Joining Metrology and Meteorology Communities for Climate Change

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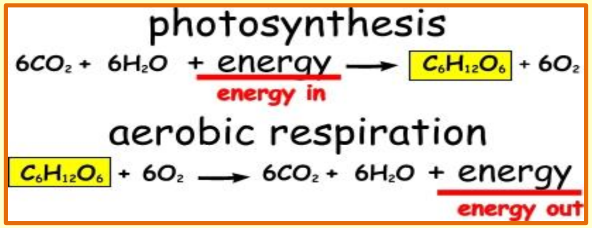
Agenda

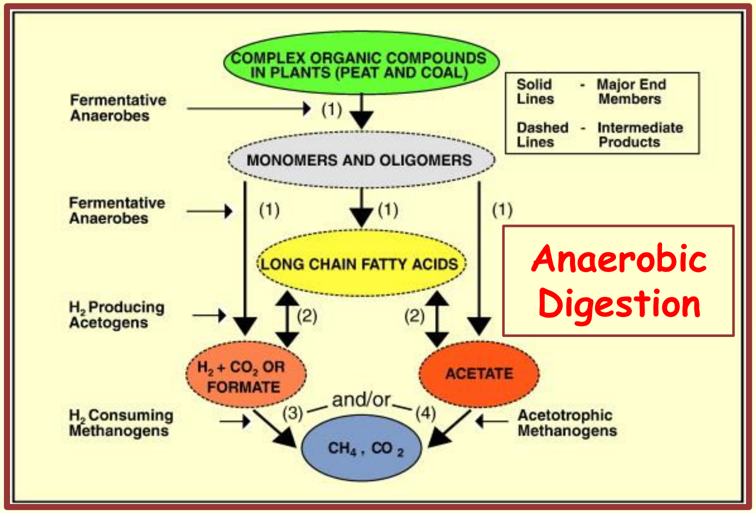
- The Technical Problem of Greenhouse Gas (GHG) Emissions Joining Metrology with Use and Understanding of the Dynamics of Earth's Atmosphere (Meteorology)
- Emissions Diagnosis and Quantification: the Scope of NIST's Efforts to Improve Emissions Measurement Capabilities
- Mitigation Issues faced by Governments
- NIST Program Components
- Measuring Emissions in Cities & an International Measurements Test Bed Framework
  - Working a Bit Outside the National Metrology Institution Box

Terms, Definitions, and a Bit of the Landscape

- **Earth's Greenhouse**
  - The atmosphere transmits short wave radiation (visible), absorbs long wave (3 – 15 µm)
- **Greenhouse Gases (GHGs) Produced by Human and Natural Activities**
  - CO_2, methane, N_20, and many halogenated gases
    - CO_2, methane (CH_4), N_20 are the most prevalent in the atmosphere
    - NIST's GHG measurements program is focused on the 3 most heavily emitted gases, the primary gases
- **Carbon Dioxide – CO_2**
  - Anthropogenic and naturally-occurring emitters and absorbers
  - Fuel combustion for electrical & industrial power
    - A primary focus of mitigation discussions
  - Removal Mechanism
    - the natural environment – land and oceans
    - Absorbs about half current anthropogenic emissions
    - Plants absorb substantial amounts – croplands and nature



- **Methane**
  - Anthropogenic and biogenic sources
    - Anaerobic Digestion
    - Geologic – Natural Gas
    - Source attribution can be an important and sensitive issue
      - Natural Gas, Landfill and waste water treatment facilities, swamp & sewer gases
  - Removal Mechanism: OH oxidation channel in Atm.
  - GWP 23 (100 yrs), ~80 (25 yrs), Lifetime ~12 yrs



- **N_20**
  - Primary source – Agriculture (fertilizer & plowing)
  - GWP 298 (100 yrs), Lifetime 114 yrs

The General Technical Measurement Problem

A Focus on the Accuracy of Greenhouse Gas Inventories

- GHG Inventory:
  time integrated (summed) GHG mass flowrate
  = mass flowrate * GHG mass concentration * time period
- GHG's of main interest
  - CO_2: Combustion (Anthropogenic) and Biogenic Sinks (managed and unmanaged)
  - Methane (CH_4): Geologic (Natural Gas, Anthropogenic) and Biogenic Sources
  - Nitrous Oxide (N_2O): Agriculture (Anthropogenic)
- GHG's are mixed with other atmospheric gases in various amounts

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

$\dot{M}_{GHG}$ – GHG Mass Flux

$\dot{M}_{Total}$ – Total Mass Flux

C_j – j^{th} GHG Concentration

GHG Inventory & its accuracy depends both on gas \ concentration and total gas mass flow determination.

SI Traceability can ensure levels of comparability between GHG inventory values, especially between sources and sinks, often widely separated in the world.

Greenhouse Gas Mitigation Issues

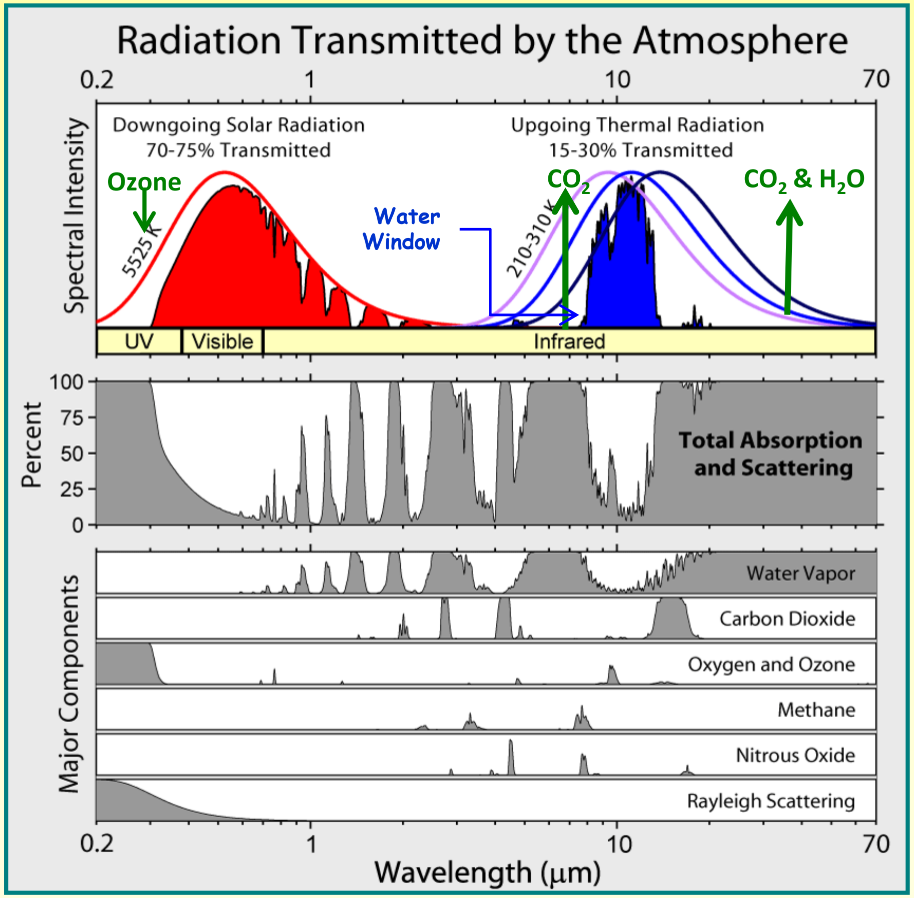
- Desired GHG inventory accuracy targets can be elusive
- National inventory accuracy statements are thought to be good, if below 10%
  - Many UNFCCC Annex 1 Countries claim such accuracy levels
  - Some skepticism in segments of the climate science community
- National GHG mitigation targets in the U.S.
  - President Obama has set an emissions reduction target of 17% by the year 2020 relative to 2005 U.S. emission levels
  - Longer term target levels of 50% and 80% by 2050 have been put forth
- Demonstrating that targets such as these have been achieved is a challenging and complex issue with many aspects and approaches
  - Heavy involvement by the climate science community
  - Improved GHG inventory quantification capabilities are needed for a range of applications
  - Opportunity for National Metrology Institutions to develop and provide improved measurement capabilities and the supporting standards

What is NIST Doing in Greenhouse Gas and Climate Science Measurements

Program Objectives:

- Advance measurement tools and standards development to:
  - Improve the accuracy capability for:
    - Greenhouse gas emissions data, and
    - Remote observations, both satellite and surface-based
  - Independently verify greenhouse gas emissions data both nationally and internationally, and
  - Extend the science base needed to better understand and describe the Earth's climate and its change drivers.
- Enable international measurement standards and protocol development that ensures accuracy and provides confidence, and reliability of local and global assessments of GHG emissions.

Program Components



- Stationary/Point Source Metrology
  - Continuous Emission Monitoring Test Beds
- Distributed GHG Source Metrology
  - Flux Measurement Tools
    - Differential Absorption Lidar Developments
  - Advanced Measurement Systems for Urban Settings
    - Dense GHG Observing Networks – Measurements to Independently Verify GHG Emission Inventories
    - Indianapolis Flux Experiment
    - Los Angeles Megacity Carbon Project: Extension to Megacities and Development of an International Metrology Framework for MRV
- GHG Measurements, Standards, Ref. Data, and Tools
  - GHG Concentration Standards
  - Spectroscopic Reference Data
  - Surface Air Temperature Assessment
- Climate Science Measurements - Advanced Satellite Calibration Standards
  - Optical and Microwave
- Black Carbon Aerosol Measurement Science
  - Optical Properties
  - Reference Materials and Measurements

Point Source Metrology:

Comparing Fuel Calculation and Direct CO2 Measurements Using Reported Emission Data

Electricity Generation ~40% of U.S. CO_2 Emissions Inventory

Question:

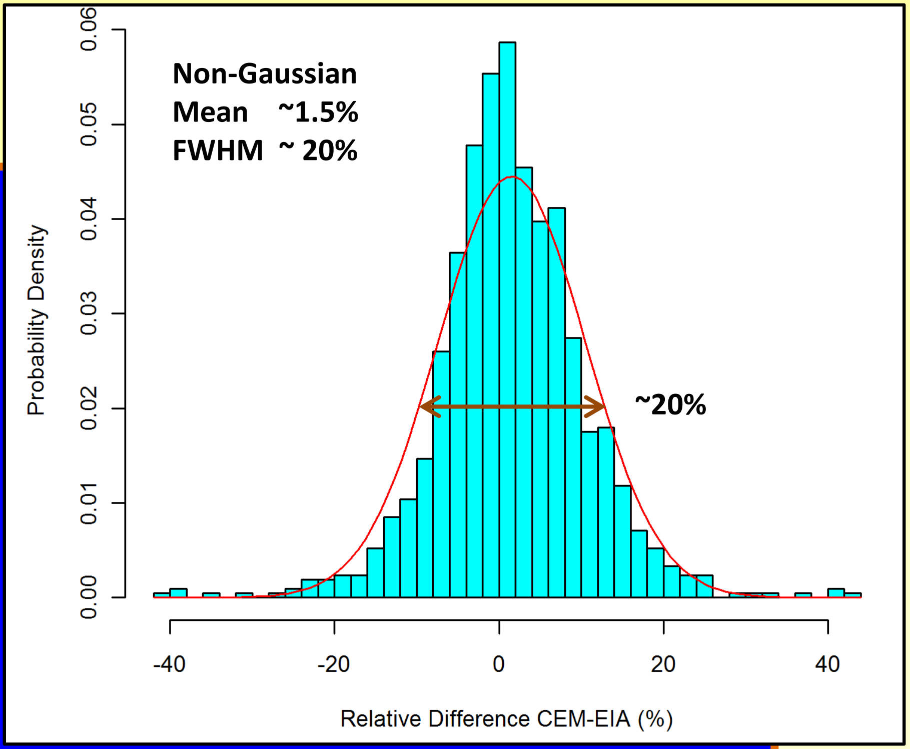
What is the Agreement Between the 2 Mainly-Used Methods of CO_2 Emissions Reporting Information?

- Fuel Calculation vs.
  Continuous Emissions Monitoring (CEMs) Methods

- Fuel Consumption and Measured CO_2 Emissions Data – 2005 & 2009 U.S. Reporting
  - Pre-Combustion – Fuel Calculation Method
    - Amount of carbon burned 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, NO_x Required by U.S. EPA
- EPA and DoE databases contain >4800 entries
  - 1066 (2005) and 944 (2009) have complete fuel type, mass, and energy content data
  - All the data required to compare the tow methods

Comparative Analysis:

Fuel Calculation CO_2 – CEMs CO_2



Accuracy Improvement Potential

- **CEM Measurements**
  - Improve stack gas mass flow measurement
  - Reduce gas concentration uncertainty
    - Current EPA regulations allow ± 2% unc. for uncertainty
    - NTRM Program meets this need
- **Fuel Based Calculations**
  - Increase fuel carbon content accuracy
    - Calorimetry and sampling issues
  - Improved mass determination
    - 2 phase flow issue
- **NIST's Investment in Point/Stationary Source Metrology**
  - Improved gas flow measurement capabilities in smoke stacks
  - Large Fire Facility – large scale CO_2 emissions source and test bed

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DISTRIBUTED SOURCE METROLOGY

Program Objectives

- Develop methods for Accurately Quantifying Greenhouse Gas Emissions from Distributed Sources and Sinks (Natural and Anthropogenic) Independent of the Emission or Uptake Process
- Transfer New, Validated Diagnostic and Measurement Technologies and Reference Data to the Private Sector and Government
- Embody These Methods in the Scientific Literature and Documentary Standards

Research Efforts

- Urban Greenhouse Gas Measurement Systems and Test Beds with International Implications
- Spectral Reference Data Using Cavity Ring Down Spectroscopy
  - Broadly supports field and satellite measurement
  - Widely used instrument constant for NIR spectroscopy-based approaches
- Advanced Photoacoustic Spectroscopy Instrument
- Differential Absorption Lidar
- Frequency Comb Spectroscopy

Urban Greenhouse Gas Measurement Systems and Test Beds with International Implications

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

GHG Measurement Methods in the Future Combining Meteorology and Metrology

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

- The importance of Cities
- 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

Area GHG Emission Sources

Why Cities Matter

Focus of Human Activities

- Population drives highest energy utilization density and largest emissions, ~70% of total
- Has not been the focus of much of the 'climate science' research effort to date

Current Urban Observatories Focused on Air Quality Monitoring

- Airborne pollution measurement networks help managers and inhabitants get a bird's eye view of their physical and social environment
- Typically data are point location observations, sometimes coupled with modeling capabilities
- Greenhouse gases are rarely monitored for local/urban settings

Issues Challenging Local Governments

- Urban GHG plumes – where does it go & who does it impact?
  - Plume dynamics, prediction of down wind locations – Forward-time modeling
  - Point observation of plumes – Measurements of chemical and particulate concentrations
- Where do they originate? -- The localization or attribution problem
  - Attribution requires localized information – who is the responsible party
  - Source attribution from independent knowledge, an infrequent capability
    - Identification of source of "fugitive" emissions
- Greenhouse Gases Inventory Needs
  - Complete and accurate accounting of emissions and uptake
  - Spatial resolution required for source identification purposes
  - Inventories are the aggregation of many individual sources
  - Disaggregation will require similar geospatial specificity

City Governments Need Actionable Information

Decision Makers, Regulators, and/or Markets Need Reliable and Actionable Information

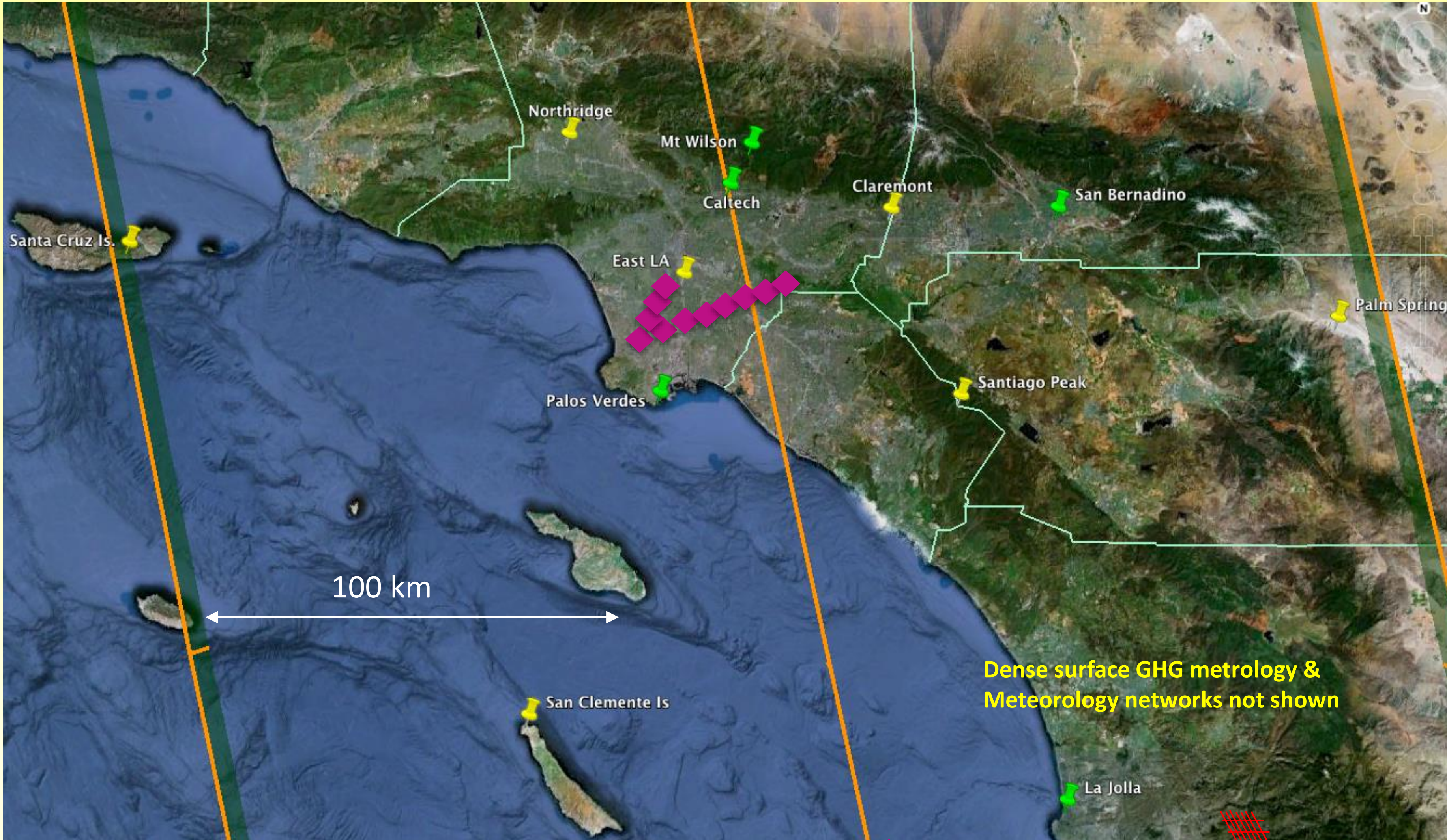
- Identify the Location of Emission Sources
  - Where To Go and Who Has Responsibility
  - Source-Independent Measurement Results Could Be Used to:
    - Diagnose and Reconcile Emissions Data Issues
    - Ultimately Validate Emissions Data with Independent Measurement Results

Scientific / Policy Questions & Challenges

- Moving to Smaller Spatial Scales is Relatively New
- Separating Emission Sources is Challenging
- Atmospheric Circulation – GHGs Imported from other Cities
- Connecting Observations with Policies
- What Makes a Sufficient Observational Capability

Satellite GHG Monitoring – A Near Future Example

OCO2 – The 1st U.S. Satellite to Measurement Greenhouse Gases from Space



Existing/planned GHG station

Proposed GHG stations

GOSAT samples

OCO-2 samples (1 x 3 km spot

OCO-3 samples

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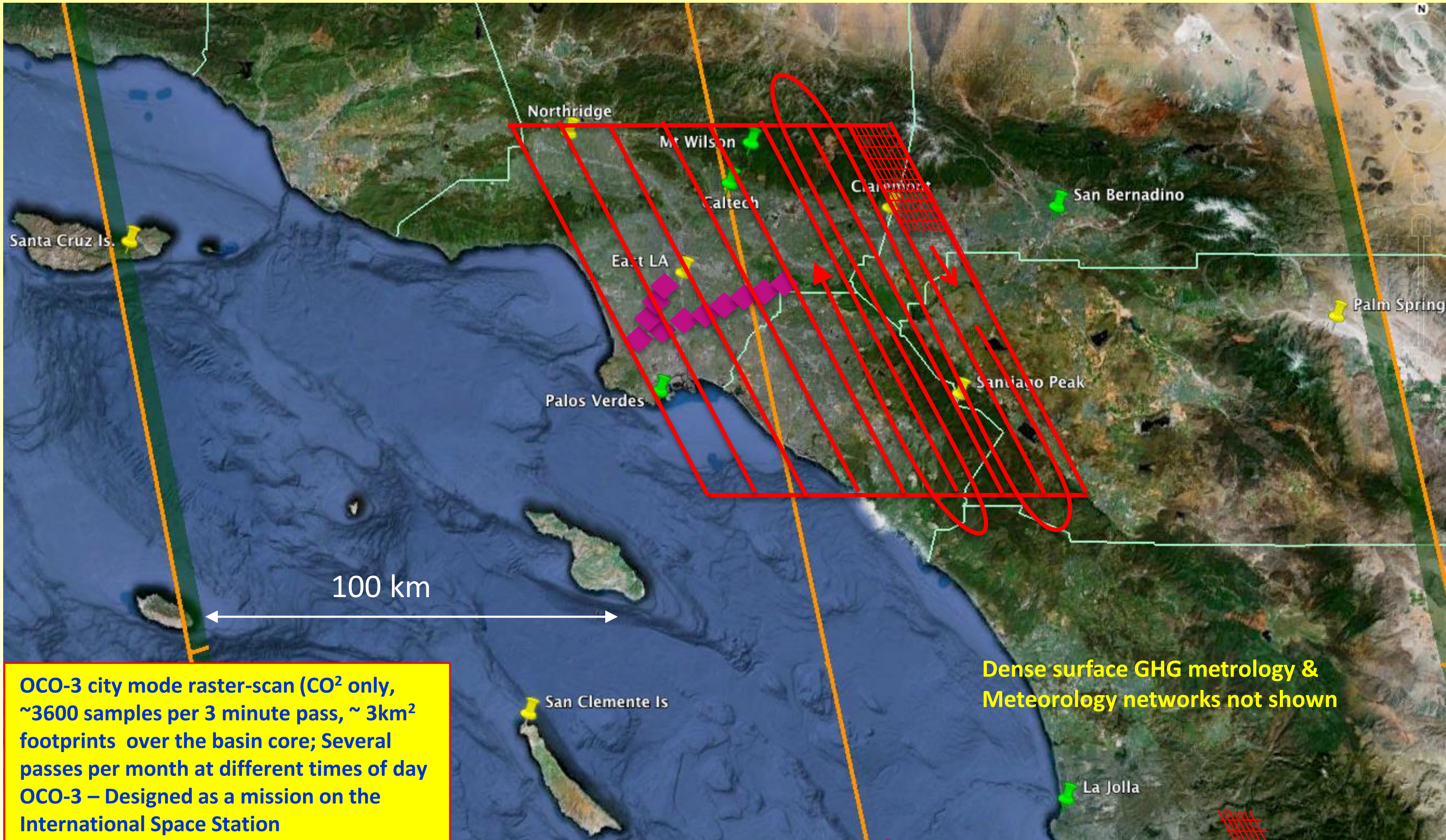
Satellite GHG Monitoring – A Ne arFuture Example

OCO-3 Measurement Density over a Megacity

(Los Angeles Example, starting 2017)



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

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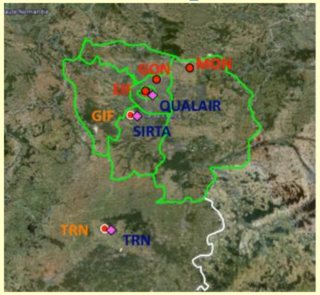
The LA Megacity Carbon Project

MegaParis CO_2 Project



http://co2-megaparis.lsce.ipsl.fr/#en

Motivation:

Determination of GHG emissions of a city in terms of uncertainty, may have estimated differences between actual emissions and reported emissions that differ by 50% or more when comparing inventory estimates with atmospheric measurements for a specific location, sector or gas.

Objective:

Reduce uncertainty by jointly improving GHG inventories and atmospheric observations to monitor trends in emissions. Application of independent and accurate measurements, identify errors in data or assumptions that will improve the fidelity of inventories and ultimately, validate what is actually being emitted to the atmosphere.

Approach:

Use dense GHG observing networks coupled with state-of-the-art boundary layer measurement and characterization methods to observe trends in the emissions in / to / from the LA Air Basin.

http://megacities.jpl.nasa.gov/portal/

The Indianapolis Flux Experiment (INFLUX)

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

A Test Bed for Performance Assessment of Urban GHG Measurement Approaches

The General Technical Measurement Problem

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- **Greenhouse Gases are moved through the atmosphere by the wind**
- **Meteorological measurements and models are a means of determining wind velocity and directions over the region of interest – a city**
- **The accuracy of meteorological measurements (wind speed & direction) is a significant measurement challenge for the metrology community engaged in developing measurement systems suitable for diagnosing the accuracy of greenhouse gas emissions and uptake.**

Muchas Gracias
Thank You

- There are significant measurements challenges presented by climate change.
- Advancing measurement capabilities to better understand these phenomena is one means of addressing these challenges.
- It is a global measurements issue.
- Working together the International Community can make progress toward solutions
- Moving forward will require participation of many nations

Questions / Discussion ?