Greenhouse Gas Measurements Program

Advancing Greenhouse Gas Emissions (GHG) Measurement Tools and Standards

A Climate Challenge:

Managing the Unavoidable and Avoiding the Unmanageable

(Adaptation) (Mitigation)

James R. Whetstone
Special Asst. to the Director for Greenhouse Gas Measurements
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National Institute of Standards and Technology

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

NIST's Greenhouse Gas Measurements Program

Purpose:

Equipping Mitigation Decision Makers and Managers With Quantitative Information Tools To Support Strategic Decisions and Charting Progress

Performance Needs:

- *1% - 3% Yearly Reductions Are Announced Mitigation Targets*
- *A Measurement Challenge*

Mitigation Measurement Challenges:

- ***Authenticating carbon credits across space and time is fundamental to success in commercial and regulatory activities.***
- ***Independent responsible party identification & quantification of emissions/uptake facilitates harmonious markets and fair regulation.***
- ***Currently unavailable measurement tools and capabilities can illuminate pressing climate science questions.***

NIST's Greenhouse Gas Measurements Program

Program Components:

- Measurement tools, methods, and reference data
  - Urban GHG Measurement Testbed System — EL,ITL,MML, PML, SPO & Others
  - Stationary/point source (smokestack) emissions — PML
  - Remote Sensing and Optical Measurements
    - A global system of GHG concentration standards traceable to the SI — MML
    - Optical radiocarbon measurement and GHG concentration gradient with altitude — MML, PML
    - Accurate spectral line shape data for atmospheric trace gases — MML
    - Photosynthetic activity in vegetation (solar induced fluorescence) — PML
- Carbonaceous Aerosols — MML
- On-Orbit Observing Instrument Radiometric Standards & Calibration — PML

Improving Urban and Regional Greenhouse Gas Measurement Tools

An Urban Emphasis

- Cities, metropolitan areas, states, and regions
  - Concentrate populations and energy use
  - Occupy a small percentage of Earth's Land
  - Estimated to be the source of ~70% of global GHG emissions
  - Paris Agreement recognizes sub-national actors – Business, Cities, and States
- Develop & Demonstrate Emissions Measurement Tools at Urban Scales
- Business, Local & State Governments Are Mitigation Policy Implementers
- Geographic Sensitivity to Identify Responsible Parties: Building & Street Level
- Accurately Quantify Emissions at Those Locations

NIST'S URBAN GHG MEASUREMENTS TESTBED SYSTEM

Urban testbeds are collaborative and multi-institutional:

- **Combining atmospheric measurements (Top-down) with emissions modeling (Bottom-up) using socioeconomic statistics, and demographic data,**
- **Estimate urban GHG emissions and their uncertainties, and**
- **Combine NIST, Federal agency, university, and private sector expertise.**

2010

The initial testbed

Indianapolis Flux Experiment (INFLUX)

9 public & private actors +

2013

2nd testbed

LA Megacities Project

12 public, non-govt., & private actors +

2014

Latest testbed

Northeast Corridor/Baltimore - Washington (NEC/BW)

5 public & private actors +

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

More are planned including expansion up the Northeastern seaboard of the U.S. …

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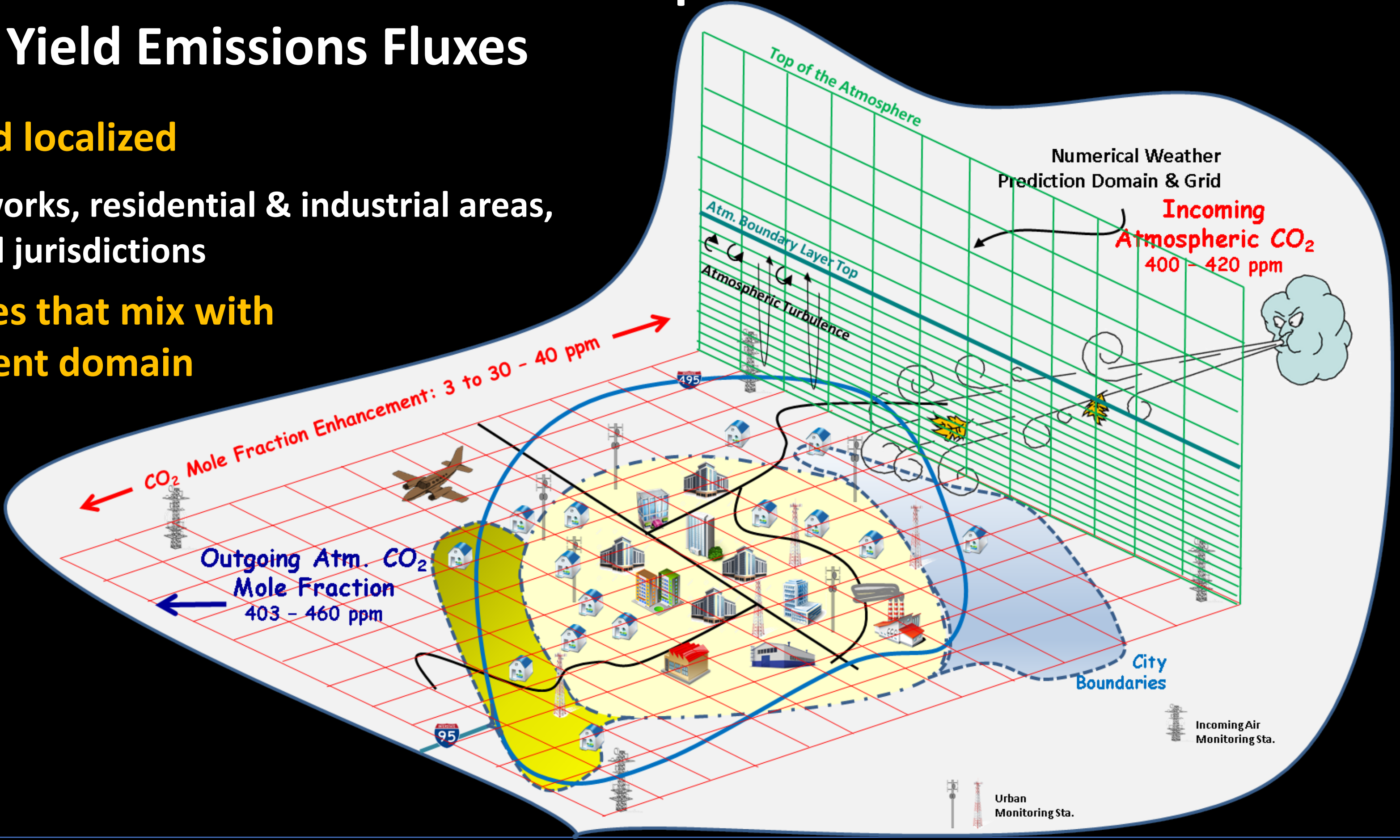
Greenhouse Gas Quantity Determination – Urban Settings

The Atmospheric Observation Approach: Top-Down

GHG Concentrations are the Observable Parameter of Atmospheric Emissions
Atmospheric Inversion Analyses Yield Emissions Fluxes

- Cities and urban centers are complex and localized
  - Commercial buildings, transportation networks, residential & industrial areas, electric generation plants, m governmental jurisdictions
- Incoming winds contain greenhouse gases that mix with emissions/uptake in the city/measurement domain
  - Tower-based observation networks
  - Aircraft observations: emissions snapshots
- Numerical weather prediction & dispersion models simulate atmospheric GHG transport
  - Spatial (1 km^2) & temporal resolution



Urban GHG Surface Networks

Combining Approaches to Achieve Sensitivity and Accuracy

- **Atmospheric Observation and Analysis – Top-Down**
  - Observations of local atmospheric greenhouse gas plumes
    - Communication tower-based GHG concentration 24/7 observation networks in urban and surrounding areas
  - Spatial and temporal scales: ~1 km^2 spatial & <1 hour
  - Scope 1 and 2 emissions: All emission sources and sinks in the domain of interest and GHG concentrations of incoming air
- **Emissions Modeling – Bottom-Up**
  - Traditional emissions factor/activity data model elaboration of USEPA and the IPCC Task Force on Inventory practices and methods.
  - Advanced emissions modeling achieve fine spatial & temporal scales:

Top-Down: Enforces GHG Mass Conservation @ NWP Scales (1 km^2)
Bottom-Up: Provides Spatial and Temporal Resolution – No Mass Cons.

Network Observing Node
Communication Tower-Based, Multi-Level Atm. Sampling

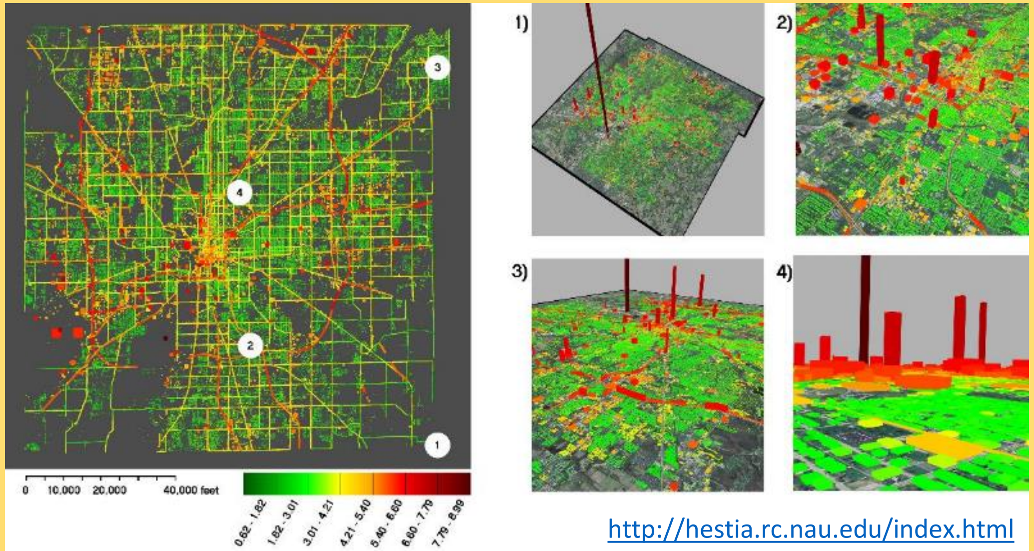
Bottom-Up: Elaborating Traditional Emissions Methods at Urban Scales

Actionable Information for City Mitigation Management

Spatially and temporally-resolved (building & street level) emissions estimation using public data

- Vulcan 3.0 (Continental @1 km^2) and Hestia (urban) Data Products — K. Gurney
- Anthropogenic Carbon Emission System (ACES) — C. Gately, L. Hutyra
- Open-Data Inventory for Anthropogenic CO_2 (ODIAC) — T. Oda, S. Maksyutov

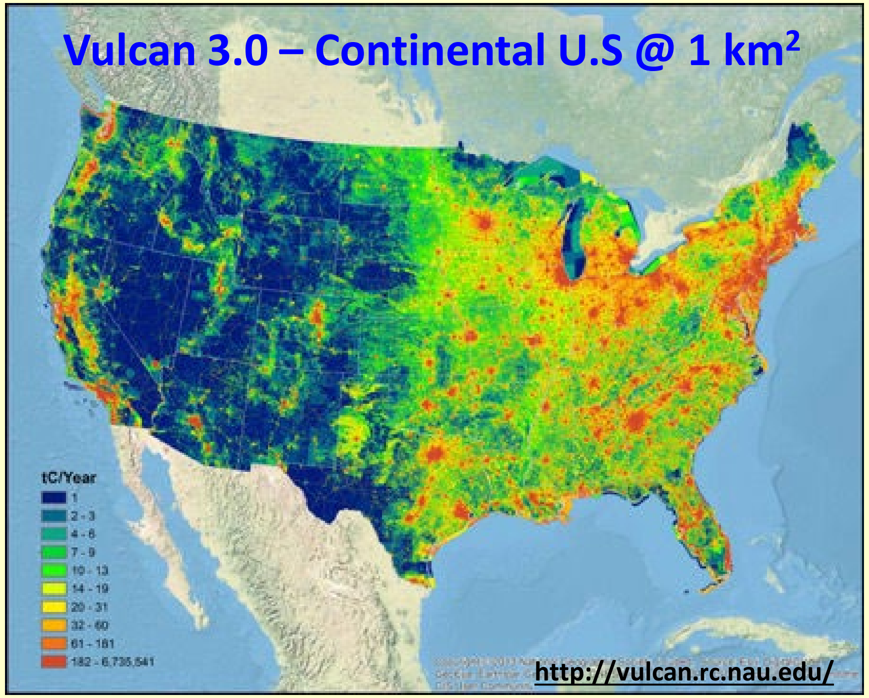
Hestia – Indianapolis – Building & Street Resolution



http://hestia.rc.nau.edu/index.html

- Fossil fuel emissions
- ± 3% comparison NOAA's atmospheric radiocarbon data and analysis
- Can be downscaled to urban areas
- Agrees with US inventory to ~10% benefiting from large data sets

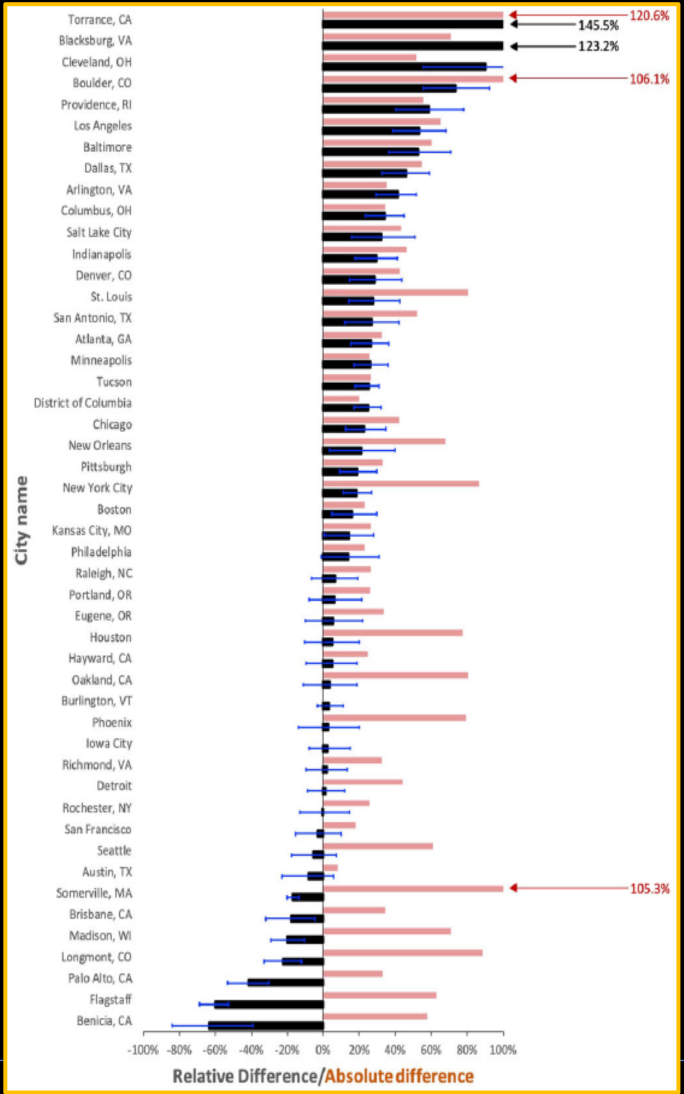
Vulcan 3.0 – Continental U.S @ 1 km^2



http://vulcan.rc.nau.edu/

48 U.S. City Inventory Self-Reports vs. Vulcan 3.0

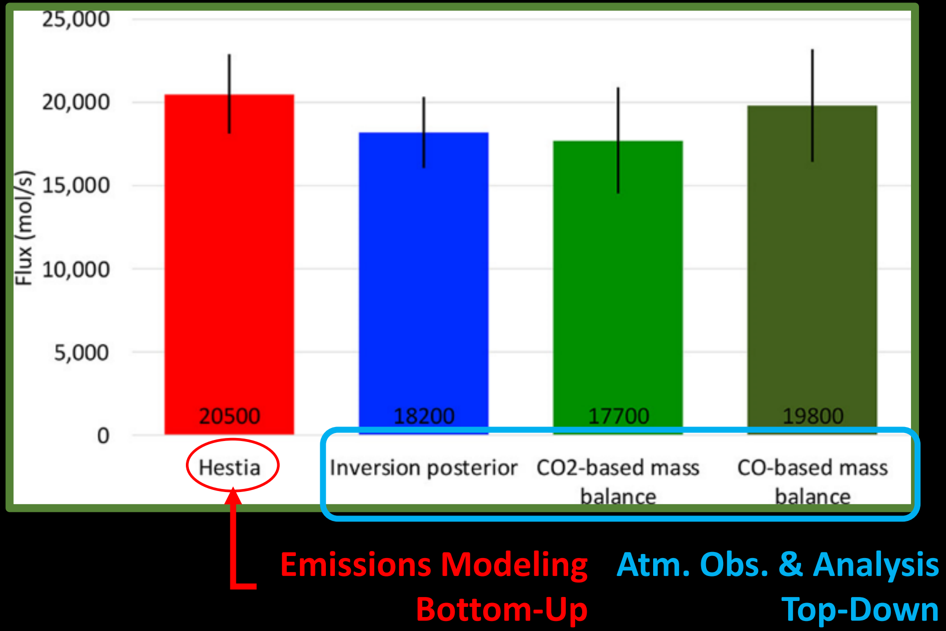
- **Vulcan 3.0 used as a reference for city emission data in Climate Action Plans**
  - Extracted Fossil Fuel GHG Inventory report from 48 US city climate action plans
- **Difference Range: ~60% over to ~140% under reporting.**
  - Perhaps due to not accounting for fuels or sectors where local information was limited or unavailable
- **Consistent in urban emission quantities across cities nationally is critical for comparing effectiveness of differing mitigation approaches and policies.**



Whole City Emissions (~2018)

The Indianapolis Flux Experiment (INFLUX)

- Improved Analyses
  - Emissions data product – Hestia
  - Surface network atmospheric Inversion
  - Aircraft mass-balance experiments
- Agreement among 3 methods:
  - ±7% agreement on whole city emissions
  - Previous estimates – 30% to 50% differences



J. Turnbull, ES&T, 2019, *53* (1), 287–295, 10.1021/acs.est.8b05552 – Dec. 6, 2018

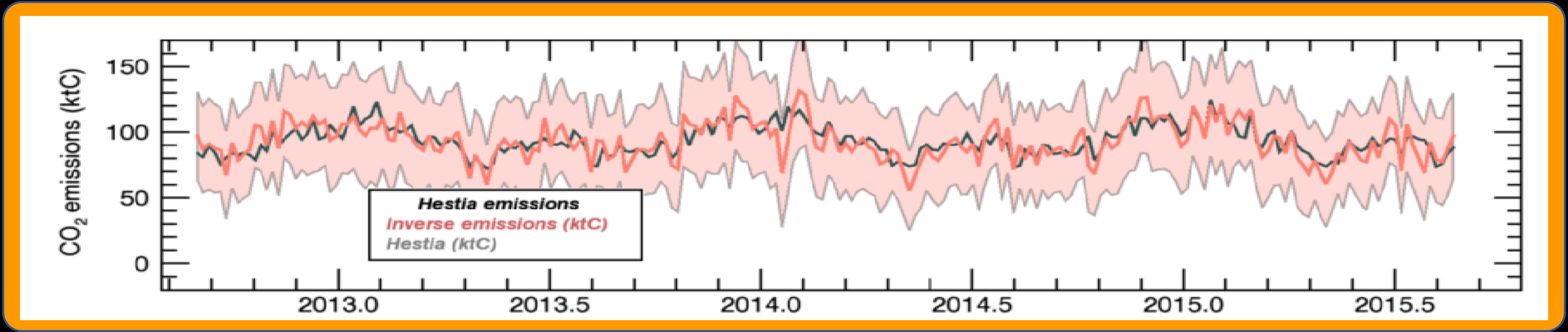
Results Achieved by:

- Harmonizing spatio-temporal mole fraction observation and analysis.
- Minimizing biological process emissions
  - Suppress vegetative emissions and uptake processes

Recent Advance in INFLUX Data Analyses

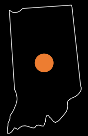
Combined emission modeling and atm. observation & analysis

- **Urban Measurement Result Convergence Over 3-years**
  (Black line – emissions model, Orange line – atmospheric inversion analysis
- **Atmospheric Inversion Model Testing:**
  - **Intentional offset of +15% of Hestia input data.**
  - **Atmospheric data and Bayesian inversion analysis correct the initial estimate by -14.2%.**
  - **Combined method confidence is increased that 3 to 5% changes over 1 to 3 years are quantifiable.**
  - **Replication in other urban settings needed to refine methods for general applicability.**



Urban GHG Measurements Testbed System Contributors

INFLUX

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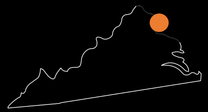


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Some Recent Results and Near-Term Plans

Selected Results

- Baltimore/Washington DC network completion
- Initiating expansion up the Northeast Corridor
- Pandemic impacts on urban emissions
  - Quantified in Los Angeles and Baltimore/Washington DC testbeds demonstrating similar analysis methods
- Advances in:
  - Determination GHG's of incoming air
  - emissions and uptake analyses of vegetation – remote sensing applications
- Comparison of inventory self-reporting in 48 U.S. cities with US continental reference

Near Term Plans

- Strengthen NIST emissions and biogenic modeling capabilities
- Continue extending Northeast Corridor testbed observing network – Washington to Boston
- Strengthen measurements and analyses linking on-orbit GHG concentration observations and surface emissions determinations
- Initiate a landfill emissions testbed for longer term measurements and analyses
- Strengthen efforts linking air quality and GHG emissions research communities.

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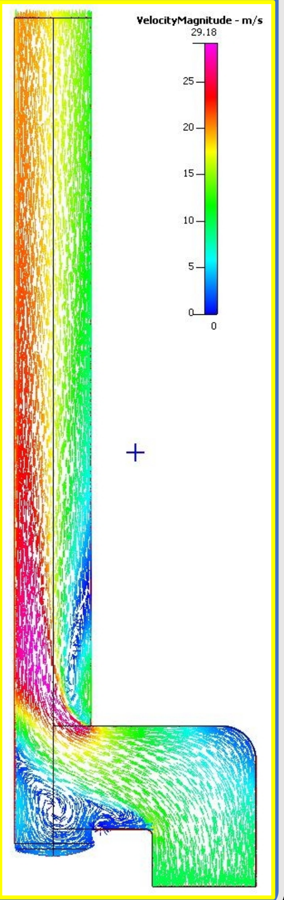
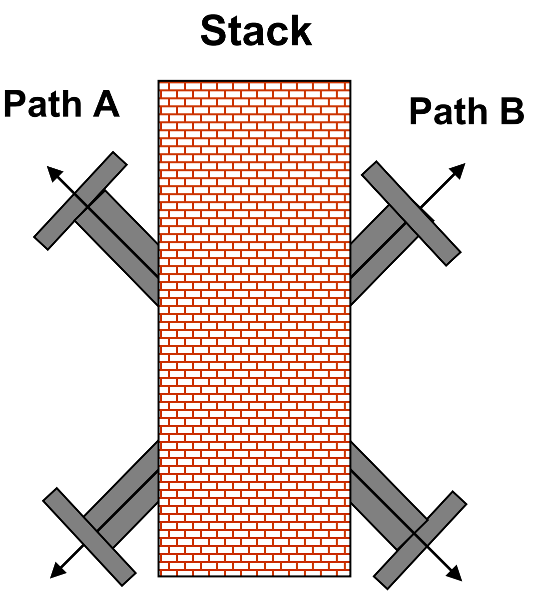
Direct Greenhouse Gases Emissions Measurement

Improved Powerplant Emission Quantities

Axial Stack Gas Velocities



- Stack emissions are warm, turbulent, and swirling
  - Challenging concentration & velocity measurement environment
  - NIST Traceable Reference Materials Program underpins EPA's stack gas concentration standards requirements (±2%) for SO_2, NO_X, & CO_2
    - Flow path diameter (mature) and Gas velocity (variable, complex, & challenging)
- NIST research has demonstrated improved application of existing technologies achieves ~1% flow accuracy
  - X-pattern ultrasonic flow metering compensates for complex velocities
  - Errors of ~1% over entire flow range with no velocity dependency
- Single path installations have ~±10% estimated uncertainty
  - NIST-developed in-situ stack gas velocity calibration methods: <2 % uncertainty
- In-Plant demonstrations – Currently on-going with EPRI

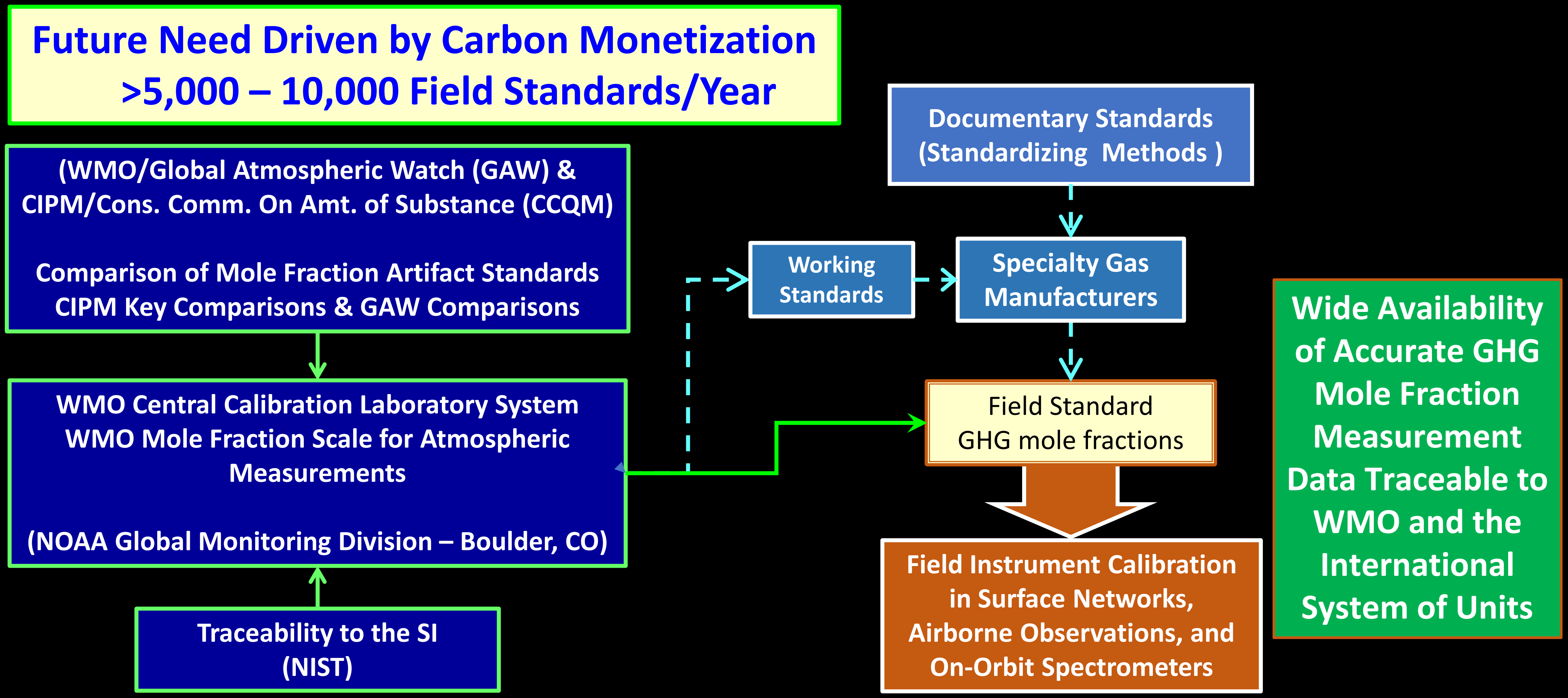


Preferred Stack Ultrasonic Flow Metering Configuration

$$\text{Emission (kg/sec)} = \text{conc. (kg/m}^3\text{)} \times \text{velocity (m/sec)} \times \text{Area (m}^2\text{)}$$

Atmospheric GHG Mole Fraction Measurements

The Standards Foundation of Atmospheric Methods



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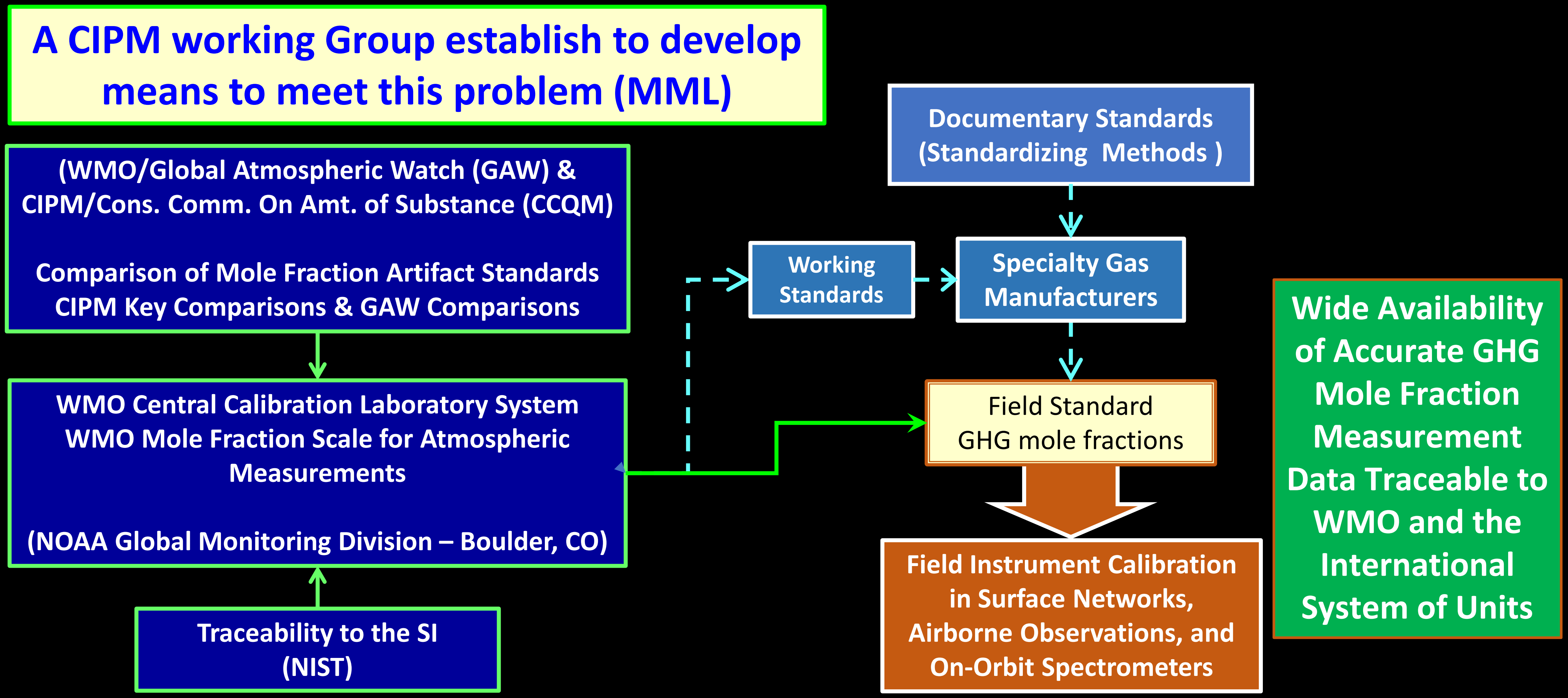

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Optical Radiocarbon Measurement & Spectral Line Shape References

First linear absorption spectrometer for bench-top $^{14}CO_2$

- Cavity ring-down spectroscopy of $^{14}CO_2$ near 4.5 µm
- Absolute and calibration-free determination of $^{14}CO_2$ concentration
- Limit-of-detection ~0. 1 fraction modern ^{14}C
- Applications:
  - Carbon-cycling studies: fossil fuel (petrogenic vs. biogenic) source apportionment
  - Radiocarbon dating

THE JOURNAL OF PHYSICAL CHEMISTRY Letters

Letter

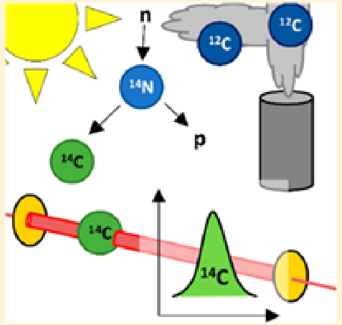
pubs.acs.org/JPCL

Optical Measurement of Radiocarbon below Unity Fraction Modern by Linear Absorption Spectroscopy

Adam J. Fleisher,* David A. Long,* Qingnan Liu, Lyn Gameson, and Joseph T. Hodges

National Institute of Standards and Technology, 100 Bureau Drive, Gaithersburg, Maryland 20899, United States

ABSTRACT: High-precision measurements of radiocarbon (^{14}C) near or below a fraction modern ^{14}C of 1 ($F^{14}C \leq 1$) are challenging and costly. An accurate, ultrasensitive linear absorption approach to detecting ^{14}C would provide a simple and robust benchtop alternative to off-site accelerator mass spectrometry facilities. Here we report the quantitative measurement of ^{14}C in gas-phase samples of CO_2 with $F^{14}C < 1$ using cavity ring-down spectroscopy in the linear absorption regime. Repeated analysis of CO_2 derived from the combustion of either biogenic or petrogenic sources revealed a robust ability to differentiate samples with $F^{14}C < 1$. With a combined uncertainty of $^{14}C/^{12}C$ = 130 fmol/mol ($F^{14}C$ = 0.11), initial performance of the calibration-free instrument is sufficient to investigate a variety of applications in radiocarbon measurement science including the study of biofuels and bioplastics, illicitly traded specimens, bomb dating, and atmospheric transport.



Quantifying radiocarbon (^{14}C) can unambiguously apportion carbon sources, yield the age of ancient

ments to the sample cell as well as the addition of a high-powered probe laser recently yielded SCAR precision

A.J. Fleisher, D.A. Long, Q. Liu, L. Gameson, and J.T. Hodges, "Optical measurement of radiocarbon below unity fraction modern by linear absorption spectroscopy," J. Phys. Chem. Lett., 8, 4550-4556 (2017).

Optical Radiocarbon Measurement & Spectral Line Shape References

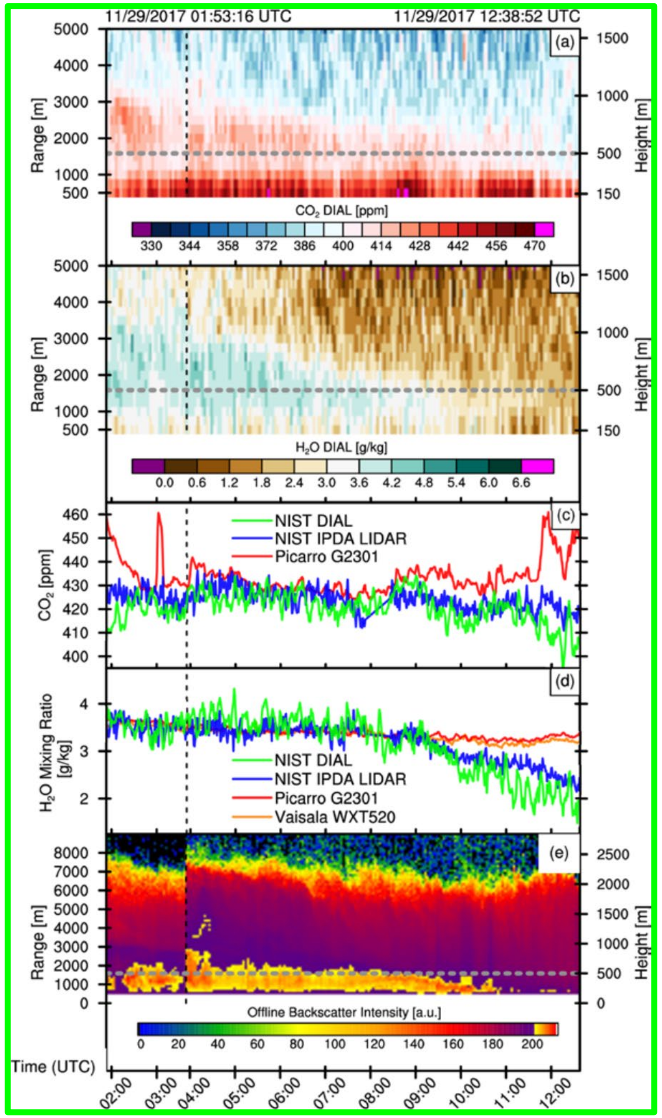
First linear absorption spectrometer for bench-top $^{14}CO_2$

DIAL Mixing Ratios

- range resolved CO_2,
- range resolved H_2O dry air

Application – Improve GHG Satellite Data

- Real-Time Vertical Concentrations
- Improve on-orbit observations for path integrated of CO_2 and CH_4 dry air mixing ratios



DIAL Prototype (PML)

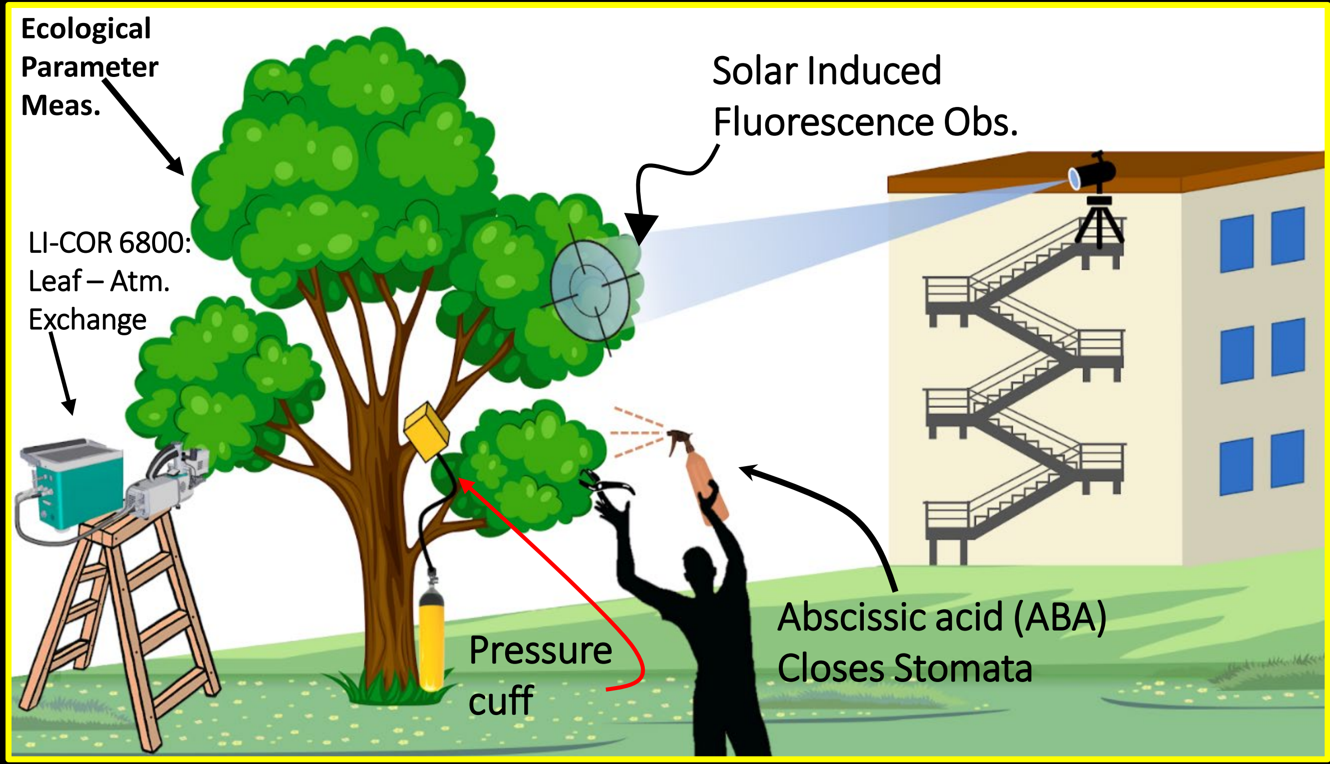
Urban Biogenic Processes
Measurements and Models

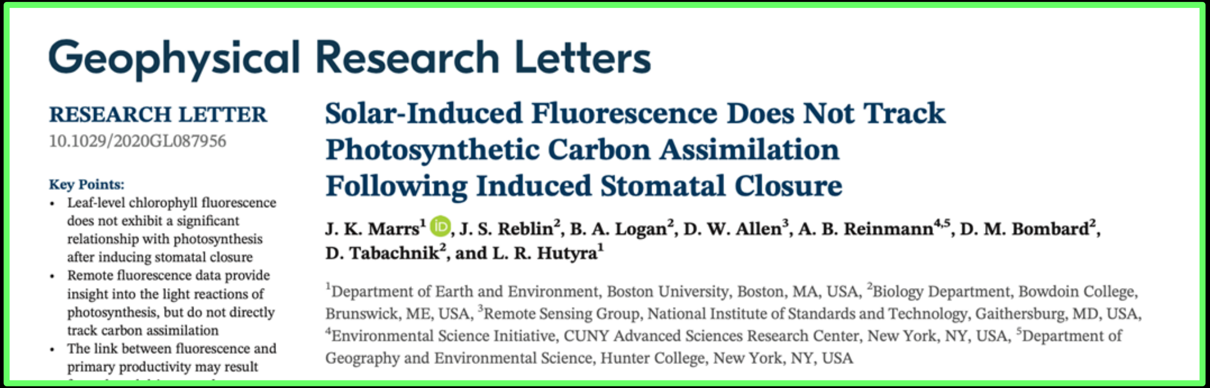
Urban Vegetation: Quantifying CO_2 Emissions and Uptake

- Vegetation Respiration Models
  - Predict CO_2 emission strength at similar levels to anthropogenic emissions
  - Few are specific to urban conditions
  - Model evaluation and development are underway in SPO

Radiative Emissions Measurements and Forest Ecology

- Forested Optical Reference for Evaluating Sensor Technology - FOREST Project
- Uses Forested Area on NIST GaithersBurg Site
- Combines Optical Radiation and Ecological Measurements
- Solar Induced fluorescence (SIF) may not be the remote sensing proxy for photosynthetic activity as has been asserted.





Geophysical Research Letters

RESEARCH LETTER
10.1029/2020GL087956

Solar-Induced Fluorescence Does Not Track Photosynthetic Carbon Assimilation Following Induced Stomatal Closure

J. K. Marrs[1], J. S. Reblin[2], B. A. Logan[2], D. W. Allen[3], A. B. Reinmann[4,5], D. M. Bombard[2], D. Tabachnik[2], and L. R. Hutyra[1]

[1]Department of Earth and Environment, Boston University, Boston, MA, USA, [2]Biology Department, Bowdoin College, Brunswick, ME, USA, [3]Remote Sensing Group, National Institute of Standards and Technology, Gaithersburg, MD, USA, [4]Environmental Science Initiative, CUNY Advanced Sciences Research Center, New York, NY, USA, [5]Department of Geography and Environmental Science, Hunter College, New York, NY, USA

Key Points:
- Leaf-level chlorophyll fluorescence does not exhibit a significant relationship with photosynthesis after inducing stomatal closure
- Remote fluorescence data provide insight into the light reactions of photosynthesis, but do not directly track carbon assimilation
- The link between fluorescence and primary productivity may result

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

Terrestrial Carbon Lab
Boston University

Bowdoin

Thanks for Your Attention

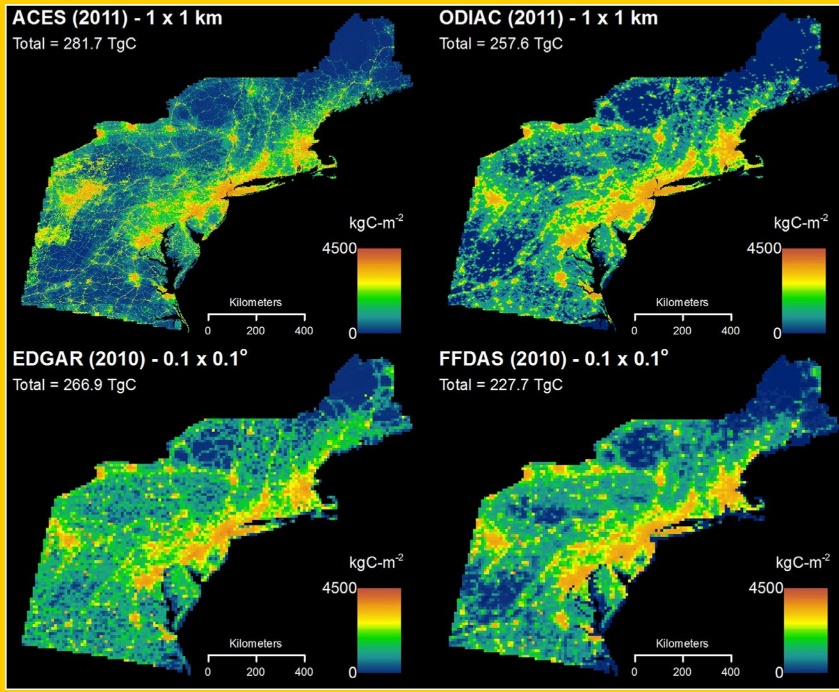
Questions/Discussion

Emissions Modeling Summary

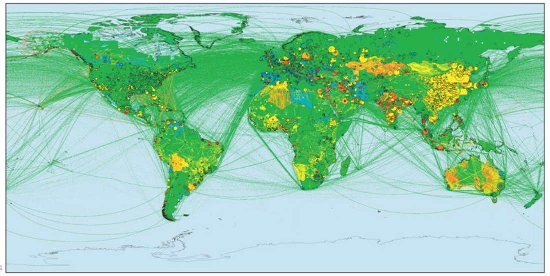
Spatially &Temporally Resolved Inventory Data Products

- **Use publicly available data for the emission factor – activity data model method**
  - UNFCC-TFI approach
  - Spatially & temporally resolved economic activity data coupled with emission factor for activities
- **Three U.S. research groups & the EU**
  - Northern Arizona Univ., Boston Univ., and NASA-Goddard
  - Edgar – EU Joint Research Center & focused on Air Quality & GHG's
- **Substantial differences in data and methods,**
  - Research efforts continue and are improving results
- **Benefit of combined emissions modeling and atmospheric measurement and analysis**
  - Vulcan 3.0 Data Product – Agreement with with $^{14}CO_2$ atmospheric inversion results at the ~1.5% level on a yearly basis.
    - 1 km X 1 km data product for the Continental U.S.
  - Vulcan 3.0 is the basis for a building – Street level resolution data product – Hestia
  - Hestia is used through out the NIST Urban GHG Measurements Testbed.
- **Differences between methods indicates the need for standards to ensure consistency and uniformity in emissions modeling backed by atmospheric measurement and analysis**

Comparison of 4 Data Products in the U.S. Northeast Corridor Show Substantial Spatial Differences.



Gately & Hutyra, 2017, J. GeoPhy. Res. - Atm, doi: 10.1002/2017JD027359



EDGAR is Global