NIST Greenhouse Gas and Climate Science Measurements Program Overview

Conference on Characterization and Radiometric Calibration for Remote Sensing
Calcon 2014

James R. Whetstone

Special Assistant to the Director for Greenhouse Gas Measurements

National Institute of Standards and Technology

Gaithersburg, Maryland

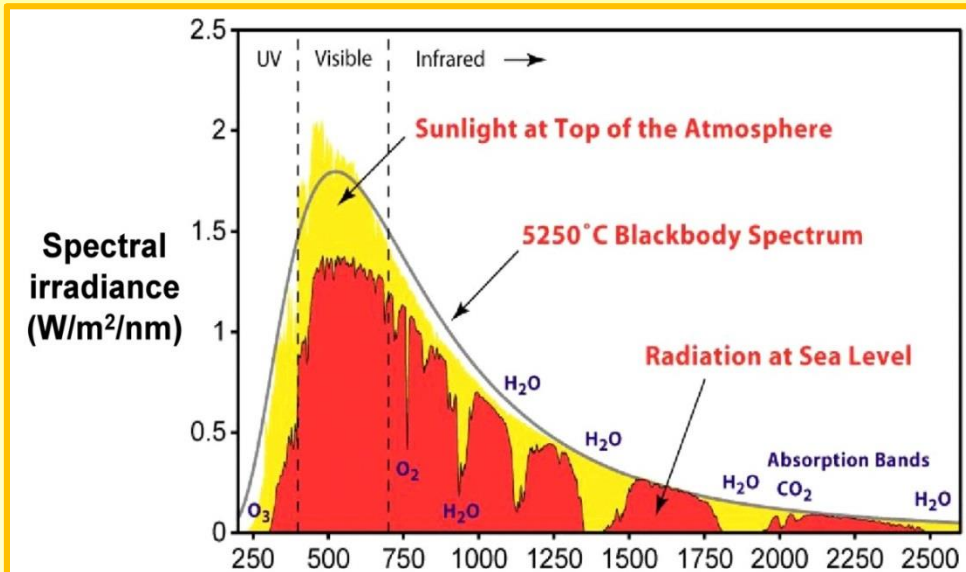
National Institute of Standards and Technology
U.S. Department of Commerce

Agenda

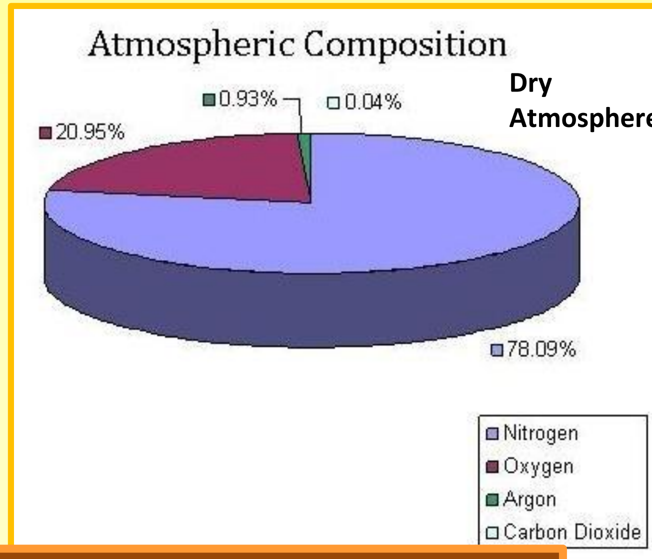
- Review of Earth's Greenhouse & Climate Impact
- Greenhouse Gas Accounting and Inventories
- The Technical Problem & its Manifestations
- NIST Program Objectives, Rationale and Components
  - Selected Project Descriptions
  - Cities, Urban GHG Concentration Domes & Satellites
  - An International Reference Test Bed Framework Concept
- Selected Program Accomplishments & Summary

Atmospheric Composition & Solar Irradiance

Molecular Absorption Processes



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



Abundant Long-Lived Greenhouse Gases

Global Atmospheric Concentrations

CO_2 – Carbon Dioxide	400	µmoles/mole
CH_4 – Methane	1.8	µmoles/mole
N_2O – Nitrous Oxide	0.32	µmoles/mole

- **Earth's Atmosphere: ~99% - nitrogen and oxygen with other gases at trace concentrations**
- **Other gases in trace amounts have significant impact on the atmosphere**
  - **Observation of the solar spectrum through Earth's atmosphere shows large gaps**
  - **Absorption by molecular gases reduce or eliminate down welling radiation to the surface**
  - **Ozone (O_3) absorption protects biologics at the Earth's surface from ultraviolet radiation**
  - **Oxygen absorb in the far red and near infrared.**
  - **The greenhouse gases absorb thermal radiation across the infrared**

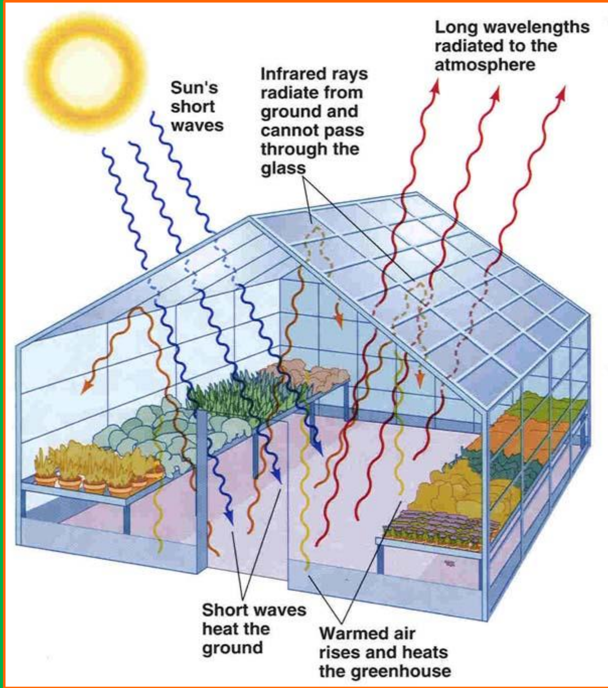
Earth's Greenhouse

Selective Absorption of Solar & Terrestrial Radiation

Selective Absorption Warms Atmospheric Gases

- Earth's surface absorbs short visible radiation, surfaces warm, and emit thermal radiation (infrared spectral region).
- Most abundant greenhouse gases (CO_2, CH_4, N_2O, & H_2O) strongly absorb thermal radiation: ~ 1.0 – 30μm
- Small concentrations of greenhouse gases have large energy uptake because their absorption strength is much larger, 100X to 10,000X, than nitrogen and oxygen
- Molecular collisions quickly transfer absorbed thermal energy to oxygen and nitrogen.

Earth's Greenhouse



Approximate Global Average Concentrations of Greenhouse Gases in the Atmosphere

CO_2 – Carbon Dioxide	400 μmoles/mole
CH_4 – Methane	1.8 μmoles/mole
N_2O – Nitrous Oxide	0.32 μmoles/mole

NIST
National Institute of Standards and Technology

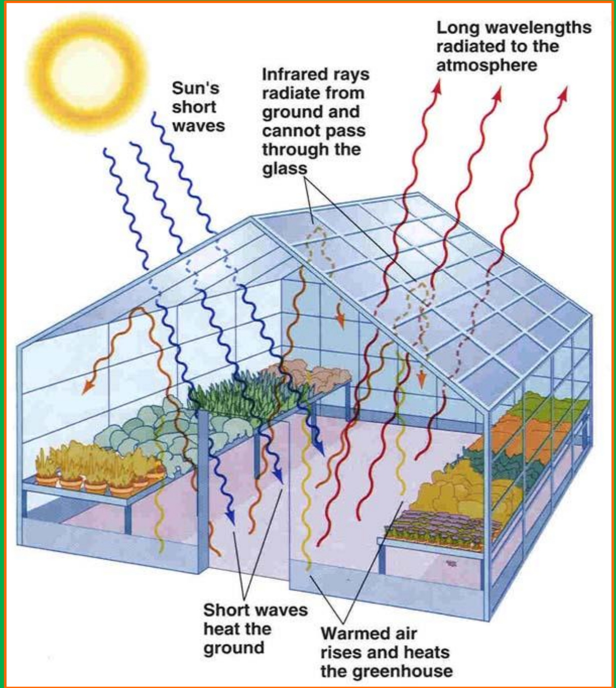
Earth's Greenhouse

Selective Absorption of Solar & Terrestrial Radiation

Selective Absorption Warms Earth's Atmosphere

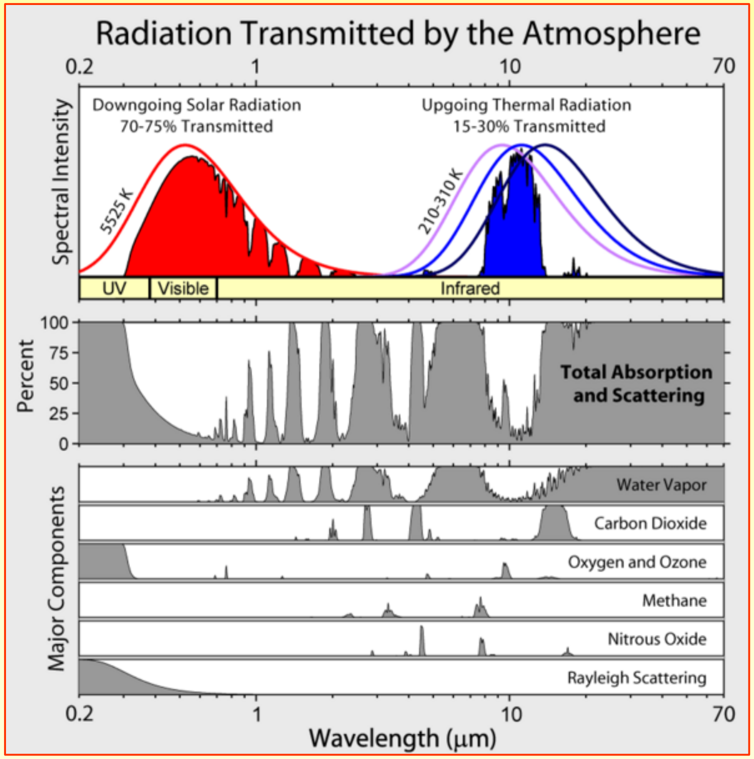
- Earth's land and oceans are warmed by the atmosphere
- Energy (heat) transferred to surfaces convectively and radiatively
- CO_2, CH_4, & N_2O:
  - Human activity (Anthropogenic) sources and sinks
  - Long-lived in the atmosphere
- Anthropogenic Water vapor:
  - small relative to ocean evaporation and condensation
  - Short lived in the atmosphere
- Greenhouse gases
  - Warm Earth ~ 35 ^{o} to 40 ^{o}C relative to zero conc.
  - Are long-lived (decades to centuries), so impact Earth's climate

Earth's Greenhouse

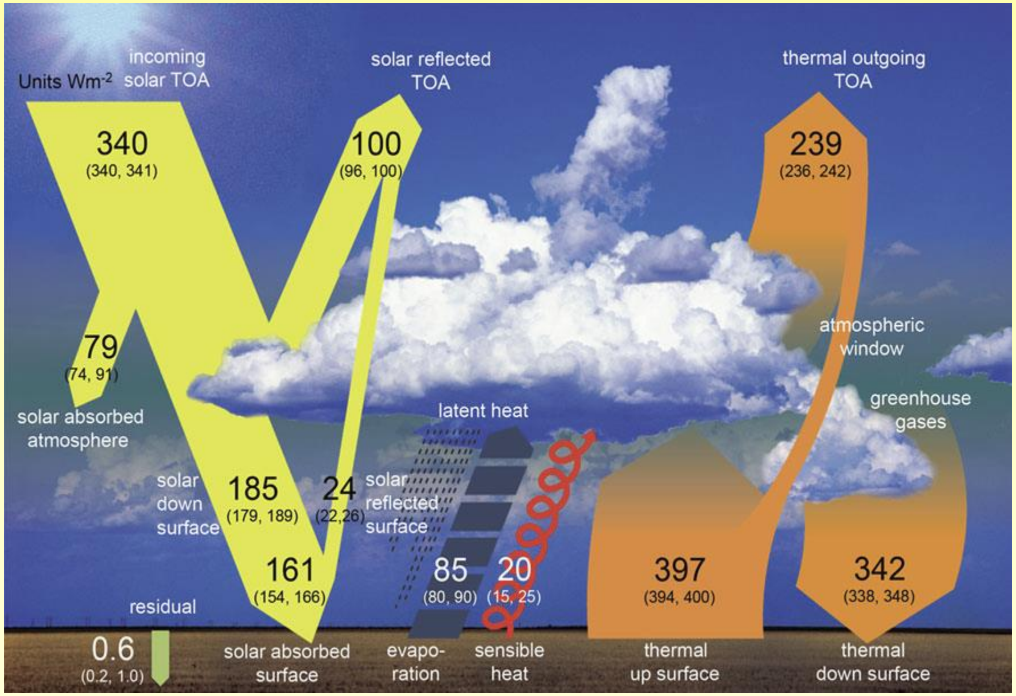


The Earth's Energy Budget

The Atmosphere as Window and Absorber



Earth's Energy Budget



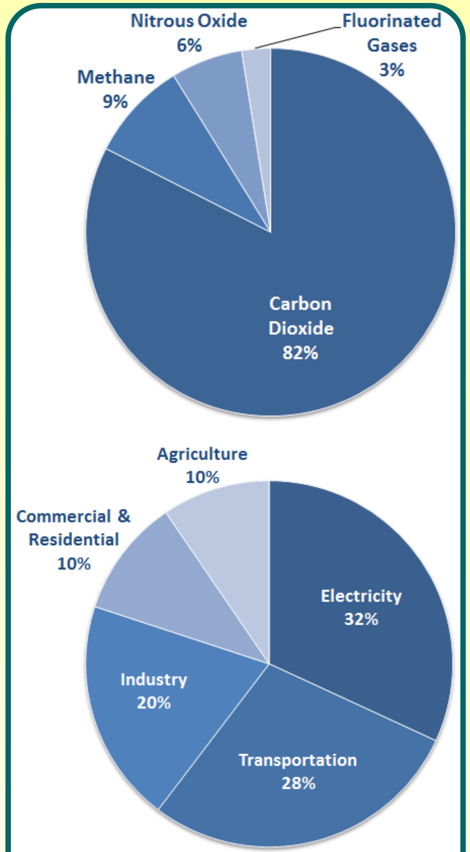
Wild, Folini, Schar, Fold, Loeb, König-Langlom. Clim Dyn (2013) 40:3107–3134

- **The greenhouse effect – radiative transmission and selective absorption**
  - **Many mechanisms interact with incoming short wavelength radiation to reflect it back to space or absorb it at the surface or in the atmosphere**
- **Long-lived atmospheric gases absorbs rather than transmitting thermal energy radiated from Earth's surface raising the atmosphere's temperature and driving shifts in the Earth's climate**

Accounting for Greenhouse Gases

Greenhouse Gas Inventories

- **Quantification of Greenhouse Gases emitted by U.S. sources and sinks from human activities**
- **U.S. EPA states U.S. inventory yearly & transmitting to the United Nations**
  UN Framework Convention on Climate Change
  - Stated in various ways
    - Economic sector, Gas type, etc.
  - Aggregated from many entities
    - Power generation, landfills, transportation, etc.
- **Self-reported data**
  - Based on EPA-recognized methods
  - 3rd party verification attests to usage of the prescribed method and accuracy of the computation
  - In climate policy discussion, often termed “bottom-up”
- **Biosphere (oceans and land) absorbs roughly half total human emissions on a yearly basis**



U.S Emissions in 2012 - 6,526M Metric Tons CO_2 equivalent

Greenhouse Gas Emissions and Climate Communities

A Range of Interests, Needs, Capabilities, & Practices

NIST
National Institute of Standards and Technology

The General Technical Measurement Problem

A Focus on the Accuracy of Greenhouse Gas Inventories

- GHG Inventory: time integrated (summed) GHG mass flow rate
  = mass flowrate * GHG mass concentration * time period
- GHG's of main interest – Trace gases in the atmosphere
  - CO_2 Combustion (Anthropogenic) and Biogenic Sinks (managed and unmanaged)
  - CH_4 Geologic (Anthropogenic) and Biogenic Sources
  - N_2O Agriculture (Anthropogenic)

$$\dot{M}_{GHG} = \dot{M}_{Total} \sum_j C_j$$

$\dot{M}_{GHG}$ – GHG Mass Flux
$\dot{M}_{Total}$ – Total Mass Flux
C_j – j^{th} GHG Concentration

GHG Inventory data & its accuracy depends both on determination of gas concentration and total gas mass flux.

Si Traceability ensures comparability assessment between inventory values, especially between sources and sinks, often widely separated in the world.

The Range of Application Areas

- **Direct Measurement in fixed geometries – smoke stacks and pipes**
- **Atmospheric transport in the atmosphere requires wind vector**

National Institute of Standards and Technology

Greenhouse Gas Emissions and Climate Communities

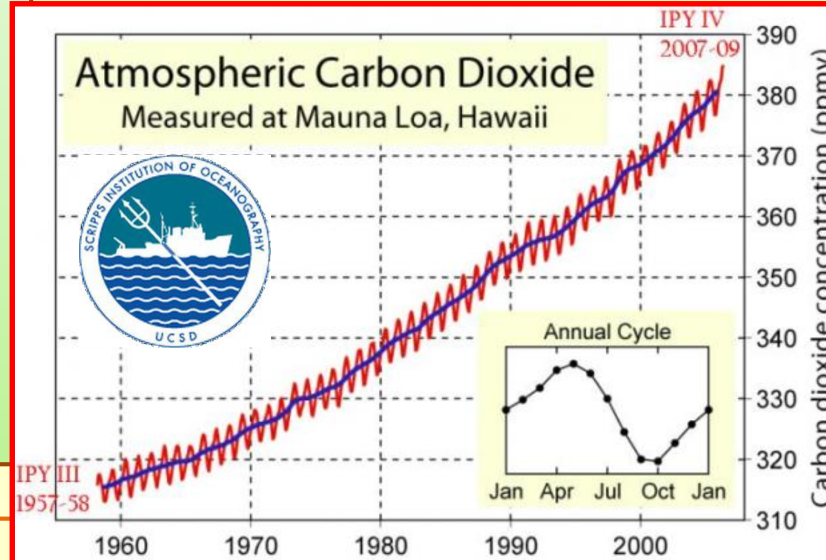
Some Definitions and Data

GHG Reporting Community:

- GHG Emissions & *Offsets* make National Inventories
- Bottom-Up - *Measurable*
- Accountancy Focus with 3rd party Verification of procedural compliance
- U.S. EPA-developed procedures predominate and are central to IPCC reporting requirements internationally - *Reportable*

Climate Science Community:

- Observing the Atmosphere to understand its process mechanisms
  - Bio-Geochemical Processes in the Atmosphere & Oceans
- Top-Down – *Verifiable Independent of the Source or Sink*
- Significant Complexity Levels
- Well-Established organizations



Definitions

- UNFCCC – United Nations Framework Convention on Climate Change
- MRV
  - Measureable – Emissions are capable of being measured
  - Reportable – Measured, and therefore, reported
  - Verifiable – *Independent* validation of reported emissions data

  } Bali Action Plan, UNFCCC - COP 13 (2007)
- NAMAs – Nationally Appropriate Mitigation Activities
  - Challenge is to meet MRV requirements for Consistency, Transparency, Comparability Completeness, and Accuracy.
- Bottom-up – Emissions determination using in-facility methodologies, e.g., Continuous Emissions Measurement (CEMs) systems for stack gas flows or fuel calculation methods for total combustion emissions
- Top-Down – Emissions determined from observations of the atmosphere – GHG flux into and through it

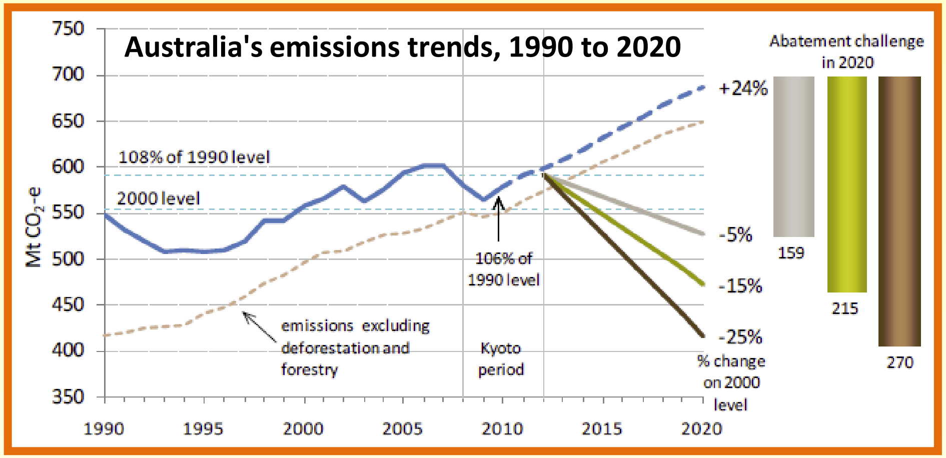
Inventories and Reduction Targets
What Accuracy is Needed to Support Policies

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

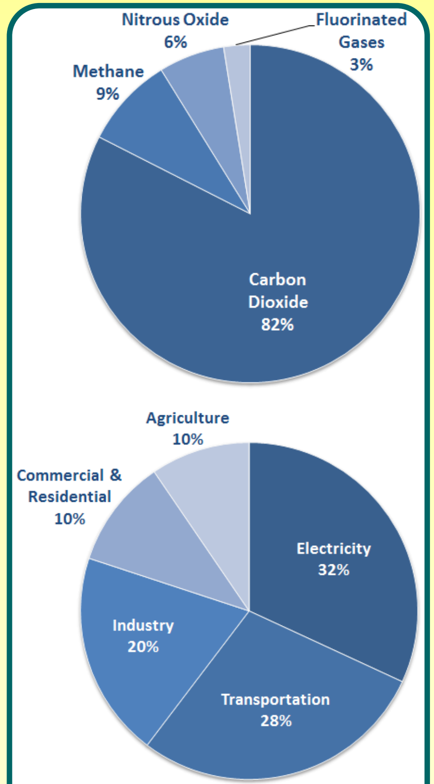
- President Obama's Climate Action Plan: 20% relative to 2005 by 2020
- EPA's recent Carbon rule ~30% relative to 2012 by 2030
- UK: At least 80% (from the 1990 baseline) by 2050
- Australia: 5% below 2000 level by 2020
- China: ??



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

NIST'S GREENHOUSE GAS AND CLIMATE SCIENCE MEASUREMENTS PROGRAM

NIST's Greenhouse Gas and Climate Science Measurements Program



U.S Emissions in 2012 - 6,526M Metric Tons CO_2 equivalent

Objectives:

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

NIST
National Institute of Standards and Technology

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

STATIONARY EMISSION SOURCES

ELECTRICAL GENERATION

Point Source GHG Metrology:
Comparing Fuel Calculated & Measured CO_2 Emissions

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

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?

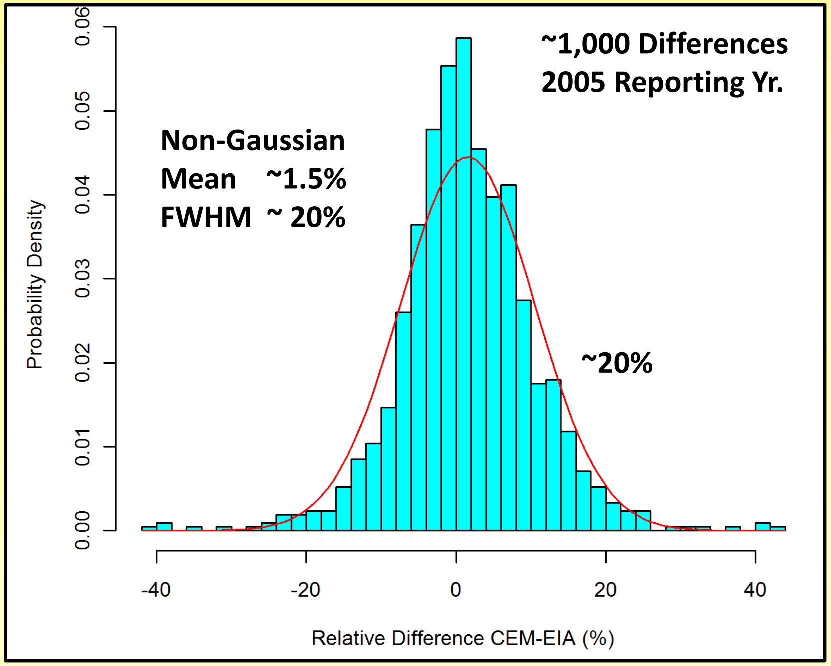
- Fuel Calculation vs. Stack Gas Flow Measurement Methods

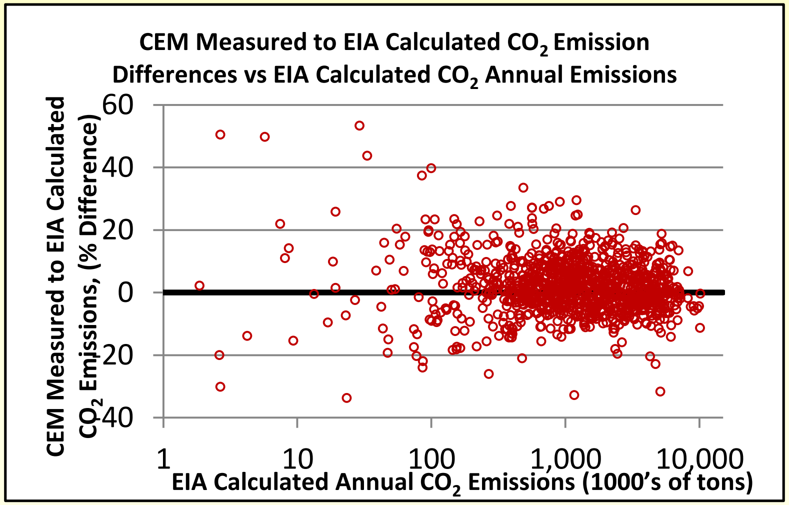
- **Public Fuel Consumption and Measured CO_2 Emissions Data Sources – eGRID (EPA) and EIA 767 Databases ~ 4800 Entries**
  - Pre-Combustion – Fuel Calculation Method
    - Amount of carbon and hydrocarbon burned (oxidized) and converted to CO_2
  - Post-Combustion – CO_2 Direct Measurement via CEMs Technology
    - Direct Measurement (CEMs Data) and Reporting of CO_2, SO_2, N_2O

Comparative Analysis:
Fuel Calculated vs Measured CO_2

Accuracy Improvement Potential

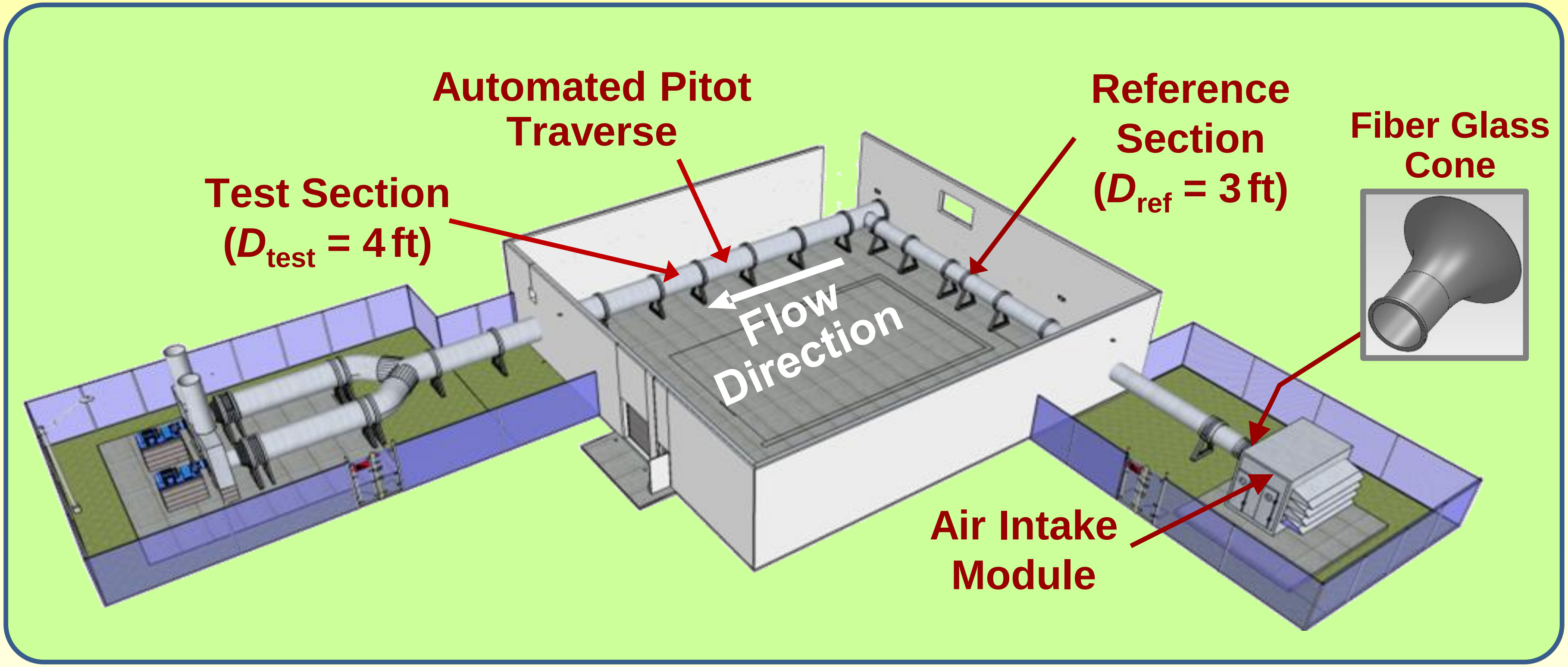
- **CEM Measurements**
  - Improve stack gas mass flow measurement
  - Reduce gas concentration uncertainty
- **Fuel Based Calculations**
  - Increase fuel carbon (energy content) accuracy
    - Calorimetry and sampling issues
  - Improved mass determination
    - Where to make the measurement
- **NIST's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





Smoke Simulator

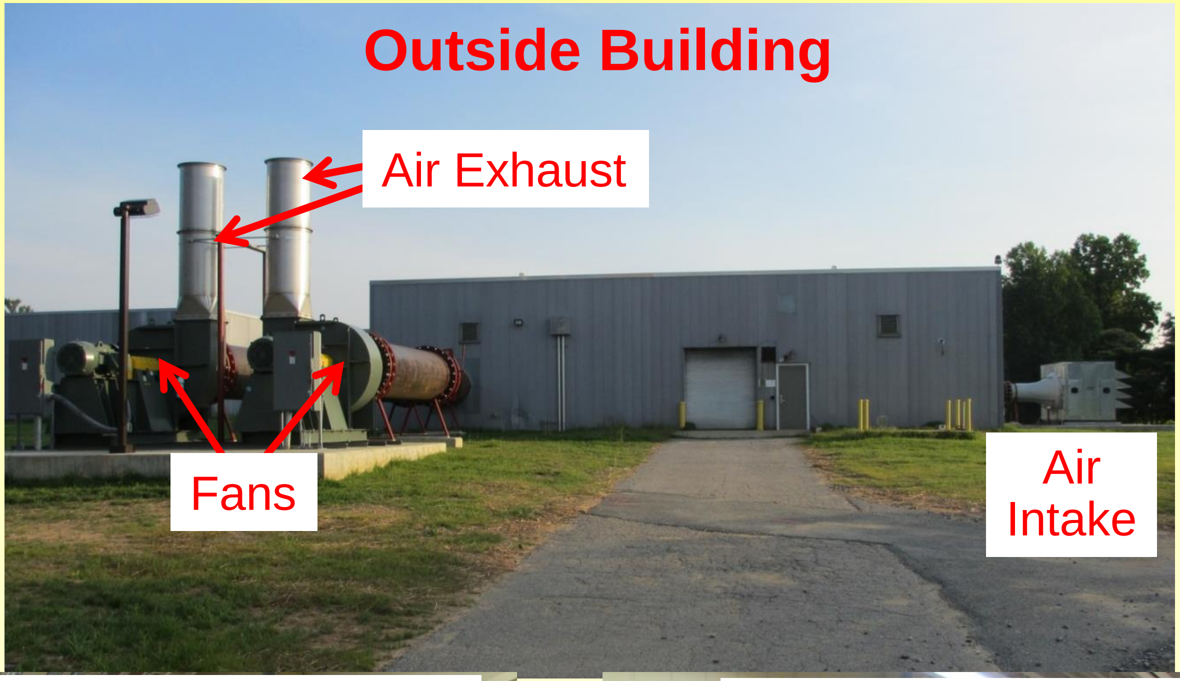
Address flow calibration issues in known, turbulent, swirling flows

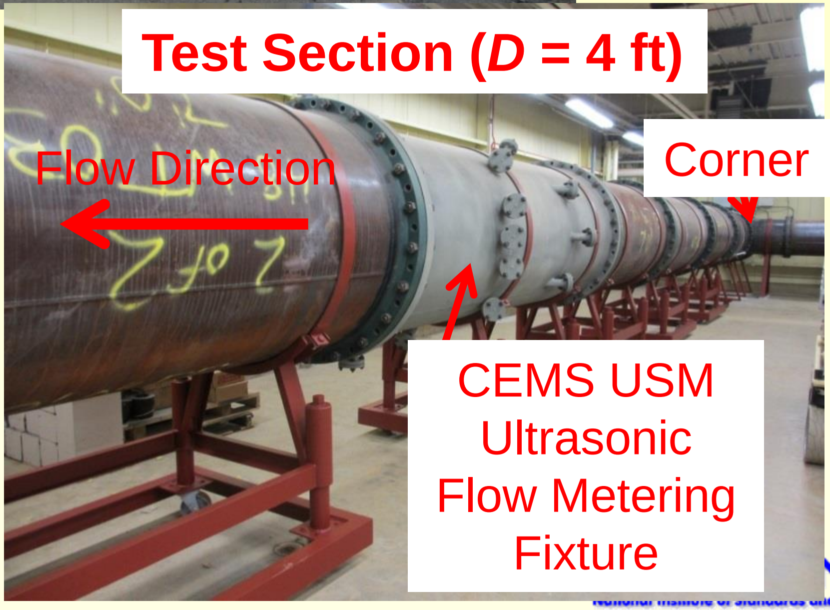


- **Horizontal orientation for cost and safety**
- **Smokestack Simulator is 1/10th the diameter of typical stack**
- **At the same velocity range – 5 to 25 m/sec**
- **Flow traceable to NIST flow standards**

NIST
National Institute of Standards and Technology

Smoke Stack Simulator





Establish the NFRL as a well-characterized and highly accurate test bed for CO_2 emissions measurements.

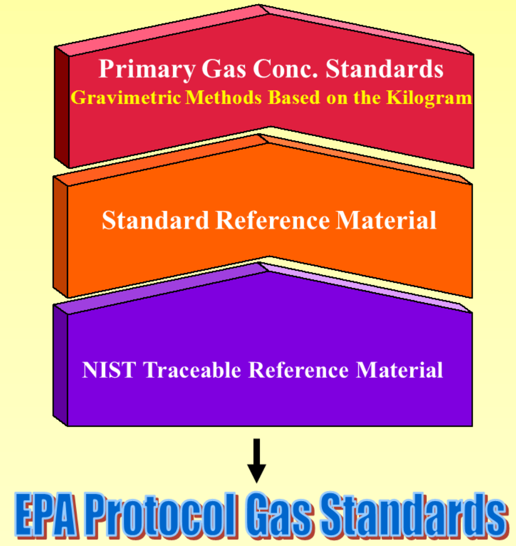
National Fire Research Laboratory

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

MEASUREMENT TOOLS, STANDARDS, & REFERENCE DATA

- Gas Concentration Standards
- High Resolution Near Infrared Spectroscopy Tools and Reference Data

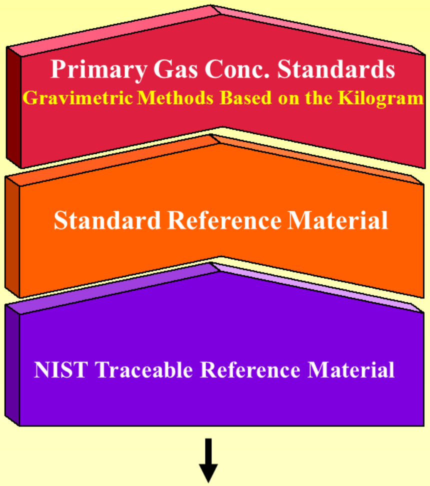
Gas Concentration Metrology
Spanning Communities



- **Gas Concentration Measurements Are Ubiquitous to Achieving Accurate GHG Measurements in All Settings**
- **NIST Gas Concentration Standards Support:**
  - CEM systems
    - High concentrations are typical of combustion flue gases
      - ~4% and lower concentrations
    - Gases are mandated for use by EPA for all electrical and manufacturing power generation plants
    - NIST Traceable Reference Materials Program
      - Quality assurance program with U.S. specialty gas manufacturers
      - ~ 150,000 standard gas cylinders / year required in the U.S. for in-situ calibration of stack gas concentration instruments (non-dispersive IR)
    - EPA uncertainty requirements (±2% relative) are modest relative to the state-of-the-art

Gas Concentration Metrology
Spanning Communities

- **Gas Concentration Measurements Are Ubiquitous to Achieving Accurate GHG Measurements in All Settings**
- **NIST Gas Concentration Standards Support:**
  - Atmospheric Monitoring
    - World Meteorological Org. trace gas concentration uncertainties are at or very near the state-of-the-art
    - WMO Central Calibration laboratory for CO_2, CH_4, N_20 NOAA's Earth Systems Research Laboratory
    - SRM 1720 (Northern Hemisphere) and SRM 1721 (Southern Hemisphere) certified for these gases in air and will meet or exceed WMO's Global Atmospheric Watch Data Quality Objectives
    - Close collaboration with NOAA-ESRL – Support linkage to WMO's CCL for these



WMO Atmospheric Trace Gas Monitoring Requirements

	Nominal Concentration	GAW Data Quality Obj.
CO_2	380 – 420 (µmol/mol)	±0.1 (µmol/mol)
CH_4	1800 – 2000 (nmol/mol)	±2 (nmol/mol)
N_2O	310 – 320 (nmol/mol)	±0.1 (nmol/mol)
CO	10 – 500 (nmol/mol)	±2 (nmol/mol)
SF_6	6 - 8 (pmol/mol)	±0.02 (pmol/mol)

MEASUREMENT TOOLS, STANDARDS,

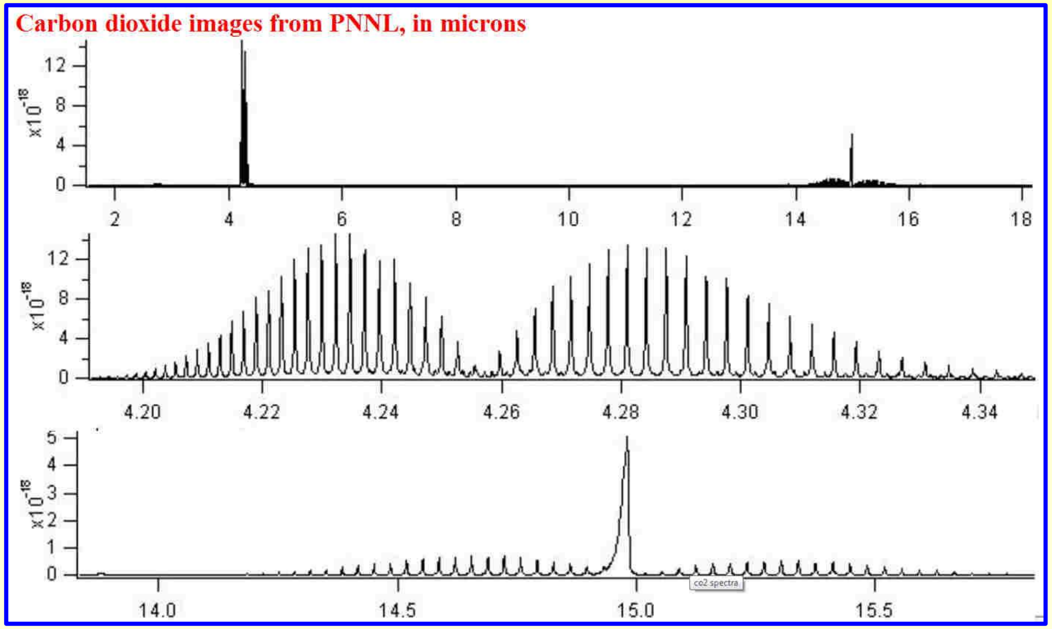
& REFERENCE DATA

- Gas Concentration Standards
- High Resolution Near Infrared Spectroscopy
  - Basics of Absorption Features
  - Tools and Reference Data
- Applications

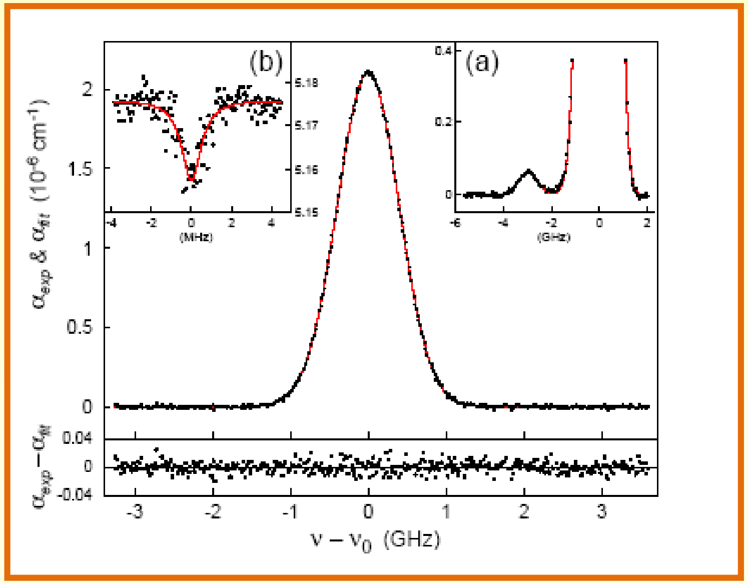
ABSORPTION SPECTROSCOPY BASICS

From Bands to Individual Lines

Spectroscopic Gas Concentration Measurement



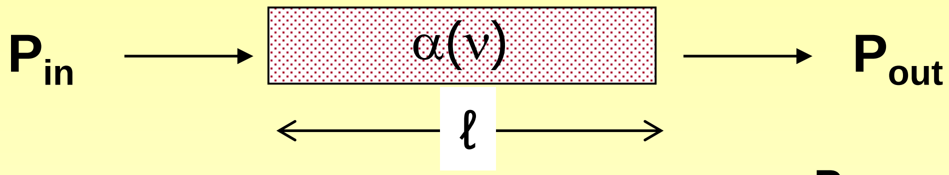
High Accuracy Reference Develop and Model Efforts



National Institute of Standards and Technology

ABSORPTION SPECTROSCOPY BASICS

Beer-Lambert Law



$$P_{out} = P_{in} \exp[-\alpha(\nu)\ell]$$

P – power

ℓ – length

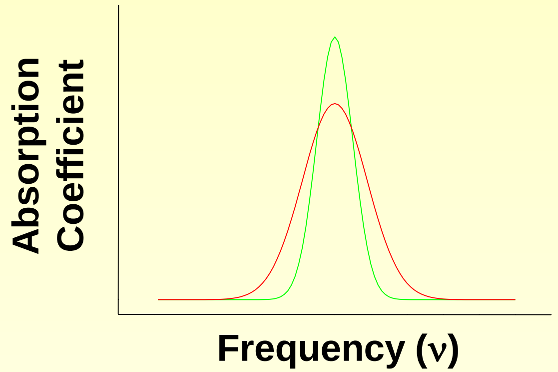
α(ν) – absorption coefficient (length^{-1})

Line-Shape Relations

$$\Rightarrow \quad \alpha(\nu) = \sigma(\nu)\rho$$

$$\sigma(\nu) = S\, g(\nu)$$

$$\int d\nu\, \sigma(\nu) = S$$



σ(ν) – cross-section (area)

ρ – amount-of-substance (amt sub/length^3)

S – line-strength (area·frequency)

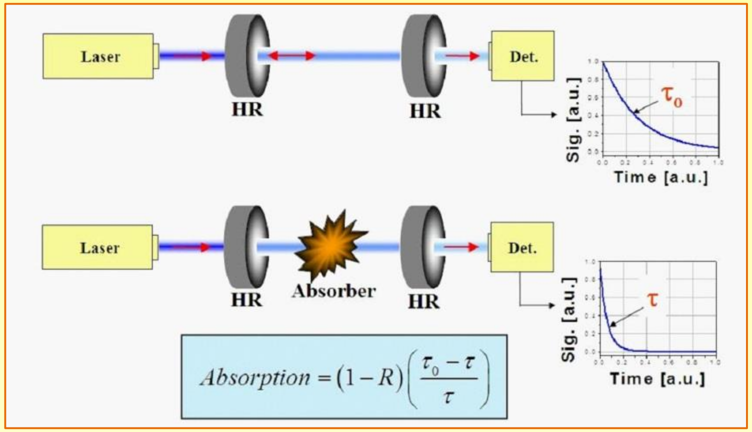
S is constant

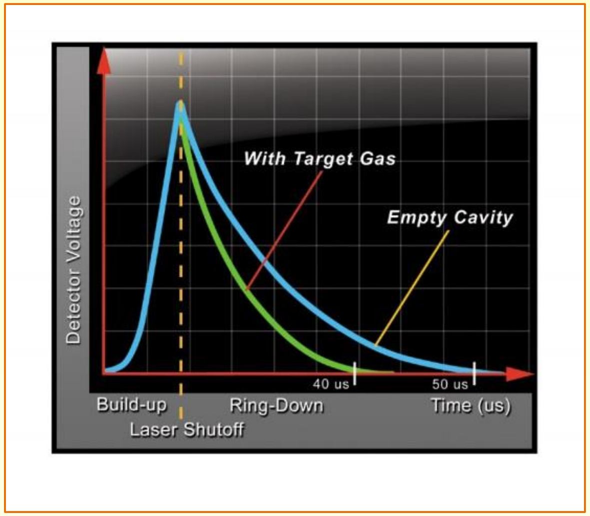
g(ν) depends on environment

Long Path Length Methods

Cavity Ring Down Spectroscopy (CRDS)

- Optical cavities made of high reflectivity mirrors (R ~ 0.99990)
- High frequency stability lasers the cavity with light.
- Once filled, the laser is switched off.
- High reflectivity mirrors make the light leak out in microsecond time periods
- Absorption response becomes a measurement of decay times
- Absorber and non-absorbing gas fills
- Noise and drift in the detector are no longer instrument noise
- Commercially-available analyzers use this method





NIST
National Institute of Standards and Technology

Frequency Stabilized CRDS

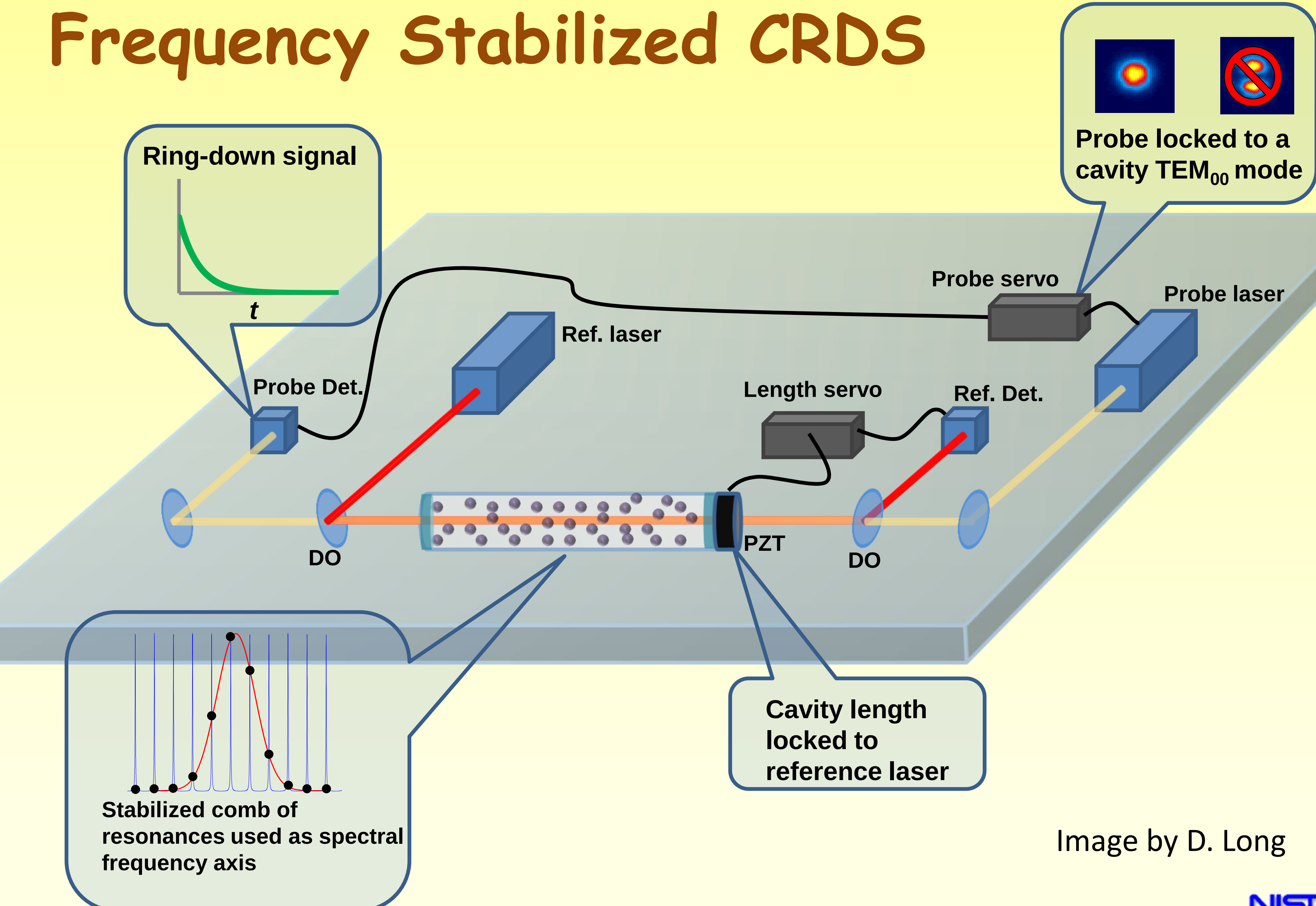
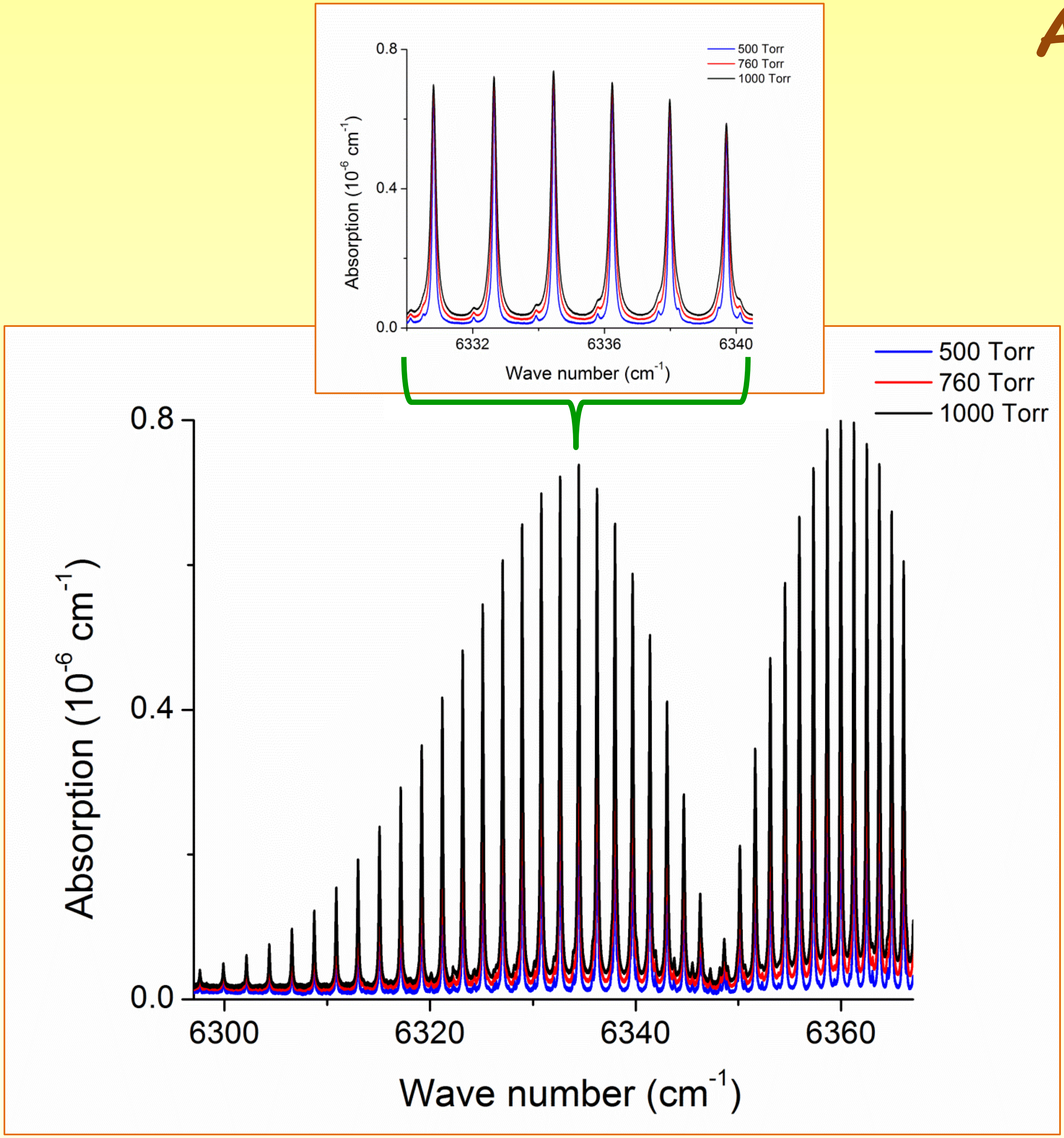


Image by D. Long

NIST
National Institute of Standards and Technology

High Accuracy Spectra of Entire Absorption Bands



2 THz wide spectra recorded in 45 minutes

425 ppm of CO_2 in air

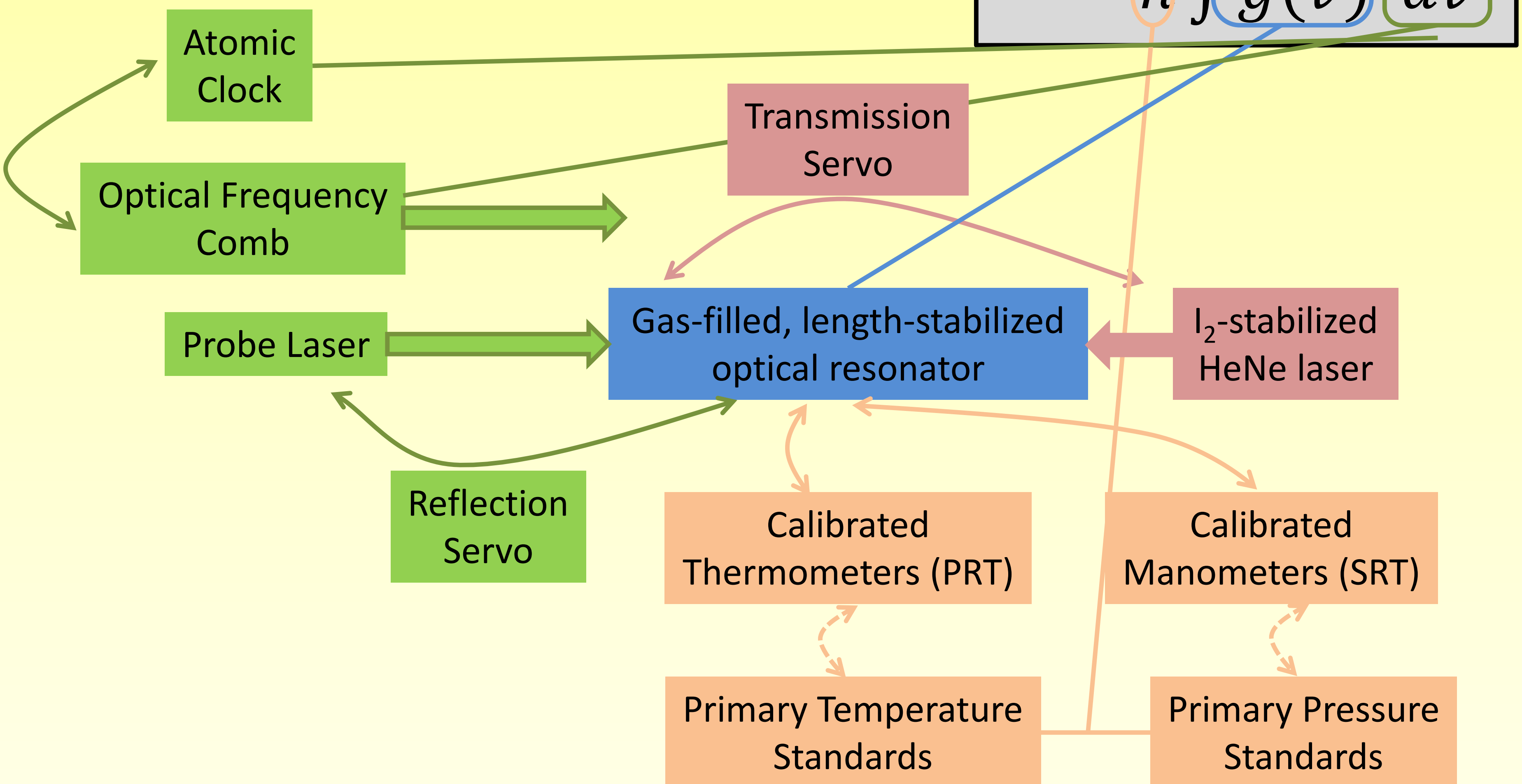
ECDL grating moved every 12 GHz

Each point is the average of 100 ring downs

NIST
National Institute of Standards and Technology

Measuring Traceable Line Strengths

$$S = \frac{\int \alpha(v)\, dv}{n \int g(v)\, dv}$$



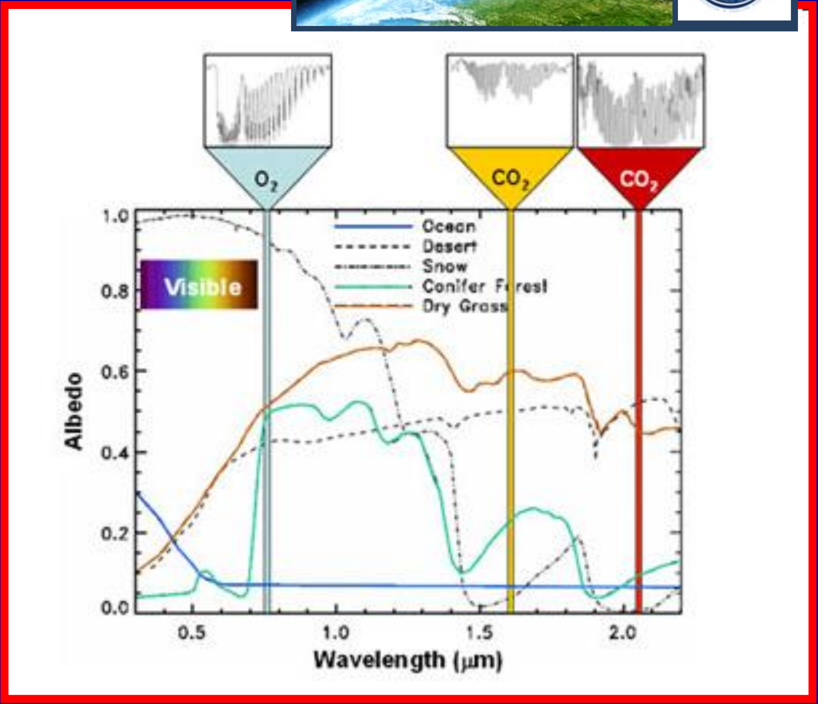
Reference Data Utilization:

NIST/NASA-JPL Collaboration:

The Orbiting Carbon Observatory 2

Improving CO_2 Measurement in the Atmospheric Column

- *Observes total column CO_2 Concentration*
- *Accuracy target : <0.5% (2 ppm)*
- *Has ~3 km^2 (1 x 3 km) spot size*
- *A new class of observing platforms with the potential for emission inventory diagnosis and verification by independent means*
- *Well-recognized, ground-based calibration methodologies are critical*
- *NIST provides spectroscopic reference data at the required accuracy levels or better:*
  - *the O_2 A-band (~765 nm),*
  - *the pertinent CO_2 bands (~ 1.61 and 2.06 µm), and*
  - *radiometric references*
- *Established radiometric traceability for the optical detector arrays for each of the 3 spectrometers*



FORECASTING FUTURE GREENHOUSE GAS MEASUREMENT NEEDS

GHG Measurement Needs of the Future

Satellite and Surface-Based Measurements: 2020 - 2050

GHG Observing Satellites On Orbit
- GOSAT - Japanese Aerospace Exploration Agency
- OCO 2 - NASA

Planned - NASA
- OCO III – Intnt'l. Space Station – Launch Date?
- ASCENDS (Active Sensing of CO_2 Emissions over Nights, Days, and Seasons) – Launch Date?

Development - ESA
- CarbonSat –CO_2 and CH_4 observations

Satellites - Total-Column Integrated GHG Concentration Measurements

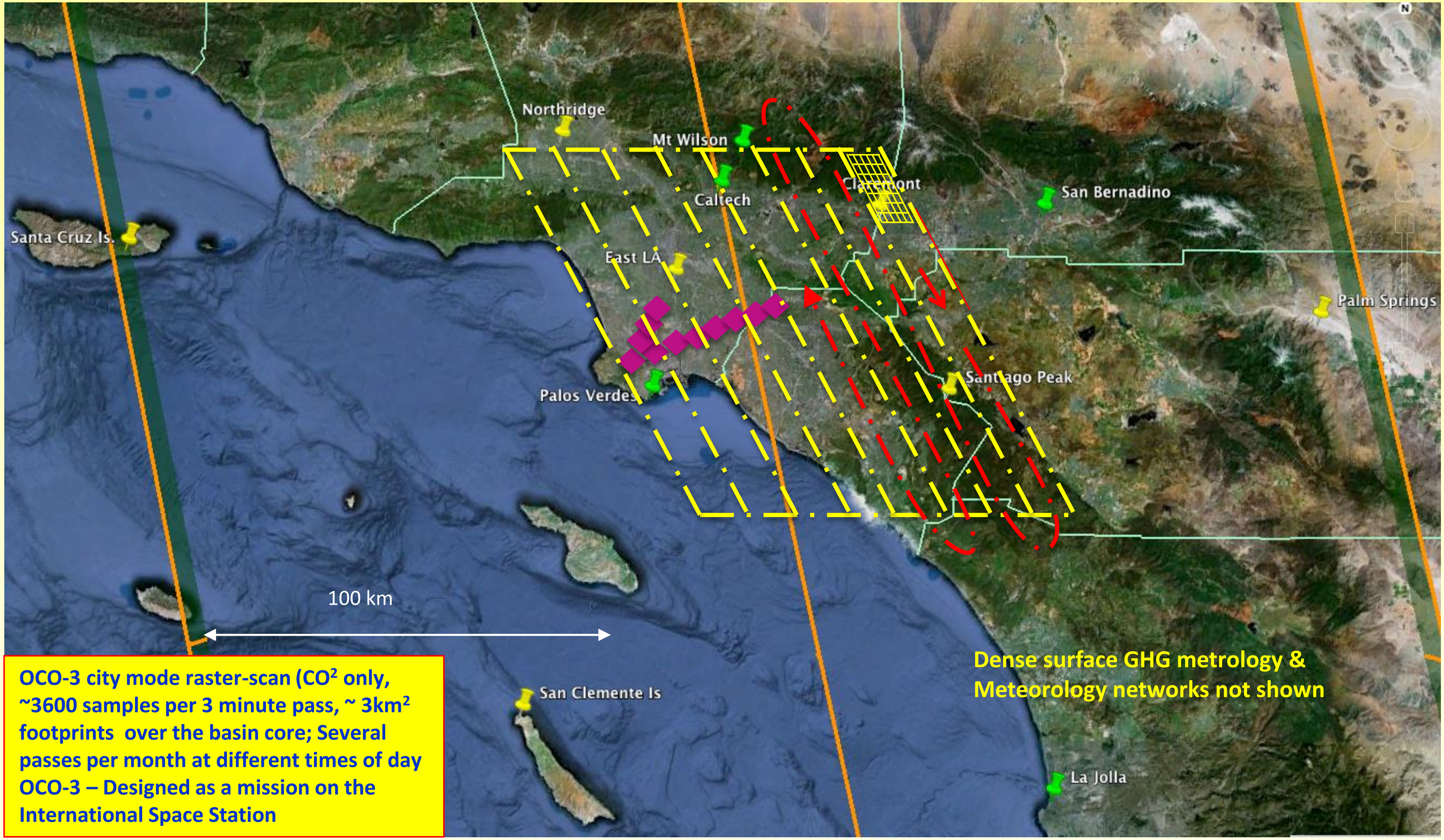
- Multiple satellite instruments planned or on orbit
  - Near-infrared spectroscopic instruments
- Effective and recognized traceability strategies needed
- Do not make GHG flux measurements as currently conceived, GHG concentration only

Surface-Based Systems GHG Concentration and Transport (Flux) Measurements

- Flux measurement capability supports attribution and independent verification of inventory data
- 1 - 5 km^2 or better geo-spatial resolution
- New measurement methodologies needed for independently diagnosing and ultimately verifying inventory data

Satellite GHG Monitoring – A Future Example

OCO-3 City-Mode over a Megacity (LA Example, ~ 2018)



OCO-3 city mode raster-scan (CO^2 only, ~3600 samples per 3 minute pass, ~ 3km^2 footprints over the basin core; Several passes per month at different times of day
OCO-3 – Designed as a mission on the International Space Station

Existing/planned GHG station | Proposed GHG stations | GOSAT samples | OCO-2 samples (1 x 3 km spot | OCO-3 samples

NIST National Institute of Standards and Technology

Developing and Demonstrating Greenhouse Gas Measurement Tools at Urban Scales in the U.S.

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 with complex topography and meteorology – an initial step toward verification of emissions

A First Step Towards an Urban International Greenhouse Gas Measurement Test Bed Framework

The Indianapolis Flux Experiment (INFLUX)

A Top-Down/Bottom-Up Greenhouse Gas Quantification Experiment

Objective: Develop measurement tools for independent verification of GHG inventories at urban and regional scales

- **Dense Observing Networks & Atmospheric Boundary Layer Transport Modeling**
  - Demonstrate measurement, characterization, and quantification of GHG Urban Domes and their dynamics utilizing a *Dense Observing Network* approach with aircraft observations :
  - 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 and temporal scales, and
  - GHG plume inversion methodologies.
- **Quantitative Goals**
  - Measure emission fluxes to within 10% or better
  - Identify major emitter locations within 1 km^2

The LA Megacity Carbon Project

Motivation:

Determine GHG emissions of a mega city with an estimated uncertainty.

Currently estimated differences between actual and reported emissions that by 50% or more when comparing inventory estimates with atmospheric measurements.

Objective:

Demonstrate a scientifically-robust capability to measure multi-year *emission trends* of carbon dioxide (CO_2), methane (CH_4), and carbon monoxide (CO) attributed to individual megacities and selected major sectors.

Reduce uncertainty by jointly improving GHG emissions data and atmospheric observations.

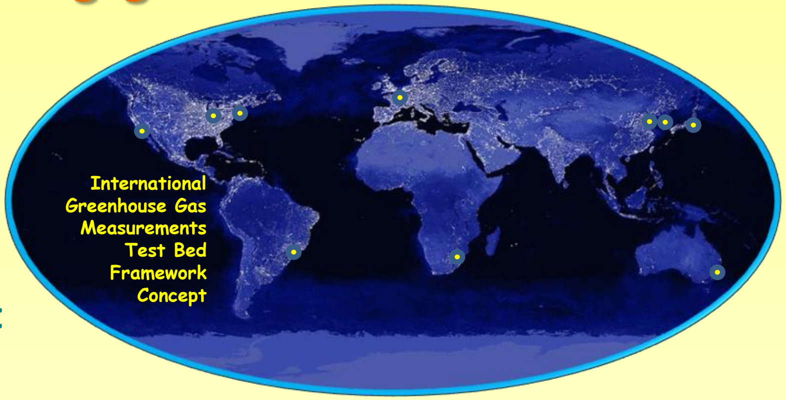
Use independent and accurate measurements, identify error sources to improve emissions data quality and ultimately, validate basis for emission inventory.

Approach:

Use surface-based GHG observing network and aircraft observations coupled with state-of-the-art boundary layer measurements and characterization methods to observe emission trends in the South Coast Air Basin.

International Greenhouse Gas Measurements Test Bed Framework

International Metrology & Climate Communities Engagement



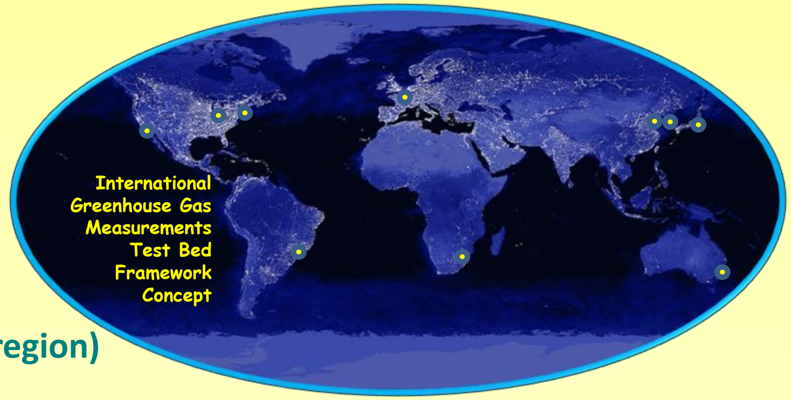
Concept:

- **Establish an International Greenhouse Gas Measurements Test Bed Framework that:**
  - Enables joint development of advanced measurement capabilities for urban and regional GHG domes and their dynamics,
  - Establishes scientific validity and performance capabilities of advanced measurement methodologies and instruments,
  - Provides a focus for multi-organization efforts with locations and organization on all continents but Antarctica,
  - Facilitates open, internationally-recognized measurement methodology development and evaluation with open data exchange and utilization across national borders, and
  - Strengthens methods to correlate and calibrate satellite measurements in-situ with those made on the surface as a means to establish SI traceability
- **As the Basis for Global Recognition of Measurement Capabilities for:**
  - Diagnosing the quality of GHG emissions data and
  - Verification support for global Measurement, Reporting and Verification (MRV) concepts likely to be required by future international mitigation agreements

International Metrology & Climate Community Engagement

International Greenhouse Gas Measurement Test Bed Framework

Approach:



- **Joint development of urban GHG measurement methodologies utilizing population centers, megacities, as test bed sites**
- **Engage with nations or regions that have:**
  - Suitably located megacities (one or two cities per continent/region)
  - The scientific and technological capabilities needed, and
  - The necessary national interest and will to commit the resources necessary
- **Joint GHG measurement science research developing methodologies thoroughly vetted for their scientific foundation, accuracy, and recognition within the international community.**
- **Use existing Convention of the Mètre structures**
  - Existing, internationally-recognized treaty organization with well-demonstrated working relationships and the necessary organizational structures largely in-place
  - Facilitates communication & organization
  - Broaden international linkages – WMO, international climate change/science

Facilitating Organization Linkages
- Individual cities, Mayor Organizations
- International cities organizations
  - C40
  - ICLEI
- International Climate Organizations
  - WMO
  - GEO – Global Earth Observations
  - ICOS – International Climate Obs. Sys.

Challenges for NMIs & the NMI Community

- **Most NMI's currently may not have the necessary skill sets and connections**
  - Partnering with national organization to aggregate the technical resources / expertise necessary to address this class of measurement science research
  - Strengthen expertise in climate science and related disciplines to successfully interface with both the national climate science community and the international community

Tools and Test Beds for Diagnosing Greenhouse Gas Inventory 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*

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 Measurement Testbed Framework

NIST
National Institute of Standards and Technology

Recent Program Accomplishments

- **Microwave Standards**
  - Brightness Temperature Standard and Dissemination Methodologies
  - New CROMMA Facility - metrology for antennas operating in climate monitoring bands (100 GHz-500 GHz)
- **Gas Concentration Metrology**
  - State of the art standards over the atmospheric concentration range
- **NIR Spectral Reference Data and Tools**
  - Highest accuracy data for oxygen, CO_2, and water vapor in the OCO 2 bands of interest
  - Demonstrated s/n levels (10^6:1) – stringent test of line shape models
  - New monitoring approach for CO_2 using photo acoustic spectroscopy
    - Cheaper, faster, accurate method –CO_2 isotopologues to improve source attribution
- **Advancing Satellite Calibrations**
  - Validation of GOES-R ABI and OCO-2 radiance scales
  - Measured CLARREO prototype blackbodies
  - Improved performance of standards for on-orbit ocean color measurements
  - Demonstrated feasibility at <1% level of lunar spectral irradiance traceability

Recent Program Accomplishments

- Measurement Science of Carbonaceous Aerosols
  - New metrology tool to measure aerodynamic size with mass discrimination
  - Demonstrated new approaches to aerosol reference materials with potential for field instrument calibration
- Establishing rigorous traceability for seawater pH
- Advanced Spectroscopic Measurement Tools
  - Differential Absorption LIDAR – path selective CO_2 concentration measurement
  - Path-integrated CO_2 concentration based on frequency-comb metrology
- Test beds for Urban GHG Domes
  - Indianapolis Flux Experiment has become operational with initial results for dense network design criteria, estimates of differences between top-down and bottom-up emissions estimates
  - Los Angeles Carbon Project is moving to operational capability
  - Establishing a 3rd test bed in the U.S. Northeast corridor – Baltimore/Washington area

Thank You

&

Questions