NIST Greenhouse Gas and Climate Science Measurements Research and Standards Program

An Overview

Council for Optical Radiation Measurements

2012 Annual Meeting
NRC - Ottawa

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Agenda

- Introduce the NIST Greenhouse Gas and Climate Science Measurements Program
  - Rationale, Approach, & Objectives
- A view of the landscape
- Emissions verification
- Program components
- Projects of interest

Why are Greenhouse Gas and Climate Science Measurements and Standards a NIST Priority?

- Measurement tools of greater accuracy will be, and are, needed to better quantify and validate emissions of GHG sources and sinks
  - Future recognition of U.S. GHG inventories will likely require measurement standards, tools, and methods of greater accuracy and with traceability to the SI as a minimum requirement
- A remaining challenge for climate science is improved measurement accuracy, realized through the necessary standards and advances in measurement technologies.
- NIST has the mission and many of the capabilities to meet these needs of U.S. industry, government, and the scientific community.

- An Administration priority
  http://www.whitehouse.gov/energy/climate-change#energy-menu
- OSTP/OMB Science & Technology Priorities
  - "Understanding, adapting to, and mitigating the impacts of global climate change"
  - "Moving toward a clean energy future to reduced dependence on energy is important while curbing greenhouse gas emissions."

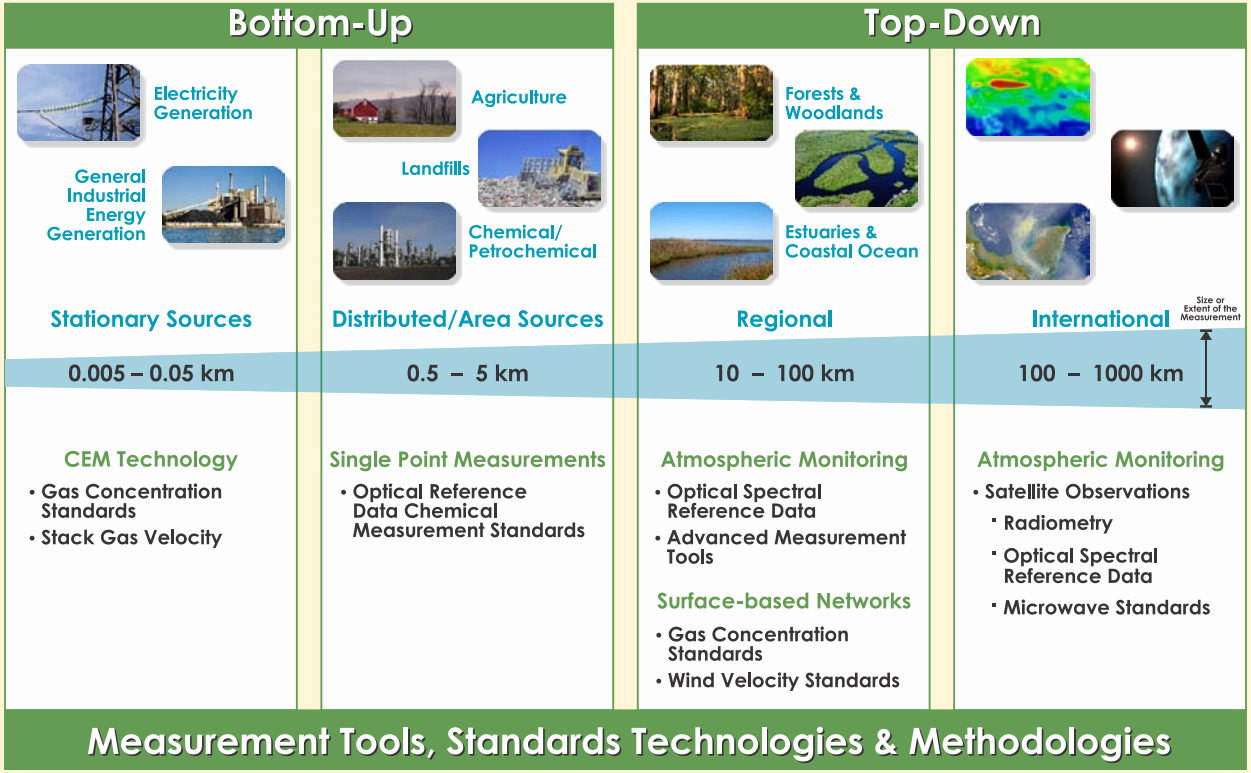
NIST GHG and Climate Science Measurements Program

Program Objectives:

- Extend the measurement science basis for accurate and comparable quantitative measurements of greenhouse gas inventories;
- Ensure measurement capabilities for:
  - accurate and reliable assessment greenhouse gas baselines,
  - quantifying greenhouse gas sinks and sources, and
  - verifying greenhouse gas emissions to and removals from the atmosphere,
  - quantities fundamental to advancing climate science.
- Enable development of international measurement standards and protocols to ensure the accuracy of global assessments of greenhouse gas emissions.

Greenhouse Gas Emissions Measurement
A World, and Local, View

- GHG Emission Inventories are aggregated from many components
- Source/Sink Scale
  - Emitter size, - stack size, area of landfill, etc., extent of natural landscape features
- Quantification Methods
  - Measurement tools & standards are a universal requirement across these sectors
  - Improved quantification capabilities will require advances in measurement tools, capabilities, and standards



- Methodological Approaches
  - Bottom-Up: GHG emissions determined by the owner – at the source or sink, prior to emission
  - Top-Down: GHG amounts and locations determined by post-emission observations of the atmosphere

NIST Greenhouse Gas Measurements and Climate Science Program

- **Vision:**
  NIST, working with industry, other Federal agencies and the states, will develop or extend internationally-recognized measurement standards, methodologies, and technologies to:
  - **Enhance science-based greenhouse gas emissions inventories and**
  - **to better understanding processes driving climate and weather.**
- **Program Objectives:**

  Increase confidence in GHG stationary source emissins determination by improving measurement standards, technologies, and methodologies.

  Deliverable: **Validate methodologies for field measurements of GHG point source emission inventories with accuracies of < 5% and traceable to the SI.**

  Develop and validate advanced measurement tools that improve quantitative determination and validation of GHG sources and sinks and the accuracy of climate science measurements

  Deliverable: **Transfer new, validated diagnostic and measurement technologies to the private sector and embody their usage methodologies in consensus standards.**

  Deliver new and improved standards necessary to enhance the accuracy of satellite observations

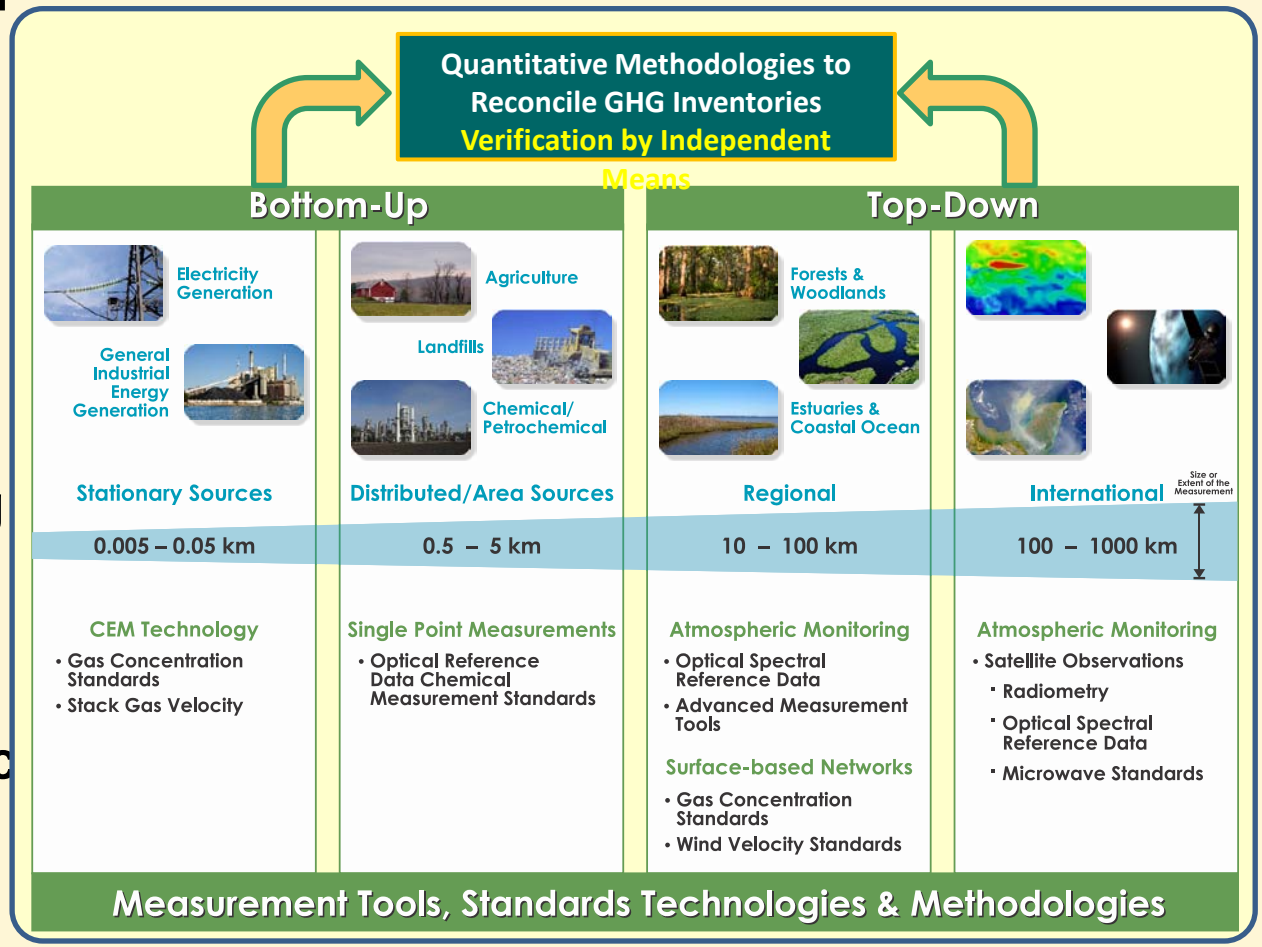
  Develop and demonstrate measurements, standards, and methodologies to reconcile U.S. inventories with atmospheric GHG monitoring observations as a technical means of addressing MRV* requirements on a local and regional basis.

  Deliverable: **Develop enhanced quantitative reconciliation capabilities and demonstrate in a major U.S. geographical region.**

* **Measurable, Reportable, and Verifiable emissions Inventories**
UNFCCC Bali Action Plan

Measurements Supporting Independent Verification of Greenhouse Gas Inventories

- **Methods to Independently verify inventory statements can support future national & international agreements**
- **Extension of Top-Down methods that observe the atmosphere are a means to independently verify emissions data provided by the entity.**
- **These measurement methods are promising technologically but require substantial development to attain the necessary scientific veracity at useful scales – urban & local scales.**



NIST GHG & Climate Science Measurements Program Components

- **Point Source Metrology**
  - Continuous Emission Mon. Test Bed - Smokestacks
- **Distributed GHG Source Metrology**
  - GHG Flux Measurement Tools
  - GHG Emission Dispersion Analysis
- **GHG Measurements, Standards, Ref. Data, and Tools**
  - GHG Concentration Standards
  - Atmospheric Lifetime References
  - Spectroscopic Reference Data
  - Surface Air Temperature Assessment
  - Surface Solar Intensity Meas. & Standards
- **GHG Inventory & Regional Emissions Profile Methodologies**
  - Dense GHG Observing Networks
  - Emissions Validation by Independent Means

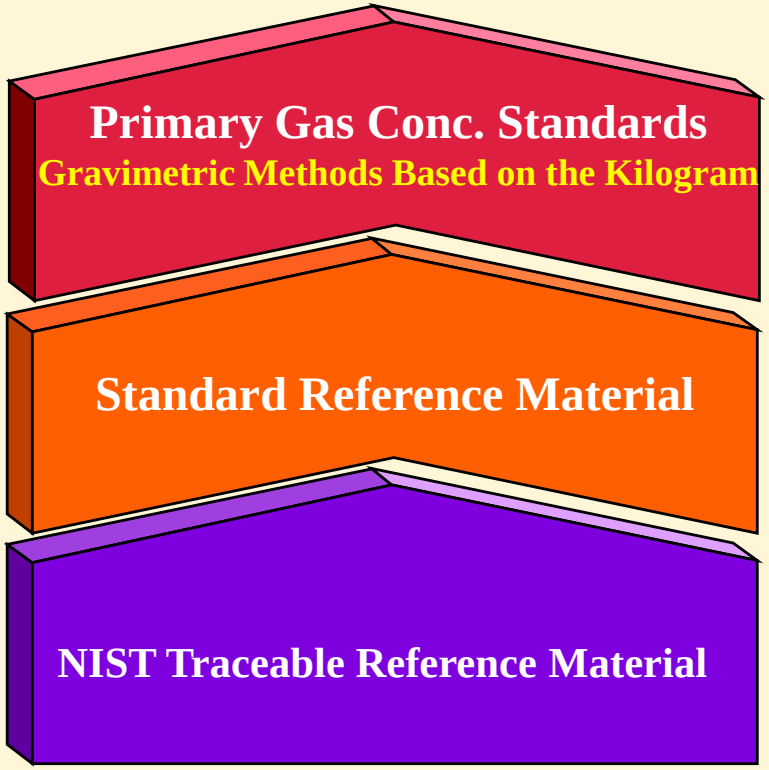
- **Advanced, Field-Deployable Detection Technologies**
  - Frequency Comb IR Sources
- **Satellite Calibration**
  - Optical Reflectance and Transmittance Standards
  - Microwave Standards
  - Thermal Infrared Standards
  - Scene Generation
- **Aerosol Measurement Science**
  - Black Carbon Morphology
  - Black Carbon Bulk Properties
  - Black Carbon Optical Properties
  - SOA Formation Mechanisms

Research Grants

- Measuring Greenhouse Gas Emissions by Inverse Methods: A Pilot Program - Scripps & LLNL
- Development, Improvement, and Assessment of the Accuracy of Aircraft-Based Mass Balance Measurements of the Integrated Urban Emission Fluxes of Greenhouse Gases – Purdue, Univ. Colo., and Penn State Univ.
- Multi-wavelength LIDAR System to Characterize Atmospheric Composition & Chemistry – Michigan Aerospace
- Buoy Sensor Technology for Long-Term Submerged Observation of the Marine CO_2 System and Isotopic Composition – Woods Hole Oceanography Institution

A Few Program Highlights

Gas Concentration Standards
Traceability Hierarchy



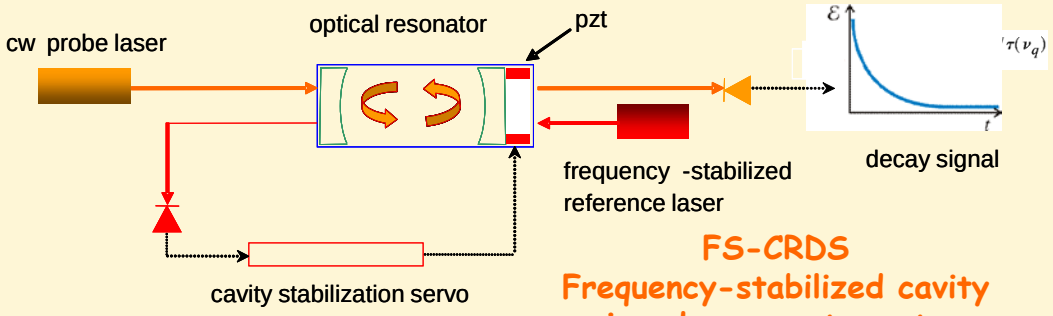
EPA Protocol Gas Standards

Fundamental for Daily Stationary Emission Source Emissions Measurements

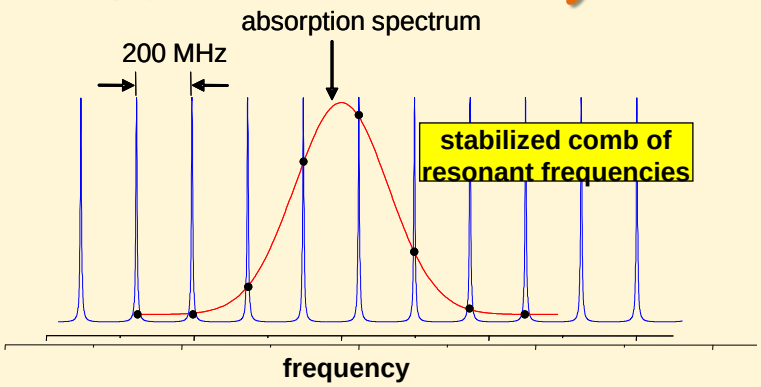
- **PSM (Highest Accuracy)**
  - NIST (ISO 6142) gravimetrically prepared gas standards
- **SRM® (Most Certain)**
  - NIST certified CRM
- **NTRM® (Highly Certain)**
  - Produced by ISO 17025 Specialty Gas Company (SGC) to NIST specs – NIST Certifies/Audits QC systems
- **EPA PGSs (Compliant)**
  - SGC Produced to EPA protocols, dual analyzed-EPA audited, traceable to a SRM or NTRM (± 2%)
- **Standards in atmospheric concentration ranges**
  - Requirements are near or at the state of the art and WMO requirements
  - Collaboration with NOAA/ESRL/GMD
  - Comparison with other National Metrology Institutions
  - Basis for pCO_2 Reference Materials

High Accuracy Spectroscopic Reference Data

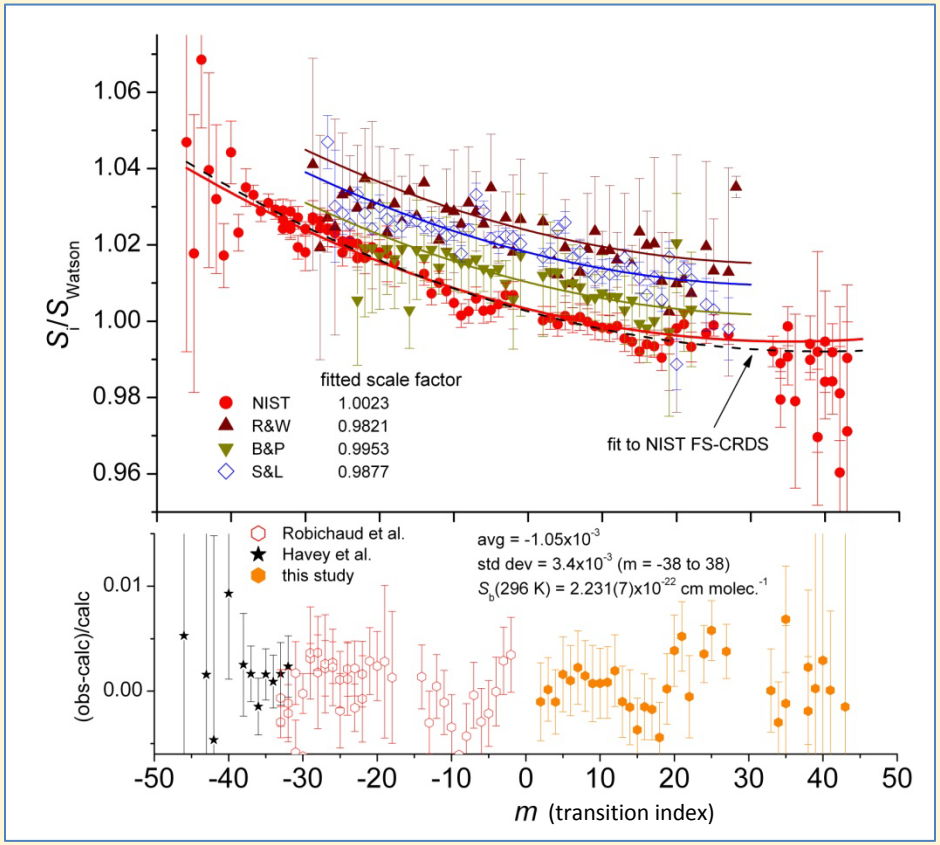
Visible and Infrared (1.45 – 1.6 μm Atm. water window)



FS-CRDS
Frequency-stabilized cavity ring-down spectrometer



- Accurate absorption line intensity & shape measurements augmented with high accuracy absorber number density determination reduced absorption line intensity uncertainties from 2% to 0.3%
- Update HYTRAN Database
- Quantified corrections required to accurately describe line intensities in the O_2 A-band (~765 nm)



Standard Reference Data Utilization:

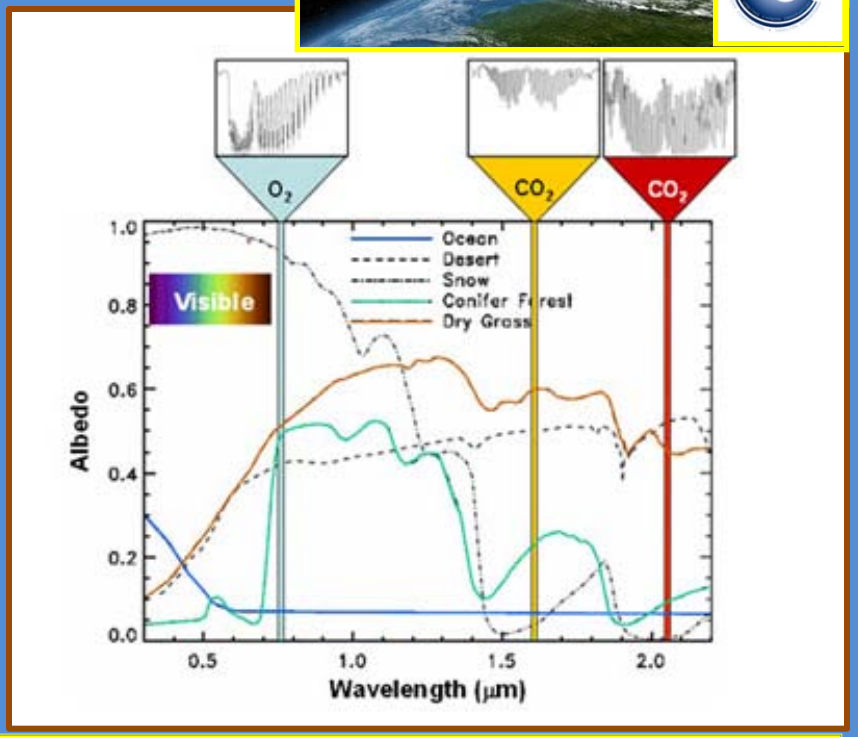
NIST/NASA Collaboration:

The Orbiting Carbon Observatory II

Improved CO_2 Determination in the Atmospheric Column

CO_2 observations from orbit at the <0.5% (2 ppm) level requires world class spectroscopic reference data for CO_2 and the O_2 A-band and radiometric measurement capability.

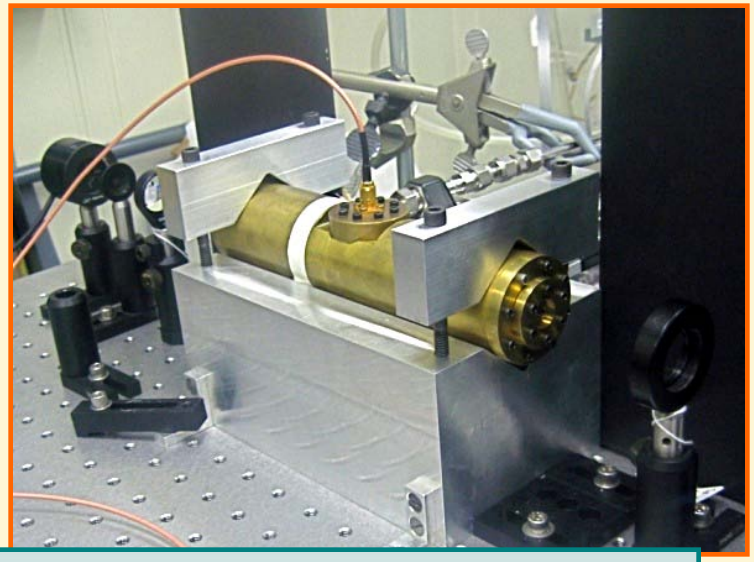
Diatomic oxygen (O_2) p uniformly mixed in the atmosphere, provides known atmospheric concentrations for remote sensing observations.

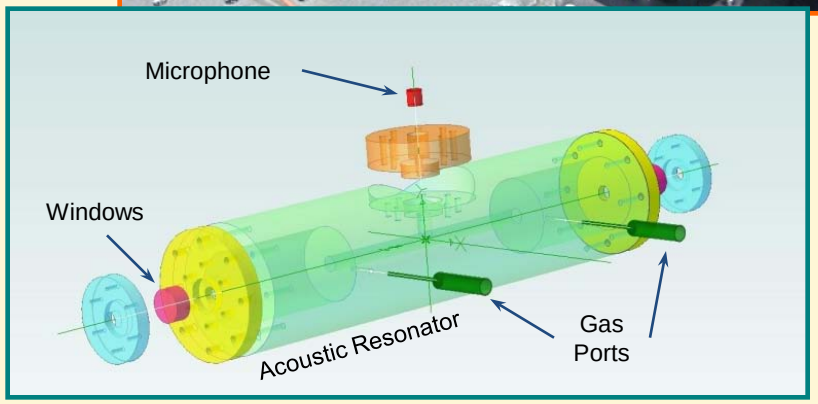


- *Utilizing its gas standards and high precision cavity ringdown spectroscopy capabilities, NIST has completed projects supporting NASA's OCO II. The lowest uncertainty spectroscopic line parameter measurements available for the O_2 A-band are the result.*
- *Current efforts address the CO_2 bands used by OCO II and the needs of commercial vendors of CRDS instruments for high accuracy spectral reference data.*

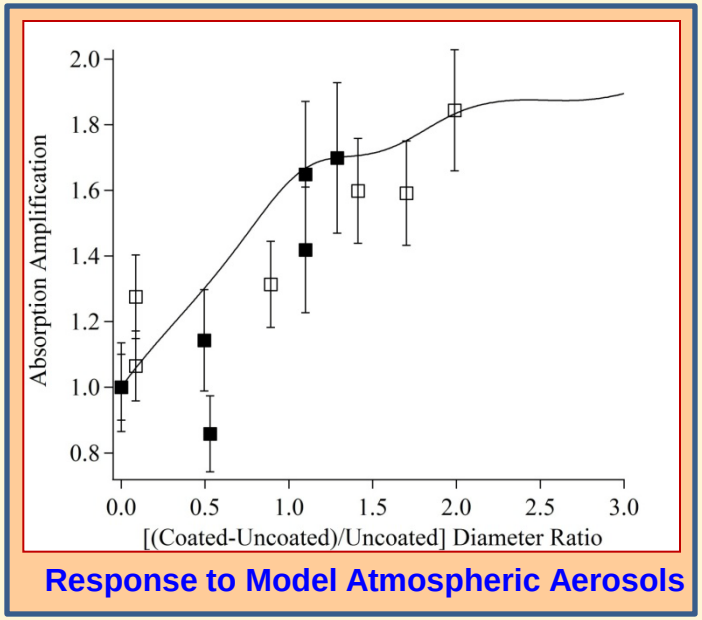
Researching New Measurement Technologies

Photoacoustic Spectrometer

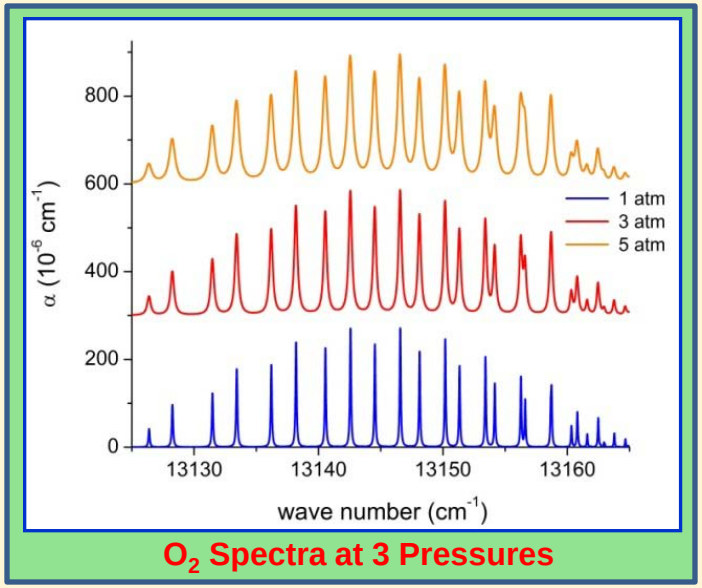




Instrument capable of measuring absolute gas concentrations and aerosol optical absorption



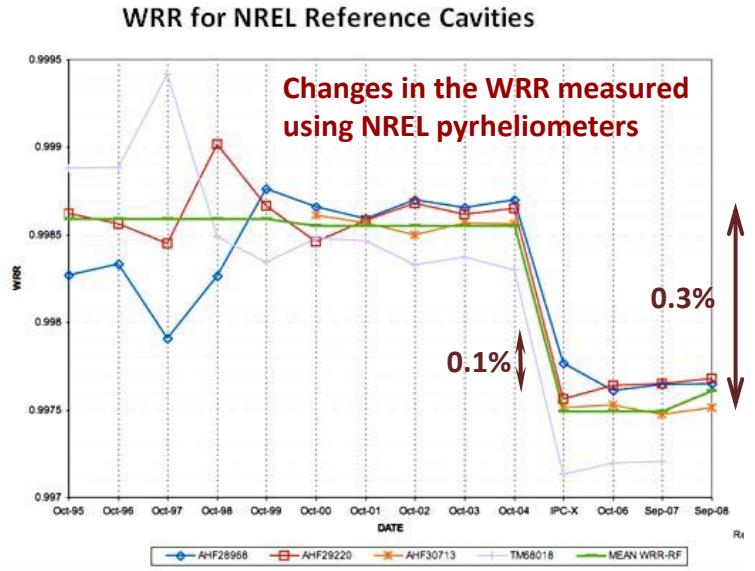
Response to Model Atmospheric Aerosols



O_2 Spectra at 3 Pressures

Surface Solar Intensity Measurements and Standards

- **Objective:**
  - Improve the accuracy of and establish the traceability to the International System of Units (SI) for surface solar radiation measurements
  - Linkage to total solar irradiance scale
- **Approach:**
  - Utilize new cavity reflectance measurement capabilities coupled with high-intensity broad-band spectrally tunable source technology to lower measurement uncertainty and establish improved standards capabilities
- **Performance Target:**
  - SI-traceable calibration capability for broad-band terrestrial solar radiometers at the 0.03% (k = 1) total uncertainty level.



- Recent World Radiometric Reference scale comparisons indicated WRR is 0.34% higher than the SI*
- WRR artifact base began with ~17 instruments. Latest comparison is based on 4.

* Fehlmann, et. al., Metrologia 49 (2012) S34 – S38.

NIST Plan for SI-Traceable Terrestrial Solar Irradiance

1. Purchase three high-quality electrical-substitution cavity radiometers (Year 1)
    a. Cavities characterized for reflectance using the NIST Complete Hemispherical Infrared Laser-based Reflectometer (CHILR)
    b. Apertures measured
    c. Electrical substitution assessed
    d. Solar tracker acquired
2. Utilize the Laboratory for Atmospheric and Space Physics capabilities in checking that the pyrheliometer is traceable to the NIST cryogenic radiometer (Year 2)
3. Compare at NREL against other pyrheliometers which are traceable to the WRR (Year 2)
4. Construct at NIST a broad-band solar simulator with the collimation properties of the sun. The source should have the spectral irradiances of AM1.5 and have 0.5 degree collimation. This could be done using a supercontinuum source and spectral shaping of the source (Year 3)
5. Participate in the next IPC (2015)
6. Develop at NIST the capabilities for direct calibrations of pyrheliometers at the higher power levels. (Year 4)

Independent Emissions Verification Methodologies

A Top-Down/Bottom-Up Greenhouse Gas Quantification Experiment in the City of Indianapolis, Indiana
The Influx Experiment

Objective:

Develop measurement tools that can provide independent verification of greenhouse gas inventories at urban and regional scales

- **Phase I – NIST and university partners initiated the INFLUX (Indianapolis Flux) Experiment in 2010 as a Pilot project**
- **Phase II – INFUX has been extended to demonstrate measurement, characterization, and quantification of GHG Urban Domes and their dynamics utilizing a *Dense Surface-Based Measurement Network* approach coupled with aircraft observations and advanced planetary boundary layer characterization:**
  - **A measurement method of demonstrated performance supporting the concepts of Measurable, Reportable and Verifiable (MRV) GHG Emissions and Removals**
  - **Demonstrate reconciliation methodologies for bottom-up (self-reported) inventory statements with top-down measurement results**
- **An Interdisciplinary Research Effort Advanced by Recent Technological Advances in:**
  - **Real time measurements of greenhouse gas mixing ratios in the atmosphere,**
  - **Atmospheric boundary layer measurements and models,**
  - **GHG inventory determination at urban spatial scales, and**
  - **GHG plume inversion methodologies.**
- **Quantitative Goals**
  - **Quantify emission fluxes to within 10% or better of inventory value**
  - **Identify major emitter locations within 1 km^2**

Current Project Participants:

- **Purdue University**
- **Penn State Univ.**
- **Arizona State Univ.**
- **Univ. Colorado - NOAA/ESRL**
- **PICARRO Instruments**
- **Earth Networks**
- **NASA – JPL & Ames**

The Rationale for INFLUX

Urban Dome Characterization and Dynamics Measurements

- Quantification of greenhouse dynamics in urban areas
  - Advanced and diverse observing systems
  - Development and demonstration of Independent emissions verification in support of measurable, reportable, and verifiable (MRV) mitigation strategies - Bali Action Plan.
- Investigation the feasibility and performance of tracer-transport methods using:
  - Dense, surface-based observing networks coupled with aircraft-based measurements,
  - Advanced atmospheric boundary layer observation and modeling

  to determine GHG emission source location and strength in urban areas.
- Accurate modeling of transport and mixing in the atmospheric boundary layer (ABL), responsible for carrying GHGs from their source to the point of measurement, is essential.
- Observing system design, using multiple instruments and observing methods provide multi-scale measurements as a basis for mimicking the complex and evolving dynamics of a city – Indianapolis, Indiana, USA

INFLUX – An Initial Step Toward Identifying and Establishing Standard Measurement Methodologies to Independently Verify the Amounts of Greenhouse Gases Emitted To or Removed From the Atmosphere. The Initial Focus is on the Largest Sources - Cities

Measurement Challenges – Why NIST

Measurements Results Often Influence/Are Critical to the Quality of Decisions

- **Confidence in and Recognition of Measurement Results Requires:**
  - Measurement Accuracy & Comparability across time and space
  - Common basis of reference – standards base
  - Methods/protocols that relate point-of-use measurement results to recognized standards - ***Traceability to the SI****
- **A Primary NIST Responsibilities as the U.S. National Measurement Institute**
  - Realize and disseminate U.S. national measurement standards to industry, academia, and gov't
  - Ensure international recognition of U.S. measurement standards by other nations
    - Treaty of the Metre Organizations
      - » the International Committee on Weights and Measures,
      - » the International Bureau of Weights and Measures, and
      - » National Metrology Institutions (NMIs)

Traceability of Measurement Results

- *"… Property of the result of a measurement or the value of a standard whereby it can be related to stated references, usually national or international standards, through an unbroken chain of comparisons all having stated uncertainties." (VIM, 6.10)*

***SI – The International System of Units**

The Base or Fundamental Units

Length, Mass, Time, Electric Current, Temperature, Amt. of Substance, Luminous Intensity

- **State-of-the-Art measurement science capabilities and excellence are the basis for NIST's ability to provide reliable measurements and standards that often drive innovation**

Thank You
for Your Attention

Questions
or
Comments