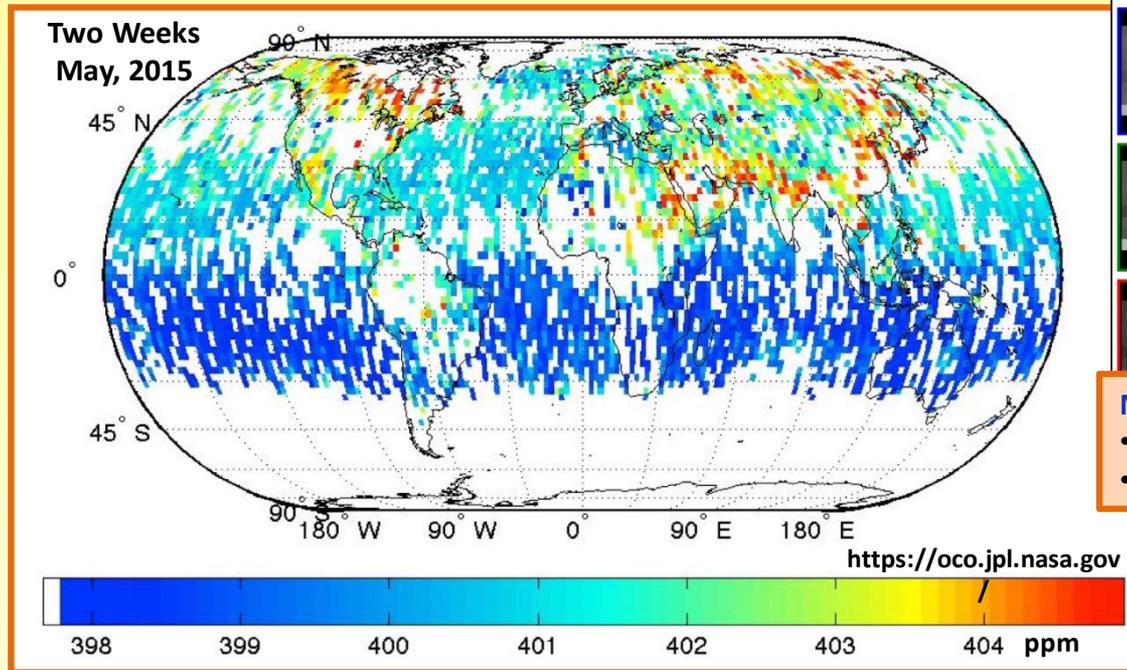


## Microwave Remote Sensing

Develop and deploy SI-traceable brightness-temperature standards and metrology to support US weather forecasting and climate science measurements.

# Atmospheric CO<sub>2</sub> & Ocean Observations from Space

## Standards and Measurements Advancing Carbon Cycle Science



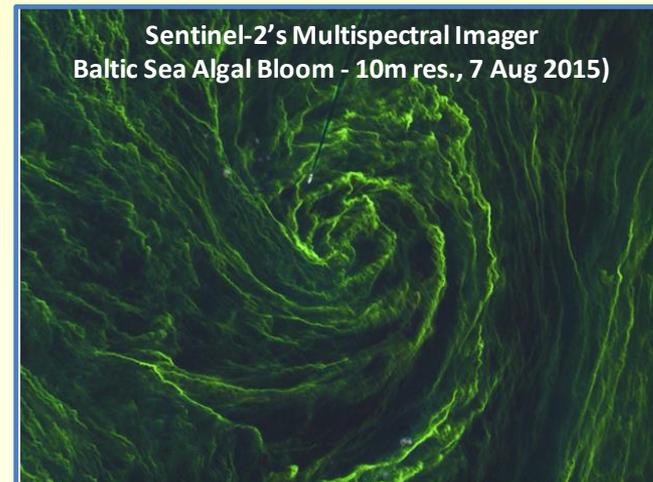
### NIST Contribution:

- High Spectral Line Shape Ref. Data &
- Detector Radiometric calibration

### Orbital Carbon Observatory 2 (OCO-2)

### Advance global carbon cycle understanding

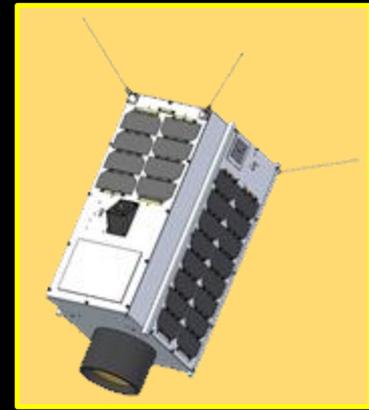
- Interplay of atmospheric CO<sub>2</sub> with the oceans via physical, biological, & chemical processes
- Ocean color depends on what is in the water and is observable from space.
- Marine Optical Bouy (MOBY) – Joint NIST/NASA/NOAA vicarious calibration effort



[http://www.esa.int/Our\\_Activities/Observing\\_the\\_Earth/Copernic](http://www.esa.int/Our_Activities/Observing_the_Earth/Copernic)

# Canadian Microsatellites: GHGSat-D

Univ. of Toronto Inst. For Aerospace Studies  
& GHGSat, Inc.



## Mission:

Become the global reference for remote sensing of greenhouse gas (GHG) and air quality gas (AQ) emissions from industrial sites, using satellite technology

- Next generation greenhouse gas monitoring instrument
  - Miniature hyperspectral IR imaging spectrometer
- Targeted monitoring of industrial greenhouse gas emitters
  - Oil & gas, power generation, mining and waste management
  - CO<sub>2</sub>, methane, SO<sub>2</sub>, NO<sub>2</sub>, & other gases
  - ~ 1 km<sup>2</sup> lateral spatial resolution
  - Secondary instrument measuring clouds and aerosols to enhance retrievals
- 15-kilogram satellite precursor to a potential commercial constellation for greenhouse gas and AQ monitoring
- Launch of prototype scheduled for 2015 using Indian (Antrim, Corp) facilities
- Significantly lower cost
- Similar Performance ?

A Wave of the Future ??

# Measurement Tools for Quantification of Urban Emissions and Urban Testbeds

- Advance measurement tools and methodologies independent of inventory methods to better characterize greenhouse gas emission flux data at urban to regional scales.
- Urban testbeds focus efforts on urban environments of vary meteorological characteristics and emissions profiles for method development and evaluation.

## Surface-Based Greenhouse Gas Measurement Reference Sites in a Tiered Observing Strategy

- Program Driver: Tool Development for Independent Determination of GHG Emissions
- Tiered or Layered Measurement System Architecture(s) Can Address Greenhouse Gas Measurement System Needs
  - Satellite to Ground-Based Observing/Measurement Strategy
- Strategically-Located Cities, Their Power Plants and Vehicles
  - Currently Concentrate ~70% of the World's Population
  - 85% to 90% by the Late 2000's
  - Framework proposed within the international metrology community
  - Function as Satellite Calibration Points and Advanced Measurement System Development and Demonstration sites

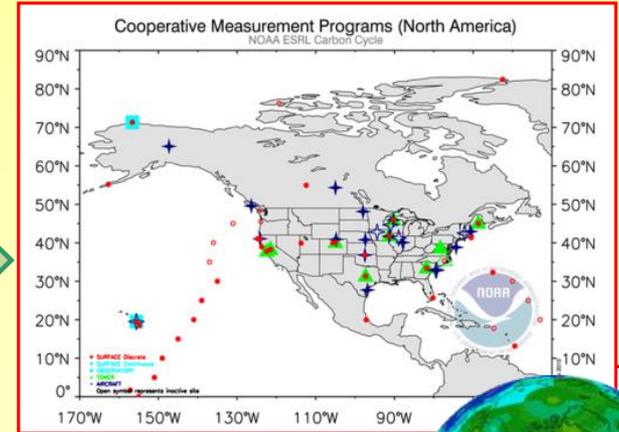
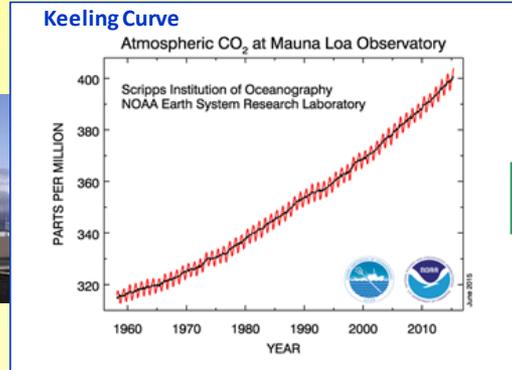
# An Integrated GHG Flux Measurement System Concept

## Urban-Regional-Continental-Global Components

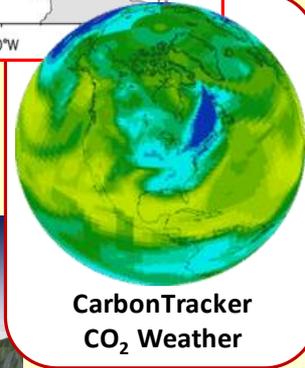
### Global Emissions



Mauna Loa Observatory  
~11,000 Ft. Altitude

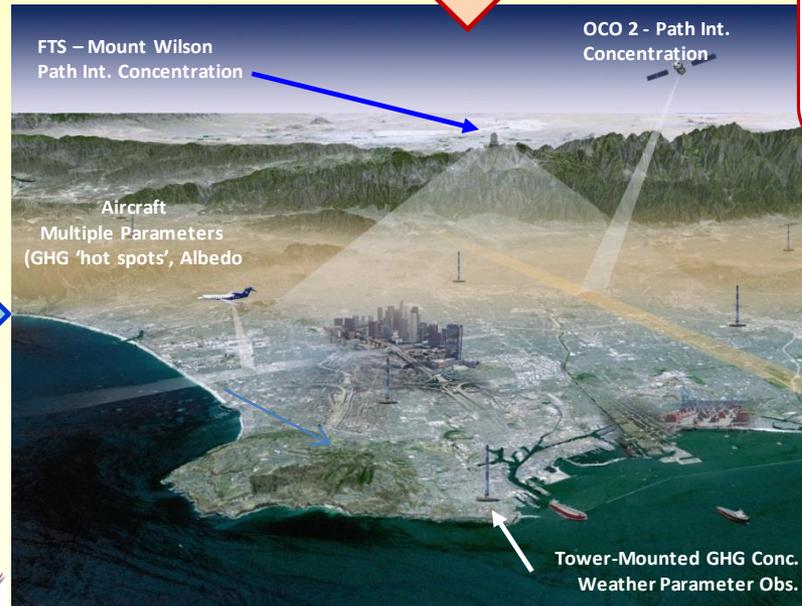


### Continental to Regional & Urban Scales



### Emissions Inventory Data for Reporting

- Primary Inventory Reporting Vehicle
- UNFCCC-Recognized Methodologies
- Emission/Activity Factor Model
- Use U.S. inventory data to Diagnose Performance of New Measurement Methods.
- Diagnose issues with inventories.



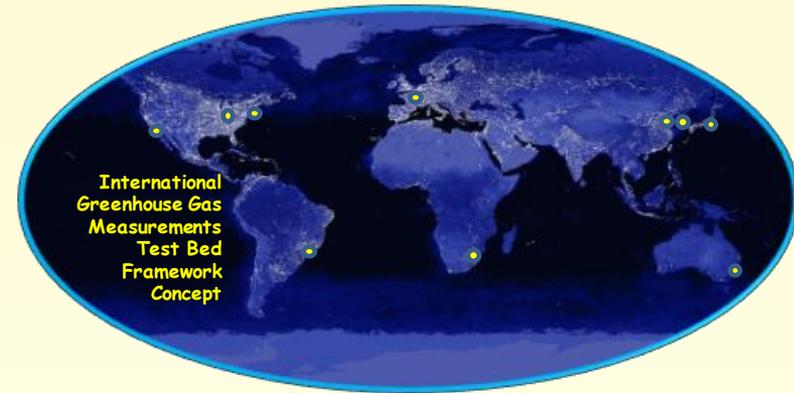
# International GHG Measurements Framework

## Engaging the Metrology & Climate Communities

### Concept:

#### For Cities and Regions Facilitate:

- Joint development and evaluation of advanced quantification capabilities for independent diagnosis of GHG inventory data
- Multi-organization and multi-national efforts
- Open, internationally-recognized measurement methodology development and evaluation and data exchange
- Satellite instrument calibration with surface methods advancing measurement accuracy and SI traceability



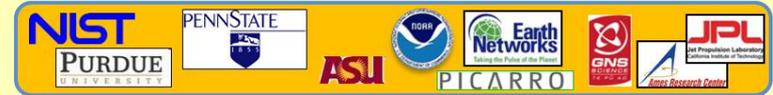
### Approach:

- Focus on Cities & Megacities as Test Bed Sites on 6 Continents
- Engage Nations or Regions Having:
  - Suitable locations and
  - The scientific and technological capabilities and resources needed

# Tools and Test Beds for Diagnosing GHG Measurements Accuracy in U. S. Urban Domes

## Developing and Assessing Performance of Greenhouse Gas Measurement Tools at Urban Scales

### The Indianapolis Flux Experiment (INFLUX)



- *A Top-Down/Bottom-Up Greenhouse Gas Quantification Experiment in the City of Indianapolis, Indiana – Initiated in 2010*

### The LA Megacity Carbon Project



- *Estimating the Emissions Trends in a Megacity Having Complex Topography & Meteorology – Initiated in 2012*

### The Northeast Corridor

- *The Largest U.S. Megacity – Initiated in 2014 – Ranging from Washington to Boston*
- *A Test Bed Having Moderately Complex Topography & Meteorology*
- *An Emissions Quantification Experiment Focused on Comparison of Process-Oriented and Atmospheric Observation Methodologies*

**A Step in the U.S. Towards an International Urban Greenhouse Gas Measurement Testbed Framework**

**THANK YOU FOR YOUR  
ATTENTION**

**Questions ?**