Greenhouse Gas Measurements Program

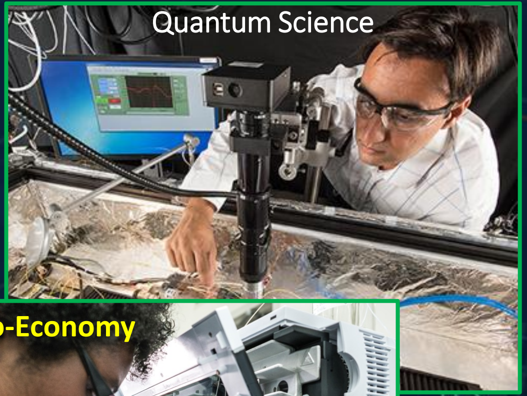
Advancing Greenhouse Gas Emissions (GHG) Measurement Tools and Standards.

Better Equipping Mitigation Decision Makers and Managers to Make Strategic Decisions and Chart Progress.

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

NIST is The U.S. National Metrology Institute

- A non-regulatory agency of the U.S. Department of Commerce
- Develops unbiased, state-of-the-art measurement science that advances U.S. technological infrastructure



To promote U.S. innovation and industrial competitiveness by advancing measurement science, standards, and technology in ways that enhance economic security and improve our quality of life.

NIST's Greenhouse Gas Measurements Program

Purpose:

- Increase accuracy of GHG emissions and remote sensing data supporting mitigation policies and their implementation

Mitigation Measurement Challenges/Statements:

- *Commercial and regulatory implementation requires demonstrated carbon credit authenticity across space and time.*
- *Parties responsible for emissions and uptake must be independently identified and their emission fluxes quantified.*
- *New measurement capabilities will illuminate some pressing climate science questions.*

Announced Mitigation Targets translate to 1% to 3% Yearly Reductions

NIST's Greenhouse Gas Measurements Program

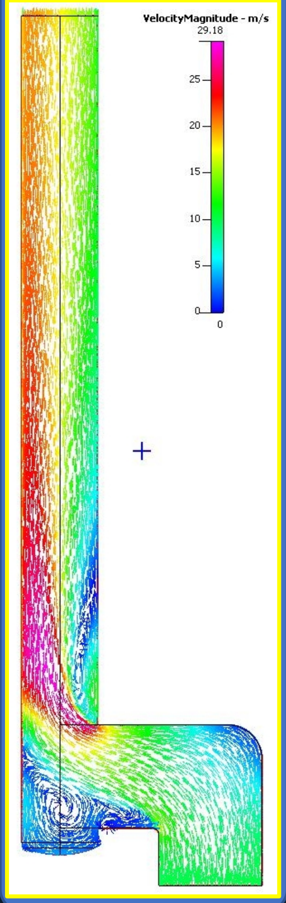
Program Components:

- Measurement tools, methods, and reference data
  - Stationary/point source (smokestack) emissions
  - Urban GHG Measurement Testbed System
  - Remote Sensing and Optical Measurements
    - A global system of GHG concentration standards traceable to the SI
    - Optical radiocarbon measurement and GHG concentration gradient with altitude,
    - Accurate spectral line shape data for atmospheric trace gases
    - Photosynthetic activity in vegetation (solar induced fluorescence)
- Carbonaceous aerosol and satellite calibration (radiometry) standards and methods

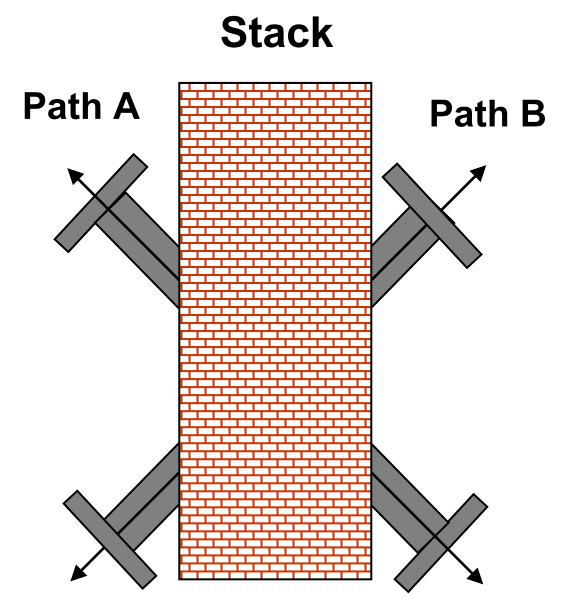
Direct Greenhouse Gases Emissions Measurement

Improving 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 technologies)
    - Gas velocity is variable and complex – a challenge
- **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



Preferred Stack Ultrasonic Flow Metering Configuration

Emission (kg/sec) = conc. (kg/m^3) x velocity (m/sec) x Area (m^2)

NIST's Urban Greenhouse Gas Measurements Program and Testbed System

Rationale:

- Globally cities are estimated to emit ~70% of total anthropogenic GHG emissions yearly
- Cities do not have reliable and robust measurement tools to quantify greenhouse gas emissions

Urban GHG Measurements Testbed System: Rationale

- **Mitigating GHG emissions will mainly be implemented locally**
  - Local governments and private sector institutions are primary mitigation policy implementers
  - Market-based and regulatory approaches will need robust and reliable emissions quantification, much as current commerce does now.
- **System Performance Needs:**
  - Identify responsible parties via geographic precision: Building & Street Scale
  - Accurately quantify emissions at those locations
- **Consistent, local emissions data underpin inventory reporting**

NIST'S URBAN GHG MEASUREMENTS TESTBED SYSTEM

Urban testbeds are collaborative multi-institution projects (including federal agencies, universities, and the private sector) to advance development of methods combining atmospheric measurements (top-down) with socioeconomic statistics, and demographic data to estimate urban GHG emissions (bottom-up) and related uncertainties.

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 +

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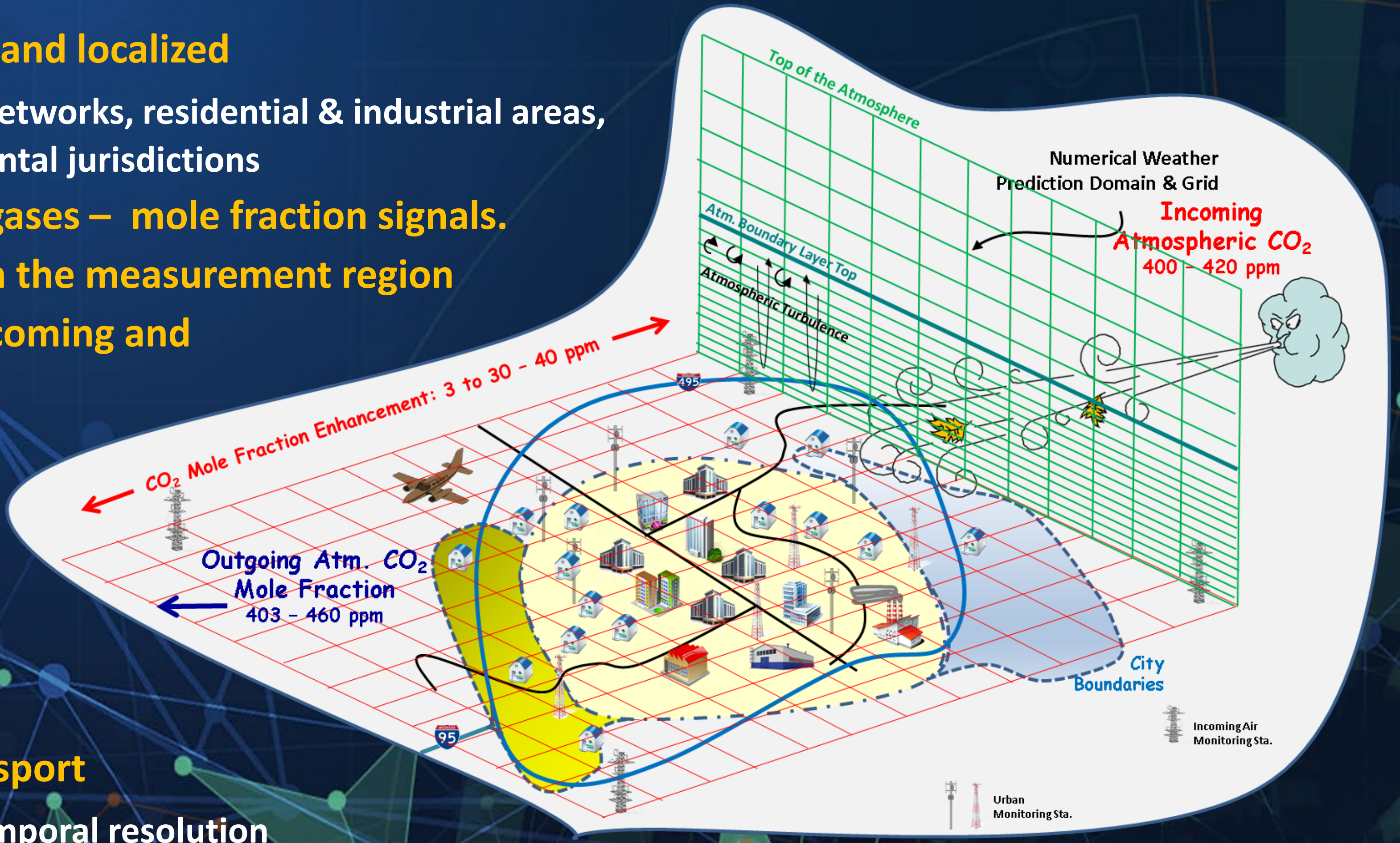
More are planned including expansion up the Northeastern seaboard of the U.S. …

Greenhouse Gas Quantity Determination – Urban Settings

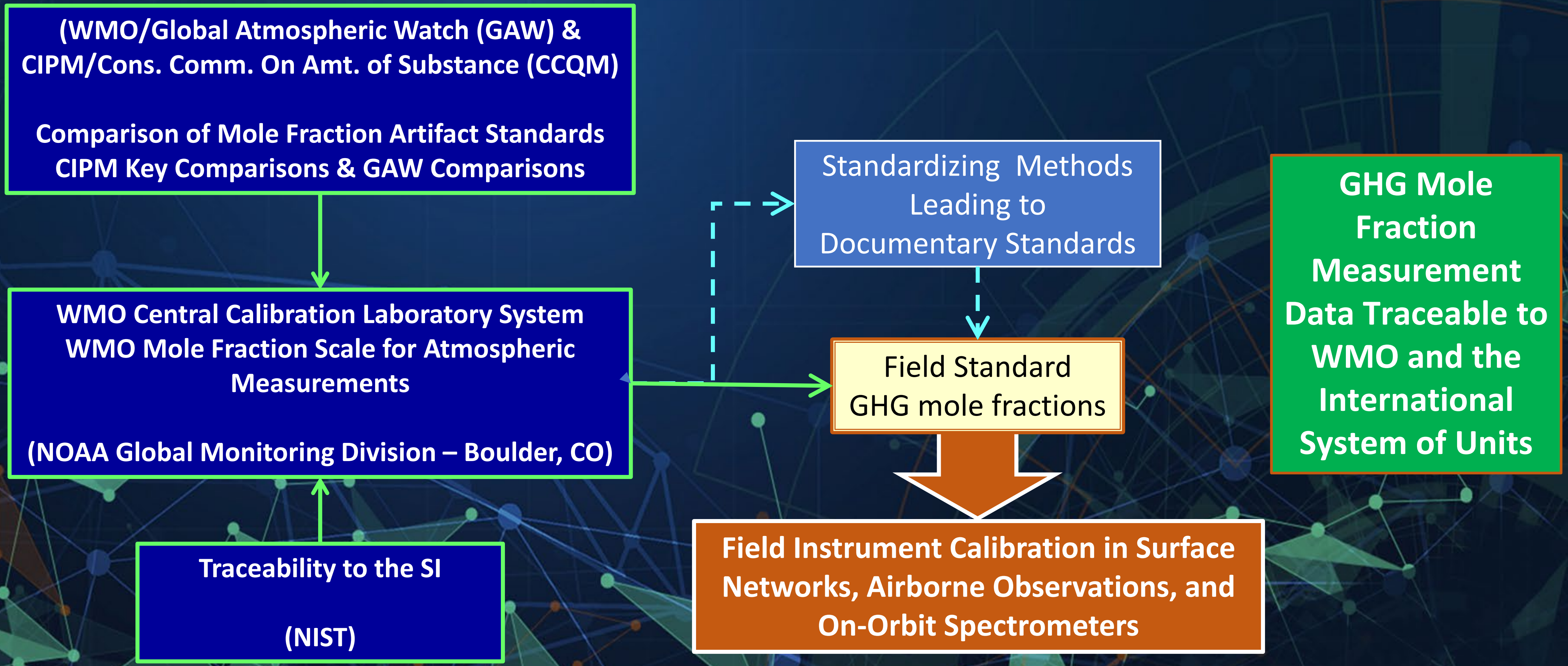
The Atmospheric Observation Approach: Top-Down

- 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 – mole fraction signals.
- Mixes these with emissions/uptake in the measurement region
- GHG concentration data consist of incoming and internal source signals
  - Tower-based observation networks identify source locations & emissions strength
  - Aircraft observations: emissions snapshots
- Numerical weather prediction & dispersion models simulate GHG transport
  - NWP grid gives geospatial (1 km^2) & temporal resolution



Atmospheric GHG Mole Fraction Measurements

The Metrology Foundation of Atmospheric Methods



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:
    - Publicly available databases of fossil fuel combustion processes
    - Currently Scope 1 anthropogenic (fossil fuel CO_2) emissions

Network Observing Node

Communication Tower-Based, Multi-Level Atm. Sampling

Urban GHG Surface Networks

Combining Approaches to Achieve Sensitivity and Accuracy

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

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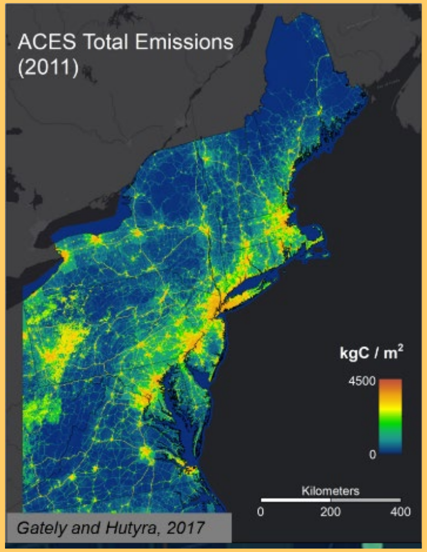
Bottom-Up: Elaborating Traditional Emissions Methods at Urban Scales

Actionable Information for City Mitigation Management



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

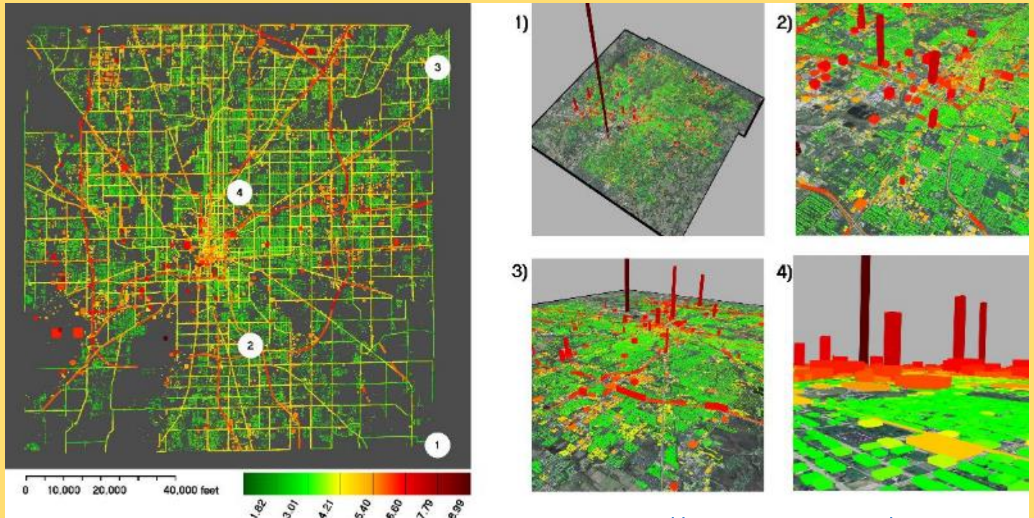
- Vulcan 3.0 (Continental @1 km^2) and Hestia (urban) Data Products — K. Gurney
- Anthropogenic Carbon Emission System (ACES) — C. Gately, L. Hutyra
- Open-Data Inventory for Anthropogenic CO_2 (ODIAC) — T. Oda, S. Maksyutov

Approach to Calibrate Bottom-Up with Top-Down

- Data mining of public datasets
- Largely anthropogenic
  - Initially power plant emissions
  - Progressed to vehicle and building emissions
  - Remote sensing – Nite Lights (ODIAC)

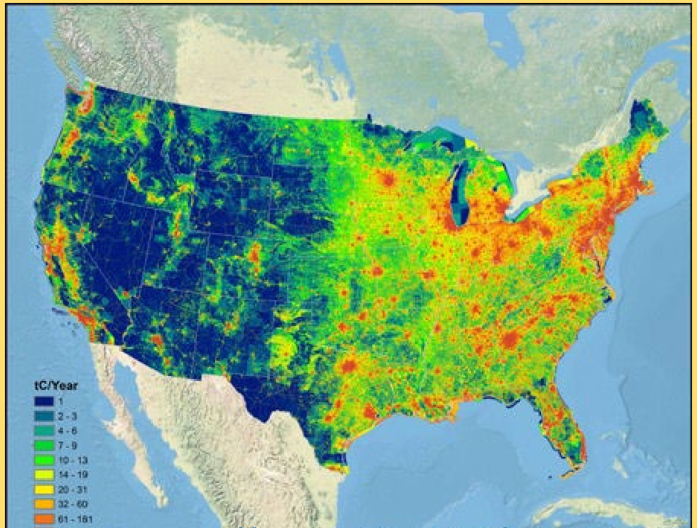
± 3% comparison of Vulcan 3.0 with atmospheric radiocarbon data and analysis

Hestia – Indianapolis – Building & Street Resolution



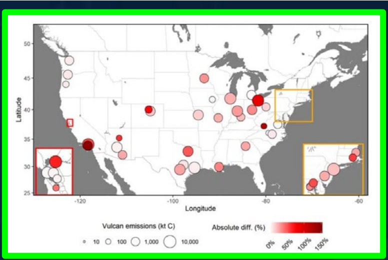
http://hestia.rc.nau.edu/index.html

Vulcan 3.0 – Continental U.S.



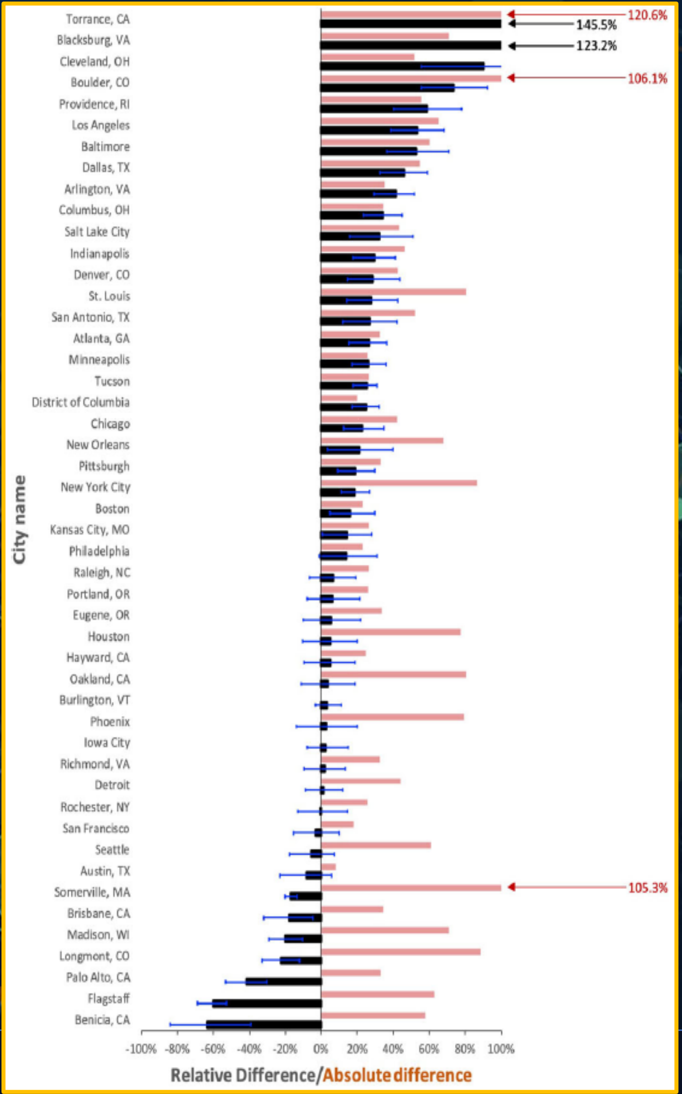
http://vulcan.rc.nau.edu/

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



- **Vulcan 3.0 used as a Reference**
  - Verified with atmospheric radiocarbon dat and analyses: ±3% level
  - 1 km^2 spatial resolution allows downscaling to city boundaries
- **Extracted GHG Inventory report from 48 US city climate action plans**
  - Only a city's fossil fuel emissions were used in the comparison.
- **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 emission amount determination from one city to the next is critical for comparing differing mitigation approaches and policies and their effectiveness.

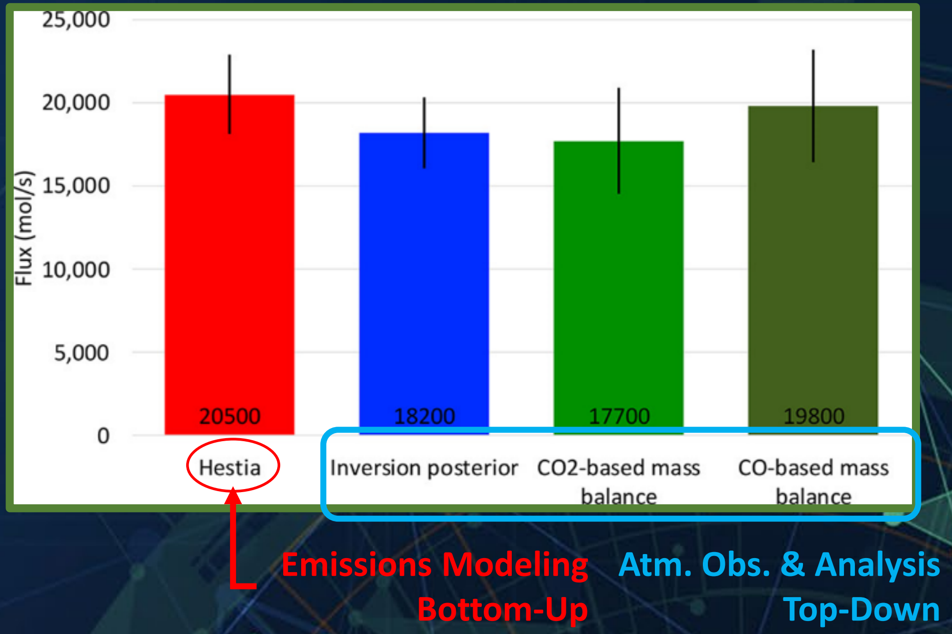


Gurney et al. (2021) Under-reporting of greenhouse gas emissions in U.S. cities, Nature Communications

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 methods:**
  - ±7% agreement on whole city emissions
  - Useful performance for cities to begin assessing mitigation progress
  - Previous estimates – 30% to 50% differences
  - Insufficient performance for assessing mitigation policy impact



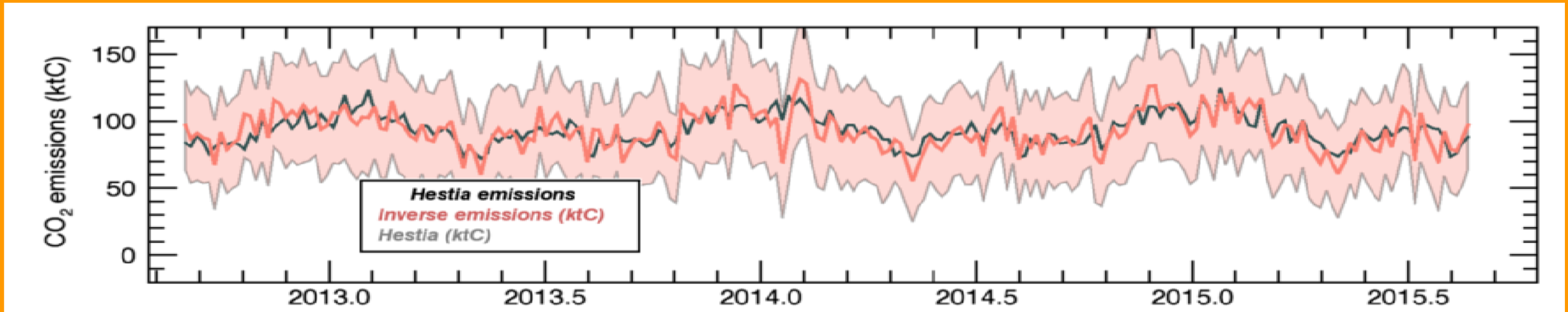
J. Turnbull, ES&T, 2019, *53* (1), 287–295, 10.1021/acs.est.8b05552 – Dec. 6, 2018

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 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.



Some Recent Results and Near-Term Plans

Selected Results

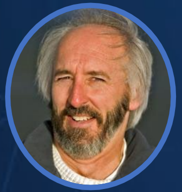
- Baltimore/Washington DC network completion
- Pandemic impacts on urban emissions
    - Quantified in Los Angeles and Baltimore/Washington DC testbeds demonstrating similar analysis methods
- Advances in:
    - Determination GHG's of incoming air
    - emissions and uptake analyses of vegetation – remote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

Near Term Plans

- Strengthen emissions modeling capabilities at NIST
- Extend the northeast corridor testbed observing network – Washington to Boston
- Strengthen measurements and analyses linking on-orbit GHG concentration observations and surface emissions determinations
- Initiate an landfill emissions testbed for longer term measurements and analyses
- Strengthen efforts to link air quality and GHG emissions research communities.

Urban GHG Measurements Testbed System Contributors

INFLUX



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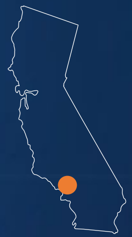

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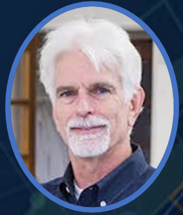

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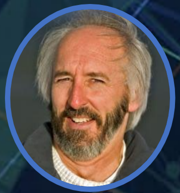

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Thanks for Your Attention