Climate Change and Renewable Energy
A Perspective from a Measurements Viewpoint

Regional Workshop on
Metrology and Technology Challenges of
Climate Science and Renewable Energy

Kingston, Jamaica

April 14 – 15, 2015

James R. Whetstone

Special Assistant to the Director for Greenhouse Gas Measurements

National Institute of Standards and Technology

Agenda

Greenhouse Gas Measurements and Standards: What's NIST Doing?

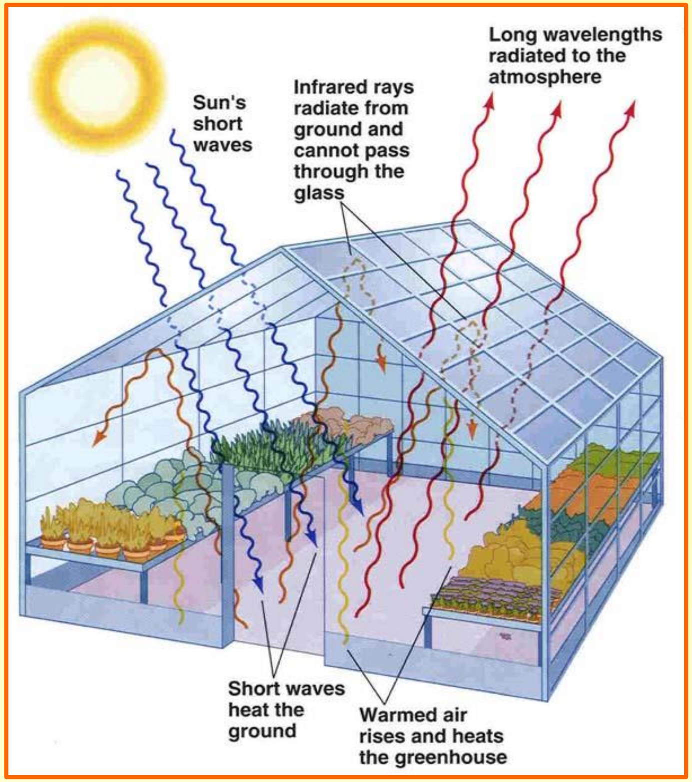
Background:

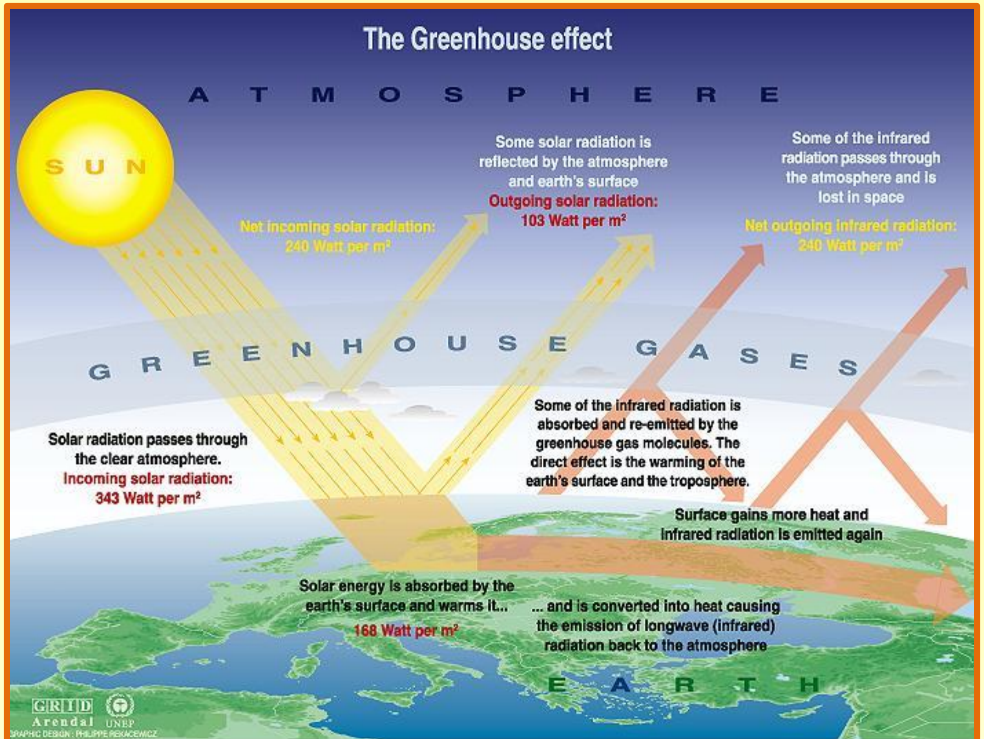
Atmospheric Greenhouse Gases Impact Earth's Climate

- **Earth's and Solar Radiation and the Atmosphere**
- **Greenhouse Gas Mitigation Efforts at National and International Levels**
- **NIST Measurement Science Program**
  - **Metrology for Power Plant Emissions**
  - **Developing Measurements and Standards for Urban Areas: Satellites and Remote Sensing Methods**

Greenhouses and Atmospheric Warming

Solar & Terrestrial Radiation Processes





Earth's Surfaces Absorb & Emit Radiation

- Shortwave radiation, visible and near ultraviolet, and heat Earth's surfaces
- Earth's surfaces emit longer wavelength radiation in the infrared,
  - Thermal, or Blackbody, radiation intensity depends only on emitting surface temperature
  - ~9.7 μm radiation emitted at ~295 K (~23 °C) surface temperature
- Thermal radiation is lost to space or absorbed by atmospheric greenhouse gases

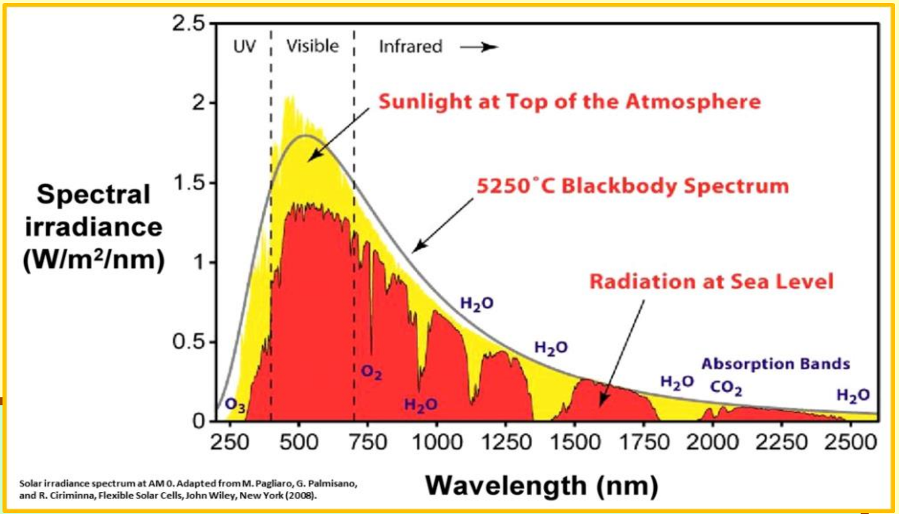
NIST

Earth's Greenhouse

Solar and Terrestrial Radiation and the Atmosphere

Earth's Surfaces Emit Radiation

- Earth's surface absorbs & converts shortwave radiation, visible and near ultraviolet, to longer wave radiation in the infrared
- Thermal, or Blackbody, radiation intensity depends on surface temperatures



Selective Absorption of Radiation Warms Atmospheric Gases

- Molecular gases, H_2O, CO_2, CH_4, & N_2O absorb thermal radiation from 2 – 30 μm
- Molecular, greenhouse, gases, at relatively small concentrations, transfer heat to nitrogen, N_2, and oxygen, & O_2 (~99% of the atmosphere)
- Radiative energy transferred to Earth's surface via radiative, conductive, and convective processes balance their impacts on Earth's climate
- Water Vapor & Gases Emitted to the Atmosphere by Human Activities
  - The most abundant greenhouse gas is water vapor – Naturally occurring & anthropogenic
  - Energy generation based via combustion is one of the largest contributors of CO_2
  - Humans activities are a relatively minor contributor to atmospheric water concentrations
  - Increased concentration of greenhouse gases other than water vaport disturbs the radiative balance that has established the Earth's climate in recent history
- The desire to reduce greenhouse emissions, mitigation, makes attractive electricity generation by means other than combustion

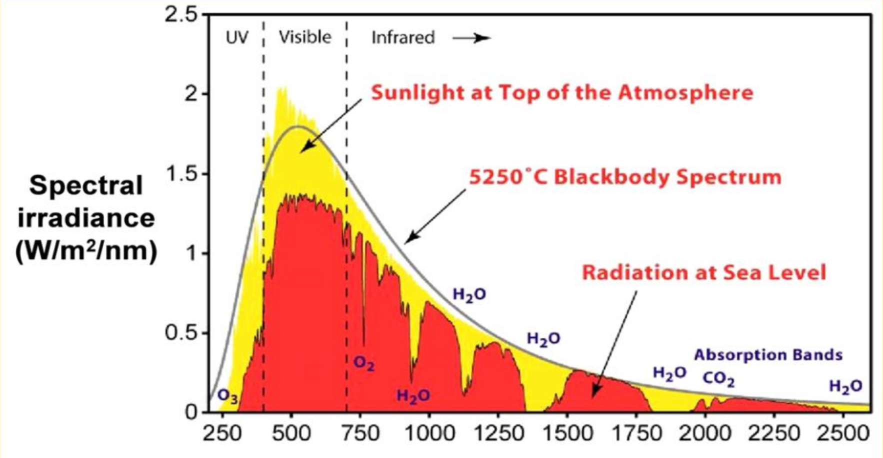
NIST

Earth's Greenhouse

Solar and Terrestrial Radiation and the Atmosphere

Earth's Surfaces Emit Radiation

- Earth's surface absorbs & converts shortwave radiation, visible and near ultraviolet, to longer wave radiation in the infrared
- Thermal, or Blackbody, radiation intensity depends on surface temperatures



Solar irradiance spectrum at AM 0. Adapted from M. Pagliaro, G. Palmisano, and R. Ciriminna, Flexible Solar Cells, John Wiley, New York (2008).

Selective Absorption of Radiation Warms Atmospheric Gases

- Water Vapor & Gases Emitted to the Atmosphere by Human Activities
  - The most abundant greenhouse gas is water vapor – Naturally occurring & anthropogenic
  - Energy generation based via combustion is one of the largest contributors
  - Humans activities are a relatively minor contributor to atmospheric water concentrations
  - Increased concentration of the other greenhouse gases disturbs the radiative balance that has established the Earth's climate of recent history

- Without the greenhouse of our atmosphere, the average temperature of Earth's surface could be -20° C or below and life as we know it would not exist

- The desire to reduce greenhouse emissions, mitigation, is an important driver for electricity generation by means other than combustion – Renewable Energy

Reducing Greenhouse Gases in the Atmosphere

International Climate Policy Drivers

MRV Concepts, Issues, & Linkages

- **Measureable, Reportable, and Verifiable GHG inventory data – Bali Action Plan**
- **A fundamental *mitigation activity effectiveness metric for GHG emission inventories***
- **MRV concepts have become:**
  - Pervasive in climate mitigation
  - Closely linked to renewable energy and energy security concepts
  - Technology, finance, & capacity building concepts applied to sustainability concepts
- **COP 20 changes**
  - Focus on "Intended Nationally Determined Contributions" (INDCs)
  - Emissions validation methodologies likely to remain
  - Effective reduction strategies require scientifically & metrologically sound methods & standards

International Greenhouse Gas Mitigation Efforts based on concepts and practices strongly aligned with the missions of National Metrology Institutes and of the International NMI Community.

- **Consistency, Transparency, Accuracy and Comparability of GHG measurements & inventories.**
- **The Capability to Measure, Report, and Verify GHG Inventories will be keystones for recognition internationally.**
- **Bali Action Plan concepts based on proven scientific principles fundamental to NMI philosophical basis – Independent Validation of Emissions Data used for Inventories**

Inventories, Reduction Targets & Energy Usage

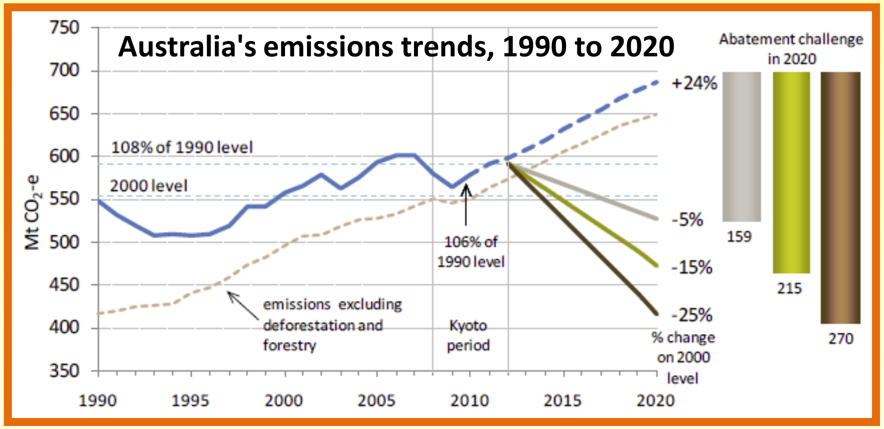
What Accuracy is Needed to Support Policies

Greenhouse Gas Emission Inventories

- The performance metrics for national and international reduction activities and the performance gauge of future policy effectiveness
- Reliable quantification is fundamental to reduction *target achievement and progress monitoring* and foundational to equity in trade and/or fairness in regulation
- Advances in a range of measurement capabilities are needed to *assess progress toward and attainment of* reduction targets.

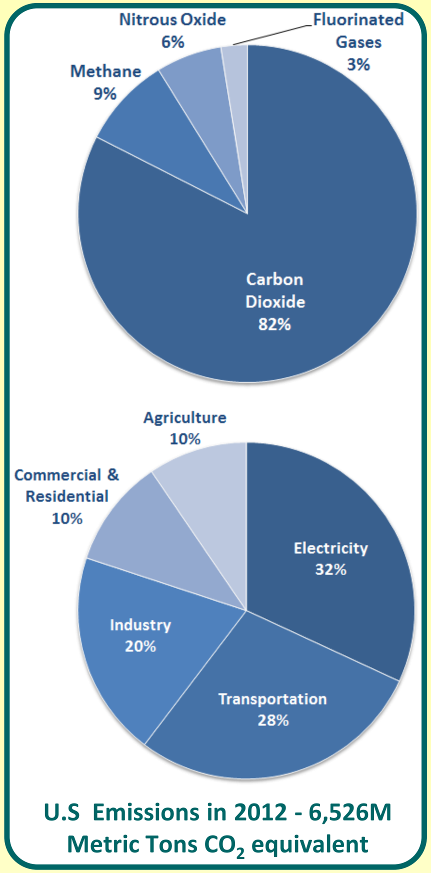
Reduction Targets – U.S. and International

- U.S.
  - President Obama's Climate Action Plan: 17 % relative to 2005 by 2020
  - EPA's recent Carbon rule ~30 % relative to 2012 by 2030
- UK: At least 80 % (from the 1990 baseline) by 2050
- Australia: 5 % below 2000 level by 2020



Indicators of Progress Toward and Achievement of GHG Reduction Targets Likely Require Quantification Capabilities at the 1% – 5% of the Target Level Using Internationally-Recognized Methodologies

NIST's Greenhouse Gas and Climate Science Measurements Program



Objectives:

- Develop advanced measurement tools and standards to improve accuracy capabilities for:
  - Greenhouse gas emissions inventory data
    - Improving emissions measurement data & thereby reporting accuracy
    - Independent methodologies to diagnose and verify emissions data with internationally-recognized methodologies
    - Applications focused on cities and metropolitan areas
  - Remote observing capabilities – satellite and surface-based
    - Extend measurement science and tools underpinning advances in understanding and description of Earth's climate and its change drivers

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
- Geospatially Distributed GHG Source Metrology
  - Measurement Tools and Test Beds Characterizing Emission in Urban GHG Concentration Domes
    - Compare methods to determine GHG Emission Inventory Accuracy – Bottom-up vs. Top-Down
    - Urban GHG dome test beds
      - Indianapolis Flux Experiment (INFLUX)
      - Los Angeles Megacity Carbon Project
      - Northwest Corridor Project
    - Propose an International GHG Metrology Framework Supporting Inventory Diagnosis and MRV Based on Megacities

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

Metrology for Power Plant Emissions

Stationary Emission Sources

A Bottom-Up method typical of much inventory data development

- Uses the properties of the process itself
- In this case fuel properties or direct measurement of CO_2 emitted from the combustion process through the smoke stack

Point Source GHG Metrology:

Comparing Fuel Calculated & Measured CO_2 Emissions

Electricity Gen. ~32% of U.S. CO_2 Emissions & Focus of the new EPA carbon rule

Question: What's the Level of Agreement Between the 2 Mainly-Used Methods of CO_2 Emissions Reporting Information? An Estimate of Accuracy in Reported Values?

- Fuel Calculation vs. Direct Stack Gas Flow Measurement Methods

- Data Sources Used
  - eGRID (EPA) and EIA Databases ~ 4800 Entries – Publically Available
  - Pre-Combustion – Fuel Calculation Method
    - Amount of carbon and hydrocarbon burned (oxidized) and converted to CO_2
  - Post-Combustion – CO_2 Direct Measurement via CEMs Technology
    - Direct Measurement (CEMs Data) and Reporting of CO_2, SO_2, N_2O

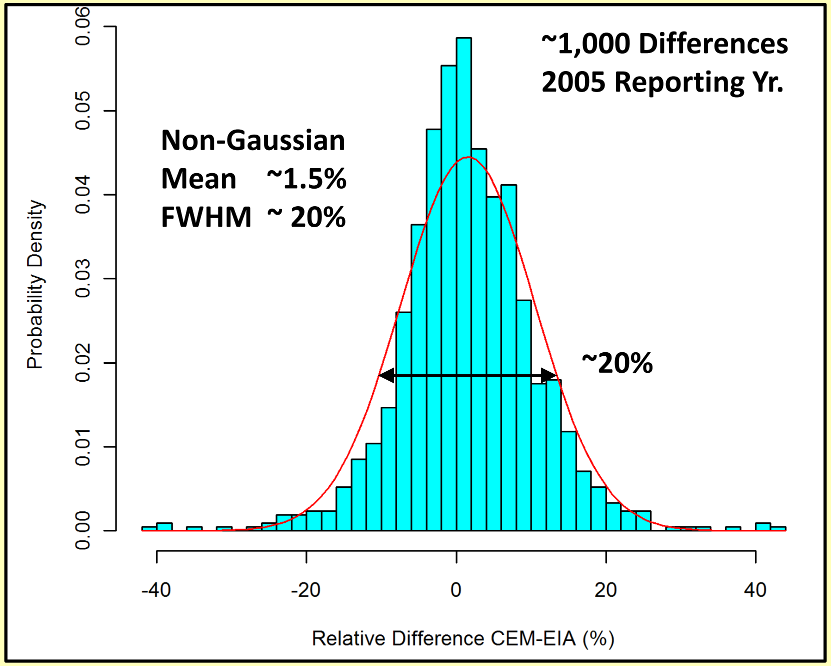
NIST

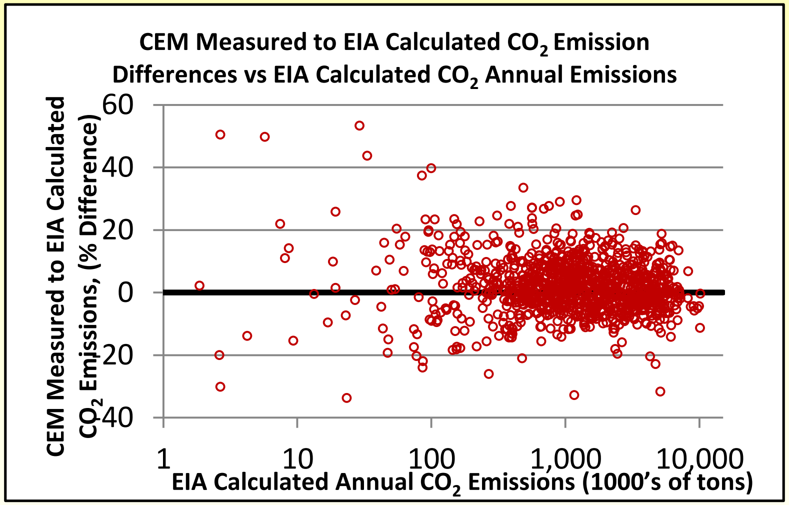
Comparative Analysis:

Fuel Calculated vs Measured CO_2

Accuracy Improvement Potential

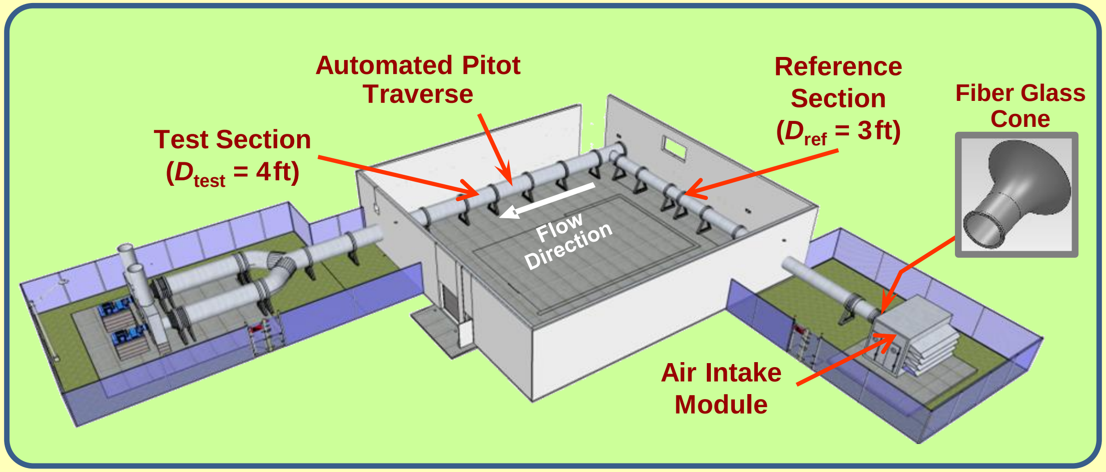
- **CEM Measurements**
  - Improve stack gas mass flow measurement
  - Reduce gas concentration uncertainty
- **Fuel Based Calculations**
  - Increase fuel carbon (energy content) accuracy
    - Calorimetry and sampling issues
  - Improved mass determination
    - Where to make the measurement
- **NIST's Investment in Pt. Source Metrology**
  - Smoke stack simulator - improved flow measurements
  - Large Fire Facility – large CO_2 emission source & test bed





NIST

Smoke Stack Simulator – Cold Flow Simulator
NFRL – Known CO_2 Emission Source



Address flow calibration issues in known, turbulent, swirling flows similar to those in stacks

- Horizontal orientation for cost and safety
- Smokestack Simulator is 1/10th the diameter of typical stack
- At the same velocity range – 5 to 25 m/sec
- Flow traceable to NIST flow standards

National Fire Research Laboratory (NFRL)

Large Emission Source with Accurately Known CO_2 Flux

- Characterize exhaust duct flows (flow RATAs*)
- Establish a mass balance for CO_2 emissions for the facility – O_2 depression calorimetry method
- Apply research results from the NIST Smokestack Simulator
- Provide test bed for new and existing stack mounted flow measurement technologies

* Relative Accuracy & Test Audit

Developing Measurements and Standards for Urban Areas:

Satellites and Remote Sensing Methods

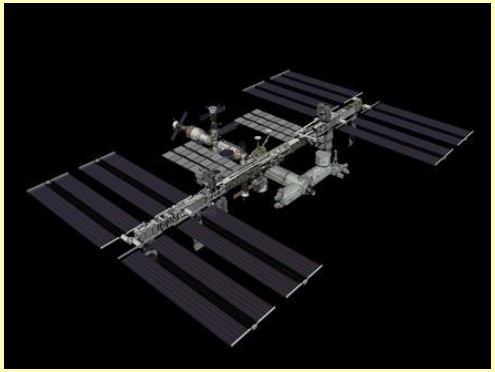
Urban Test beds as a Means of Greenhouse Gas Satellite Instrument Calibration

Top-Down Methods

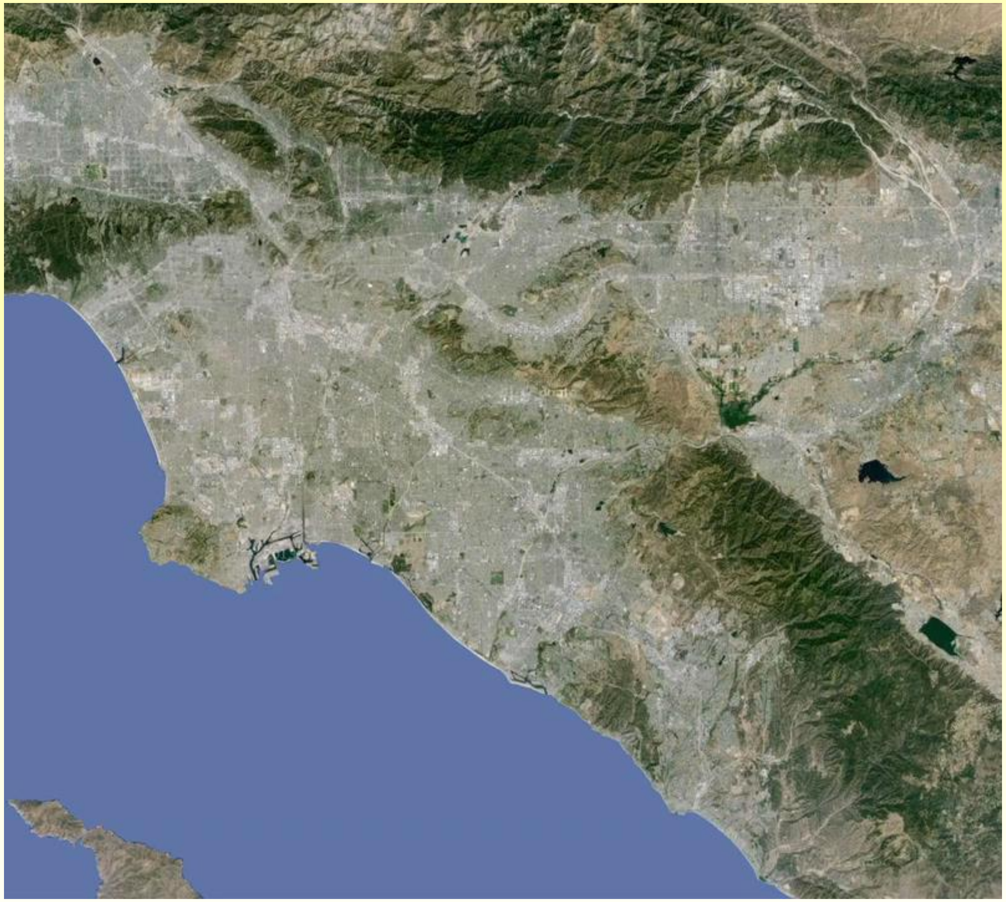
- Are independent of the process itself
- Often uses observations or the atmosphere and/or methods based upon remote sensing technologies

OCO 3 – International Space Station

City Mode



- A future space instrument designed to investigate important questions about the distribution of carbon dioxide on Earth as it relates to growing urban populations and changing patterns of fossil fuel combustion.
- Future deployment on the International Space Station (launch status: TBD).
- Continue the OCO-2 CO_2 data record for carbon cycle science with an additional capability enabled by a more flexible pointing system: Regular sampling of more world cities and power plants (over 80% of fossil-fuel CO_2 emission sources monthly) than available with OCO-2.
- Broader mapping of each city's CO_2 footprint

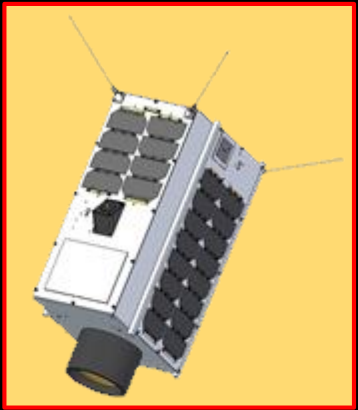


Video Credit: Graphics courtesy: Henry Kline, Sha Feng, Zhijin Li, Annmarie Eldering, and John Howard (JPL).

NIST

Canadian Microsatellites: GHGSat-D

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



Mission:

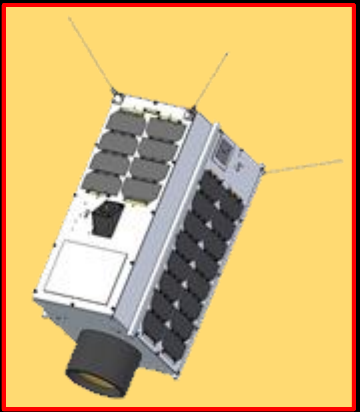
Become the global reference for remote sensing of greenhouse gas (GHG) and air quality emissions from industrial sites, using satellite technology

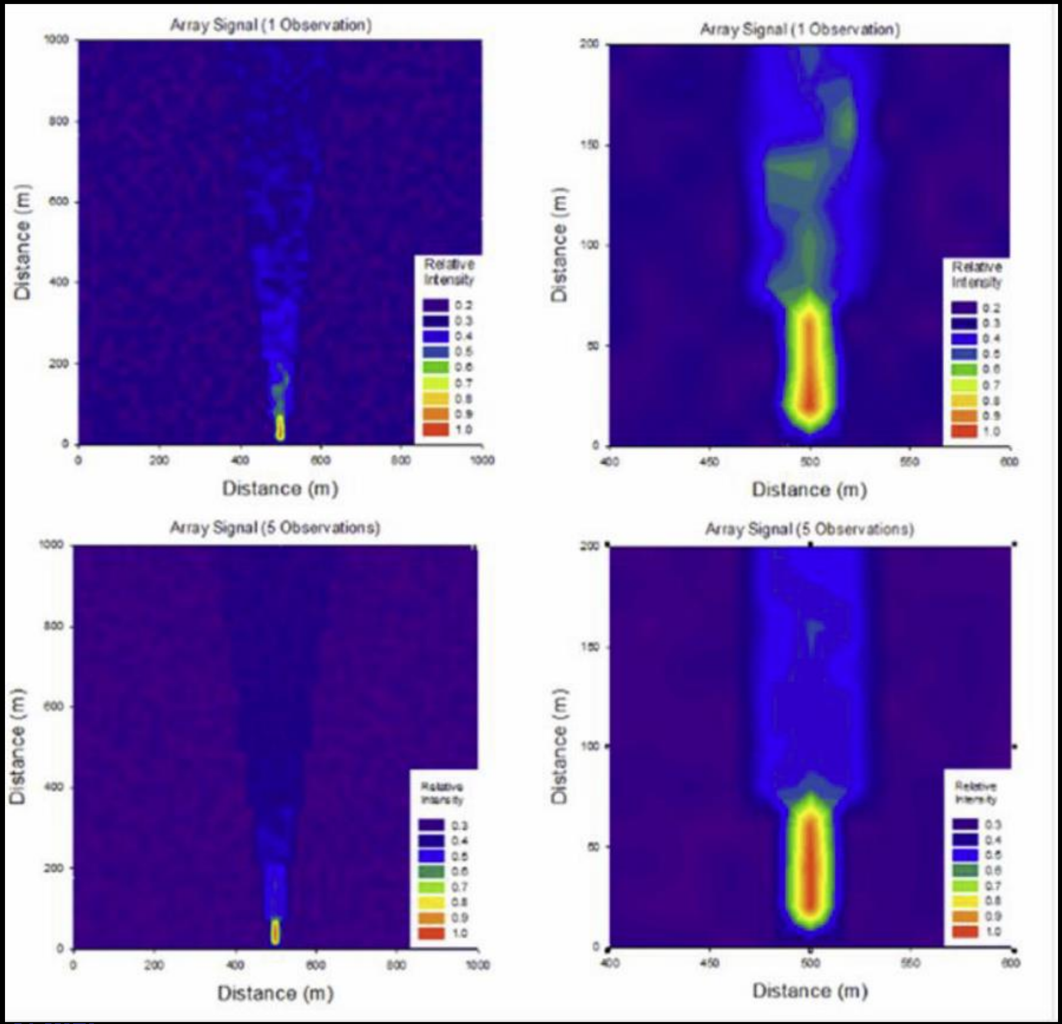
- Next generation greenhouse gas monitoring instrument based on miniature hyperspectral IR imaging spectrometer
- Targeted monitoring of industrial greenhouse gas emitters
  - Oil & gas, power generation, mining and waste management
  - CO_2, methane, SO_2, NO_2, & other gases
- 15-kilogram satellite precursor to a commercial constellation of greenhouse gas monitoring satellites
- Part of a service provided by GHGSat Inc.
  - A secondary instrument will measure clouds and aerosols in order to enhance retrievals from the primary instrument.

NIST

Microsatellites: GHGSat-D

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





Projected Capability:

Simulated Spectral Obs. of CO_2 Plume

- Top panels - single “snapshot” observation, 1 second duration, low (1 km x 1 km) & high (200 m x 200 m) resolution.
- Lower panel – 5 co-added observations, improved SNR.

COST: <$100M

Tools and Test Beds for Diagnosing Inventory Accuracy for U. S. Urban Greenhouse Gas 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*

The LA Megacity Carbon Project

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

The Northeast Corridor

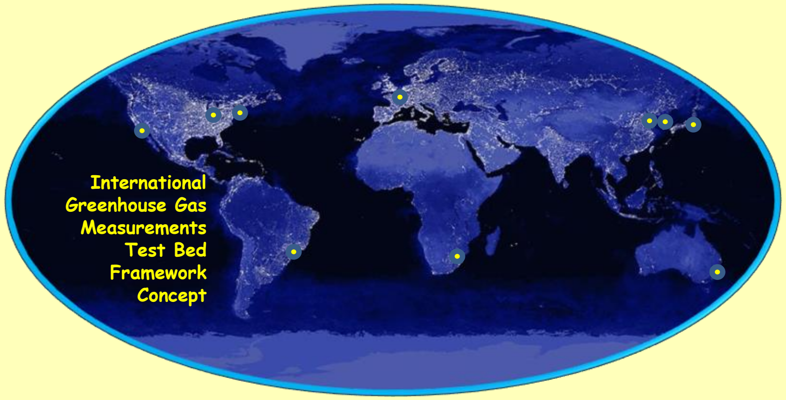
- *The Largest U.S. Megacity*
- *A Test Bed Having Moderately Complex Topography & Meteorology*
- *Initiation of The Effort Began in Mid-FY 14.*

A Step in the U.S. Towards an International Urban Greenhouse Gas Measurements Testbed Framework
Potentially Useful for Satellite Instrument Calibration

International GHG Measurements Framework

Engaging the Metrology & Climate Communities

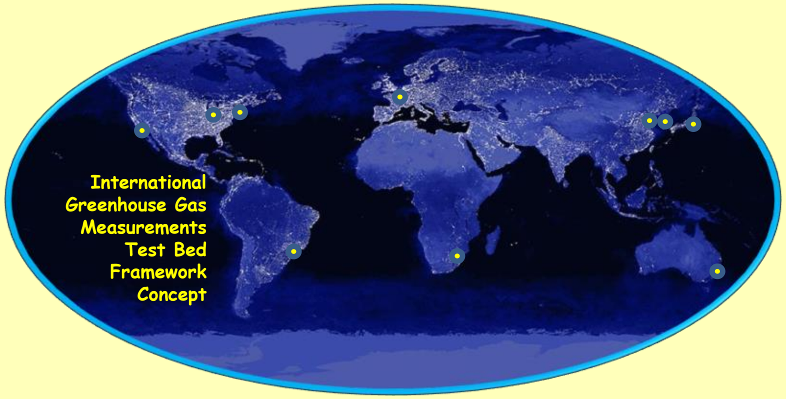
Concept:



- **An International Greenhouse Gas Measurements Test Bed Framework That Promotes:**
  - Joint development of advanced measurement capabilities for urban and regional GHG domes and their dynamics,
  - multi-organization efforts with locations and organization on all continents but Antarctica,
  - Facilitates open, internationally-recognized measurement methodology development and evaluation and open data exchange and utilization, and
  - Strengthens methods to correlate and calibrate satellite observations with surface-based observations advancing accuracy and establishing SI traceability

International GHG Measurements Framework

Engaging the Metrology & Climate Communities



Approach:

- Focus on Megacities as test bed sites
  - Increased signal levels
  - Cover 6 or the 7 continents
- Engage with nations or regions that have:
  - Suitably located megacities
  - The scientific and technological capabilities needed, and
  - The necessary national interest and will to commit the required resources
- Use existing structures of the Mètre Convention
  - Operating, internationally-recognized treaty organization with well-demonstrated working relationships and organizational structures
  - Facilitates communication & dialog
  - Broaden international linkages – WMO, international climate change/science communities

Thanks Your Attention

NIST
National Institute of
Standards and Technology