Urban-Dome GHG Monitoring: The INFLUX Project
Measurement Challenges and Perspectives


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Agenda

• INFLUX – The Indianapolis Flux Experiment
  – Background, Rationale, and Objectives
  – The Measurements and Modeling Approach
  – Initial Results
  – Future Plans
The Rationale for INFLUX

Urban Dome Characterization and Dynamics Measurements

• Quantification of carbon dynamics in urban areas
  – Advanced and diverse observing systems

• 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
The Indianapolis Flux Experiment (INFLUX)
A Top-Down/Bottom-Up Greenhouse Gas Quantification Experiment in the City of Indianapolis, Indiana

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 Measurement Network approach coupled with aircraft observations:
  – 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 km²

Current Project Participants:
• Purdue University
• Penn State Univ.
• Arizona State Univ.
• Univ. Colorado - NOAA/ESRL
• PICARRO Instruments
• Earth Networks
• NASA – JPL & Ames
INFLUX – Phase 1
An Urban Observing Strategy

Approach

• Demonstrate and improve CRDS* / mass balance-based measurement of CO$_2$ and CH$_4$ fluxes, utilizing improved instrumentation and calibration methods, flask sampling approaches, and wind speed and direction measurement methods.

• Compare trace gas measurement / atmospheric transport model results with emission inventories to better understand top-down methodology performance and methods for improvement

• Initial Observation Approach
  – 40 Instrumented aircraft flights
    • vertical profiling CO$_2$ and CH$_4$
    • flask samples analyzed for $^{14}$CO$_2$, CO, and ~30 other trace gases
  – 2 tower observation sites
    • Upstream of prevailing wind direction, SW of the city, and
    • Downstream of city center, NE corner

* CRDS – Cavity Ring Down Spectroscopy
INFLUX – Phase II
Geographically Dense, Tower-Based Observing Network Coupled with Robust Boundary Layer Forward and Inverse Modeling

• 9 - 10 tower-based observing stations added & in place in 2012 using CRDS-based mixing ratio measurements to form a *dense observing network*
  – 3 CO$_2$ and CH$_4$; 3 CO$_2$ and CO; 5 Flask sample sites
  – 4 CO$_2$ only
  – 6 towers currently operational, or nearing operational status - CO$_2$, CH$_4$, and CO
  – Consistent gas standards – WMO CCL

• Tower over flights, roughly biweekly, with vertical profiles.

• Integrated flask sampling:
  – Collect samples over two week sampling period, only when meteorology conditions meet certain criteria.
  – Vary sampling rate with wind speed and/or PBL height.
    CO$_2$, CH$_4$, CO, $\Delta^{14}$CO$_2$, $\delta^{13}$CO$_2$, SF$_6$, N$_2$O, H$_2$, with halo/hydrocarbon suite.

• Early Result – Clear need for improved meteorological parameter measurements
  – Continuous boundary layer characterization
  – High Resolution Lidar – 3D wind vectors, turbulence intensity, mixing depth, and BL height
  – Measurement of Surface Energy balance, momentum flux, & short and long wave radiation fluxes
INFLUX

Dense Observing Network Tower Locations

- 2 Original Sites (Towers 1 & 2) & 4 new sites operational (black dot indicators).
- Remaining site locations identified, tower access obtained or being negotiated with installation, connectivity, and data management to be completed by June 2012.
Aircraft Measurements
Boundary Layer Properties

- Curtain Flights patterns provide measures of downwind and upwind GHG concentrations through and above the PBL
- BAT probe samples atmosphere in front of the plane and provides the means to identify and following GHG plumes

ALAR Aircraft Measurement Capabilities
- 3D wind measurements;
- In situ measurements of CO$_2$, CH$_4$ and H$_2$O, and
- flask package measurements for CO$_2$, CO, CH$_4$, SF$_6$, H$_2$, N$_2$O, halocarbons, and $^{14}$C of CO$_2$.
- Picarro CRDS instrument exhibits in-flight precision and accuracy of better than 0.1% for both CO$_2$ and CH$_4$. 

CO$_2$ Vertical Profile
Going up and down
March 1, 2011
Curtain Flights: High Resolution Horizontal Flight Segment Time Series

- Magnified view of flight transects at various altitudes
- CH$_4$ hotspots were about 40 ppbv higher than the background.
Modeling Approach

- **Forward Model – WRF**
  - Measurements of surface energy balance, etc. used to calibrate the land surface model

- **Inversion Methodology**
Inversion Model Results
Anticipated Outcomes
A Basis for Design Recommendations for Measurement of GHG Emissions from Large Cities

• Criteria for establishing and siting urban GHG observing networks
  – Network node density and location, required observables
  – Sampling frequency

• Methodologies supporting evaluation of the performance capabilities of dense GHG observing networks
  – Methods for estimation of the uncertainty in measurement results

• The scientific basis for establishing top-down emissions measurement and assessment standards for urban dome characterization as a means of verifying self-reported emissions
Summary

- NIST is working with partner institutions to develop the measurement science and measurement tools needed to:
  - Improve the accuracy and comparability of surface-based measurement approaches for MRV purposes.
    - Emission source location - to ~ 1 km² and
    - Sources strength to within 10% of self-reported values (bottom up).
  - Demonstration of a robust, dense observing network methodology will provide:
    - A means to better characterize urban GHG domes
    - A calibration method for remote sensing measurements - on-orbit, terrestrial, or airborne
    - INFLUX - the initial research effort to demonstrate this approach to emissions verification.
  - Early lessons learned in INFLUX are expected to be extensible to other urban and regional settings, suggesting further research to be conducted for areas having significantly different terrain and meteorology.
- Successful development can lead to standard methodologies for:
  - Urban dome characterization,
  - GHG emission inventory determination by independent means, and
  - Globally-recognized measurement methodologies supporting future GHG mitigation efforts.
Extra slides
The Rationale for INFLUX

• INFLUX – The Indianapolis Flux Experiment
• Develop and test techniques/approaches for measurement of urban-scale GHG emission fluxes using:
  – Aircraft-based measurements,
  – Advanced atmospheric boundary layer observation and modeling,
  – State-of-the-art trace mixing ratio measurement capabilities
• To identify GHG emission source location and estimate flux strength in urban areas
• Objectives:
  – Determine individual source location to within 1 km²,
  – Measure source strength (flux) to within 10% of reported value, and
  – Quantify measurement uncertainties
• Success will provide:
  – Measurement capabilities for urban GHG dome characterization
  – Insights toward independent verification of GHG emission inventory claims and means for reconciliation of values obtained from bottom-up and top-down methods
  – Reliable and transparent measurement methodologies useful for evaluation of the performance of future GHG mitigation approaches
Additional Goals and General Approach

Secondary Goals

• Use emission ratios to quantify fluxes of other trace gases, e.g. CO, halocarbons,
• Partition CO$_2$ flux into biological and fossil fuel components,
• Identify and characterize point sources,
• Utilize results to improve bottom-up inventories (CO$_2$, CO etc), and
• Build improved emissions data products.

Additional Goals and General Approach

• Aircraft-based measurements – biweekly flights
• Dense, 11 tower, measurement network
• Real-time mixing ratio observations

• Data analysis & modeling
• Mass balance approach
• WRF-CHEM inversions
• Flask collections and analysis for 40 trace gases including $^{14}$CO$_2$

Bottom-up inventories
Vulcan 0.1° for US
Hestia block level for Indianapolis