Thrust 5:
Applications and Testbeds

Thrust leader:
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Princeton University

NSF-ERC Cooperative Agreement EEC-0540832

Projects in Progress

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5.2	Coupled Water, Carbon, and Nitrogen Cycles in Urban Environments
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5.5	Monitoring Trae Gas and Aerosol Properties in the Urban Environment
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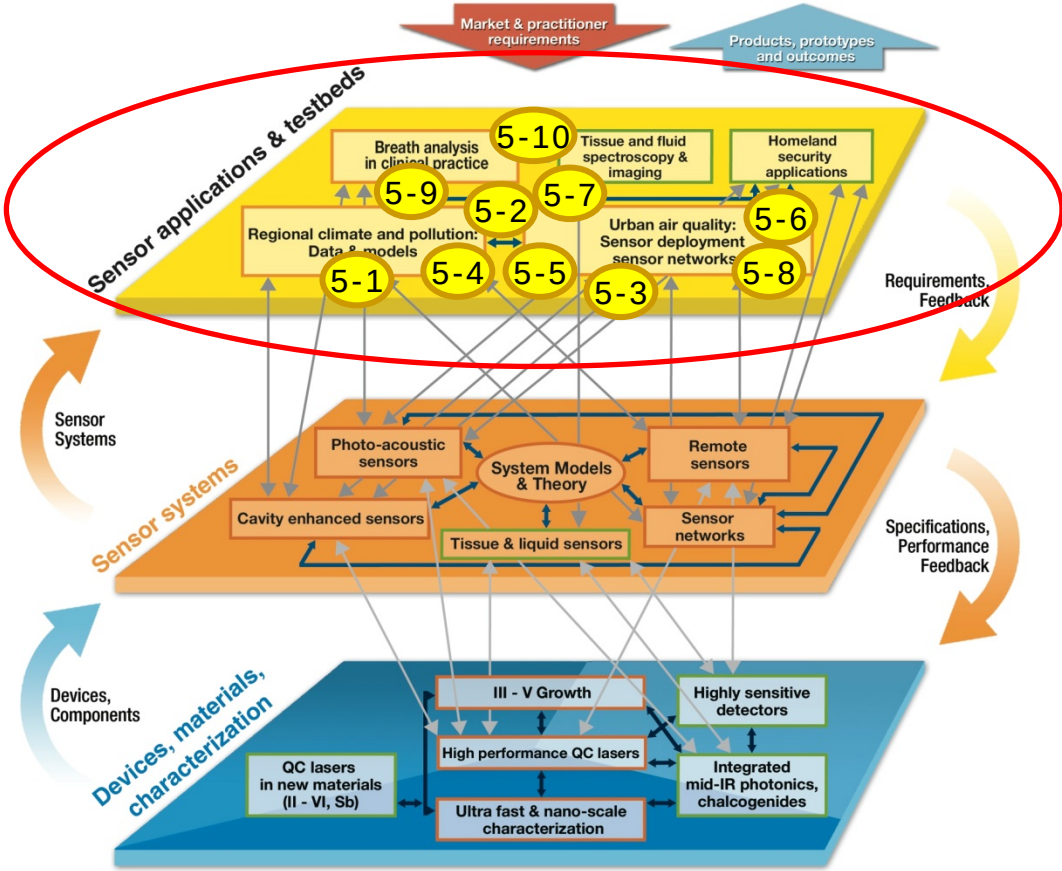
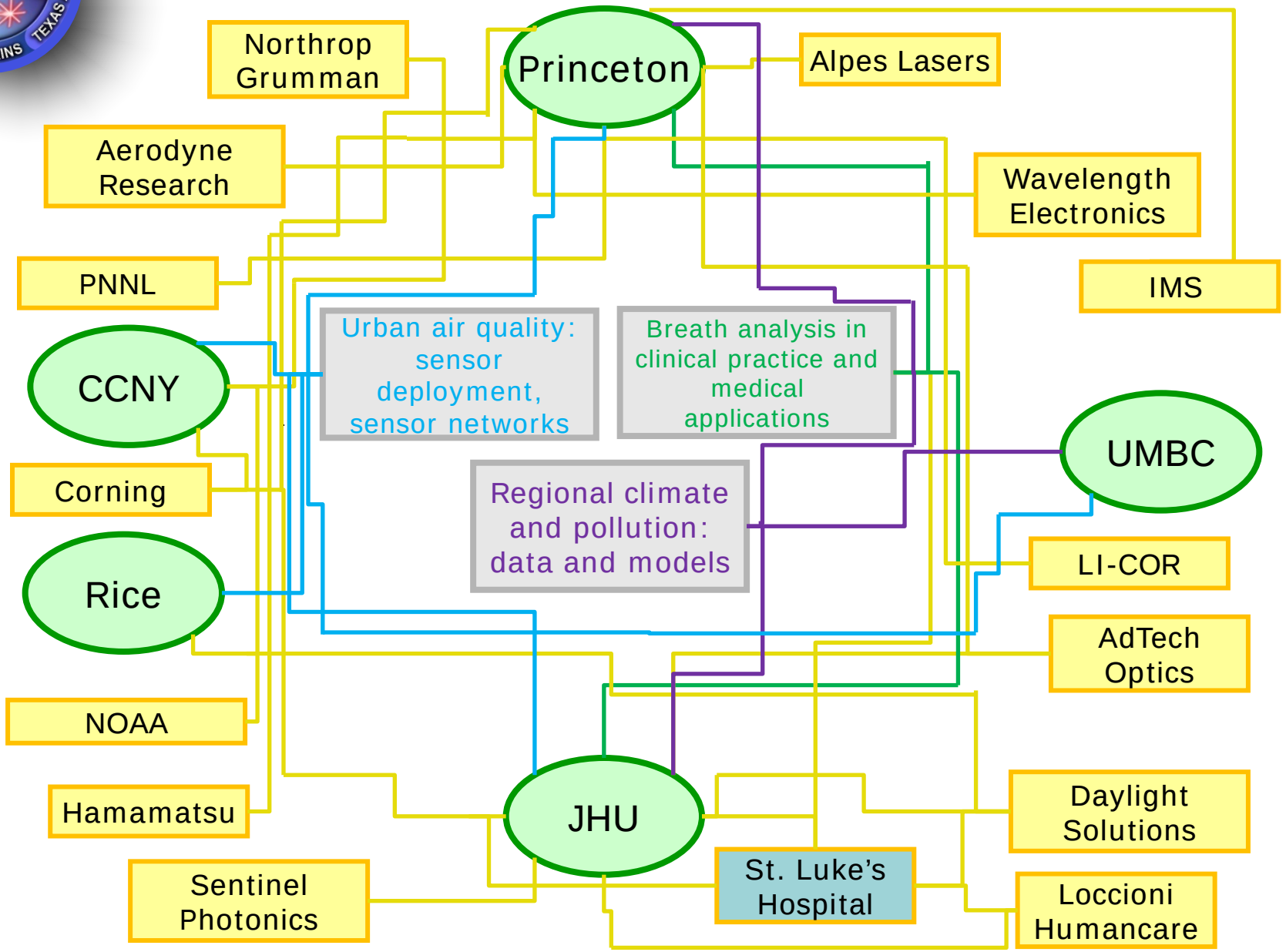
5.10	Later Therapy using 6μm QCL



Projects and Collaboration



Thrust 5 Participants

- Faculty: 16
- Graduate Students: 16
- Undergraduates: 7
- Institutions: 5

Key Companies:

Daylight Solutions, AdTech Optics, Aerodyne Research, LICOR, Hamamatsu, Alpes, Corning, Picarro, Wilmer Eye Clinic, Adtech Optics, Northrop Grumman, Wavelength Electronics, Intelligent Materials Systems

Faculty	Institution
Sam Ahmed	CCNY
Elie Bou-Zeid	Princeton
Claire Gmachl	Princeton
Rob Griffin	Rice
Barry Gross	CCNY
Jin U Kang	JHU
Fred Moshary	CCNY
Terrence Risby	JHU
James Smith	Princeton
Steve Solga	St Luke's
Lisa Spacek	St Luke's
Katalin Szlavecz	JHU
Frank Tittel	Rice
Claire Welty	UMBC
Gerard Wysocki	Princeton
Mark Zondlo	Princeton

Thrust Goals

- ***Applications:*** Air quality, regional climate, and carbon cycle assessments with a focus on urban environments and energy production; laser therapy and surgery; medical diagnostics using breath analysis.

- ***Goals:*** To develop monitoring technologies and analysis methods to address key societal problems concerning air quality, regional climate, the carbon cycle, and public health.

Deliverables

- ***Baltimore Testbed***: Wireless sensor network, point sensors, turbulent flux measurements; applications.
- ***Princeton Testbed:*** Turbulent flux measurements, wireless sensor networks, point sensors, mobile sensor platforms, lidar, open path remote sensing, applications.
- ***New York City Testbed***: Lidar, open path remote sensing, point sensor networks, applications.
- ***Texas Testbed***: Houston (Moody Tower), point sensors and mobile sensors, applications.
- ***St Lukes Hospital Testbed***: Clinical trials for fast response breath analysis; applications.
- ***Field Deployments of MIRTHE Sensors:*** SLIP, Beijing, Colorado, Texas.

Key Results / State-of-the-Art

- Vehicle NH_3 emissions in urban areas underestimated by factor of two, based on measurements from mobile platforms.
- Super-emitting well pads in the Marcellus shale dominate overall methane emissions.
- A compact, drone-based methane sensor was successfully flight tested.
- Hydrogen Peroxide sensor system based on multi-pass absorption using CW DFB-QCL was built and tested.
- Upland forests may sequester less methane than previously thought.
- Partitioning of evaporation between plant transpiration and soil evaporation exhibits pronounced seasonal and diurnal cycles.
- QCL open-path fence-line system to monitor methane and nitrous oxide was built and tested.
- Two Channel aerosol and cloud micro-pulse IR lidar was built and tested.
- Urbanization alters regional climatology of rainfall in New York, Baltimore and Beijing testbeds.
- Use of short term interventions to evaluate changes in ammonia for medical diagnostics.
- Freehand laser surgery techniques using QCL lasers developed and demonstrated.

Response to Comments

The Thrust 5 Health Testbeds are a great opportunity for students of all levels to gain an appreciation of the real world application of sensor systems for disease monitoring, though MIRTHE has not demonstrated a clear way to inculcate students into these testbeds.

To bring the topic closer to MIRTHE students, we included a tutorial on medical applications in the 2014 MIRTHE Summer Workshop.

Urban Emissions of Greenhouse Gases and Air Pollutants

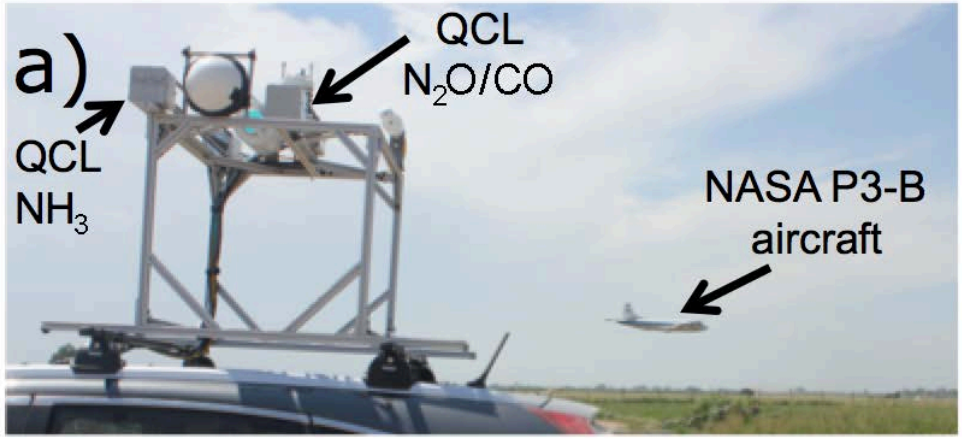
Multi-species measurements (> 8000 km) allows for fingerprinting of emissions in two field studies:

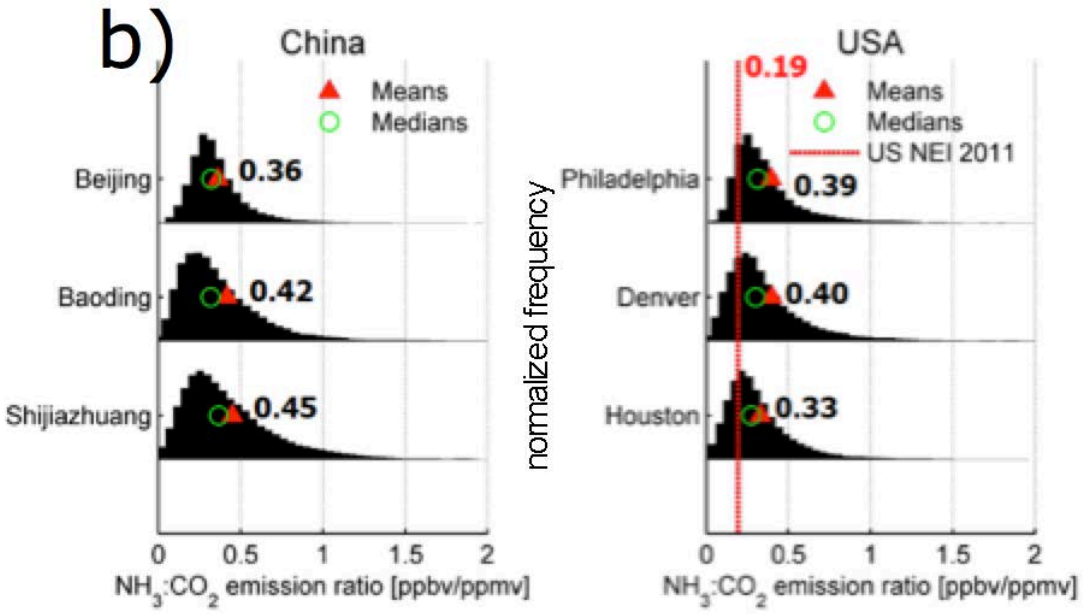
CAREBEIJING 2014, China
NASA DISCOVER-AQ, CO

Fleet-wide, NH_3:CO_2 emission ratios in US/China cities are comparable (0.39 ± 0.07)

Vehicle NH_3 emissions in urban areas underestimated by factor of two (US National Emissions Inventory = 0.19)

First validation of the NASA Tropospheric Emissions Spectrometer (TES) satellite NH_3 measurements at the single-pixel scale:



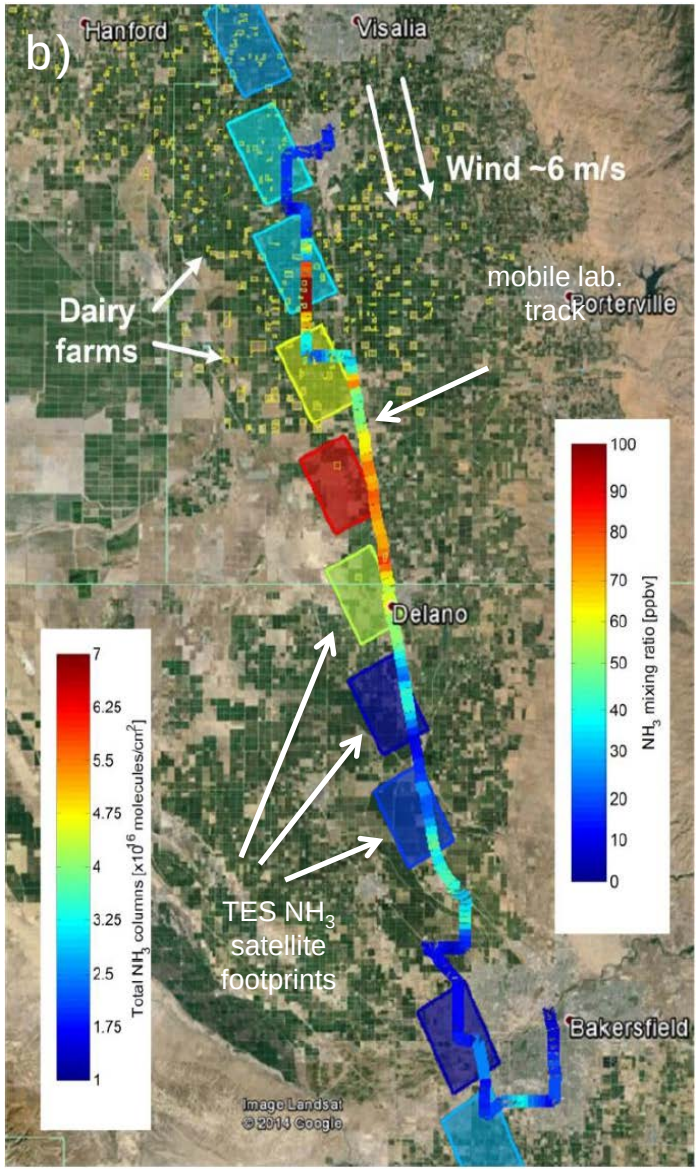


Urban Emissions of Greenhouse Gases and Air Pollutants

First validation of the NASA Tropospheric Emissions Spectrometer (TES) satellite NH_3 measurements at the single-pixel scale.

TES agrees within 6% of mobile/airborne NH_3 data

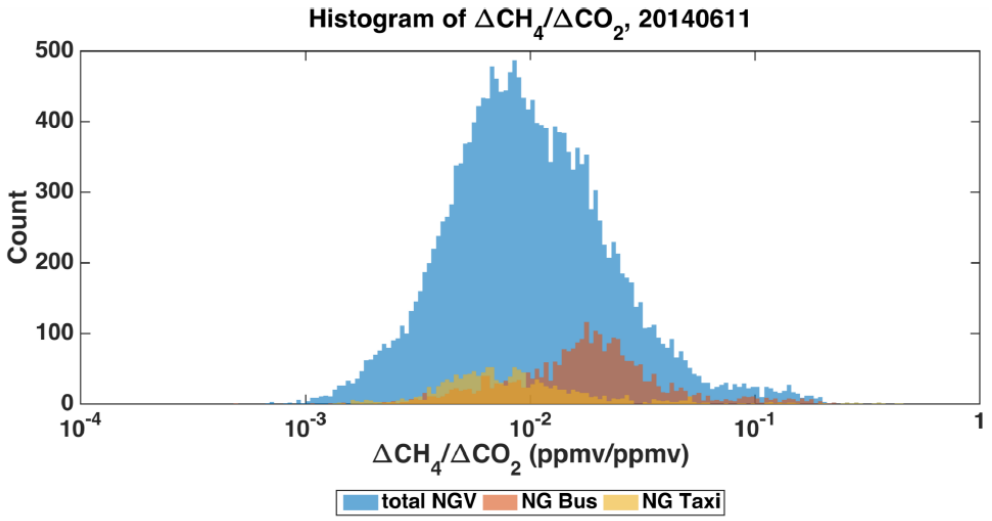
increased confidence in global NH_3 measurements

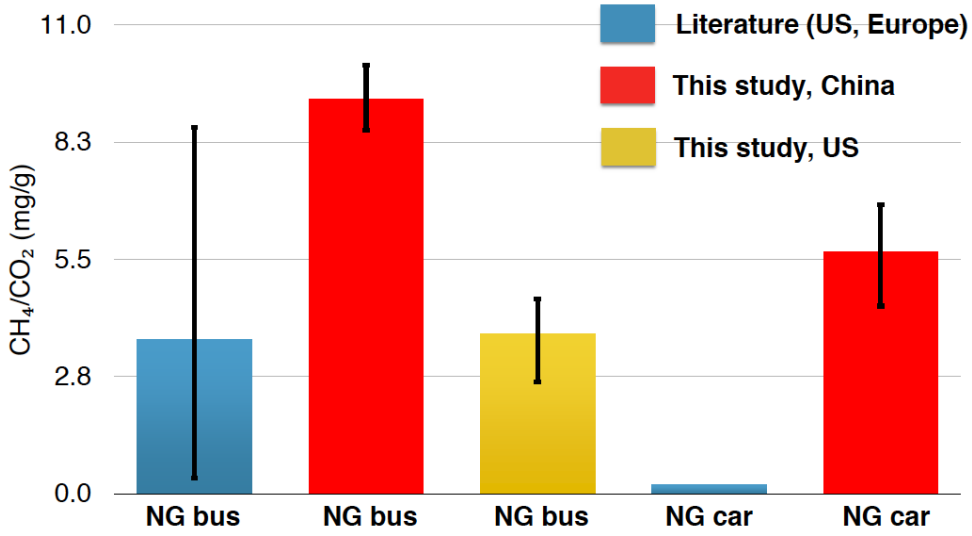


Fugitive Methane from Petrochemical Activities

Super-emitting well pads in the Marcellus shale dominate overall emissions
- 80% of emissions from only 12% of well pads
- identification of super-emitters is key for mitigation

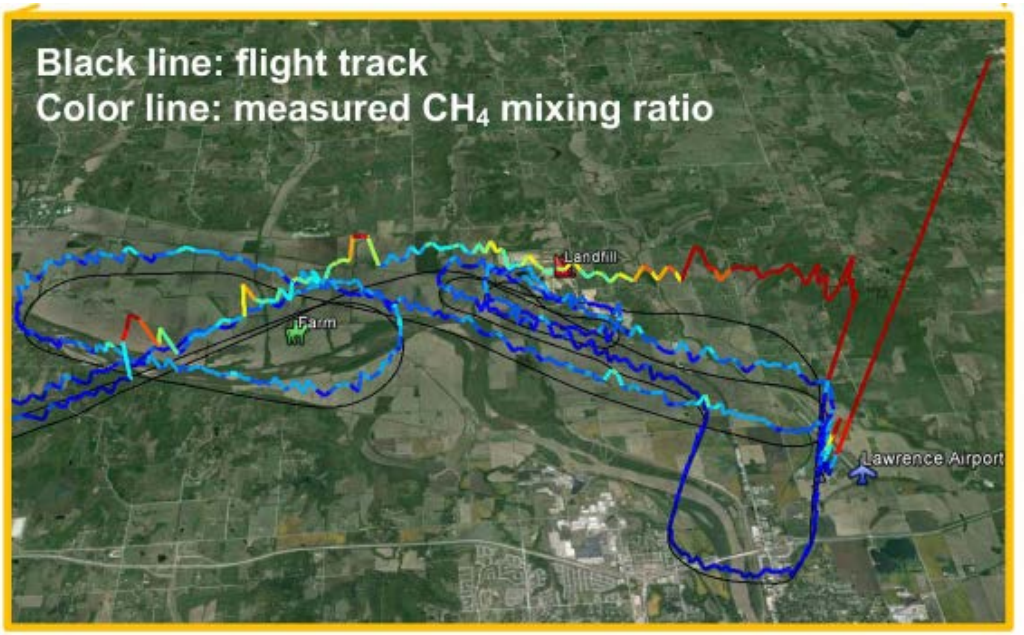
Natural gas vehicles (NGVs) in China have no climatic benefit due to leaks
- CH_4 from NGVs is 755 (±240) Gg CH_4 / year
- every 1% of vehicle fleet converted to natural gas results in a 1.5% increase in CH_4 emissions





(a) histogram of measured $\Delta CH_4/\Delta CO_2$ emission ratios from natural gas vehicles in China; (b) CH_4/CO_2 emission factors for natural gas cars and buses (red, yellow = present study); .

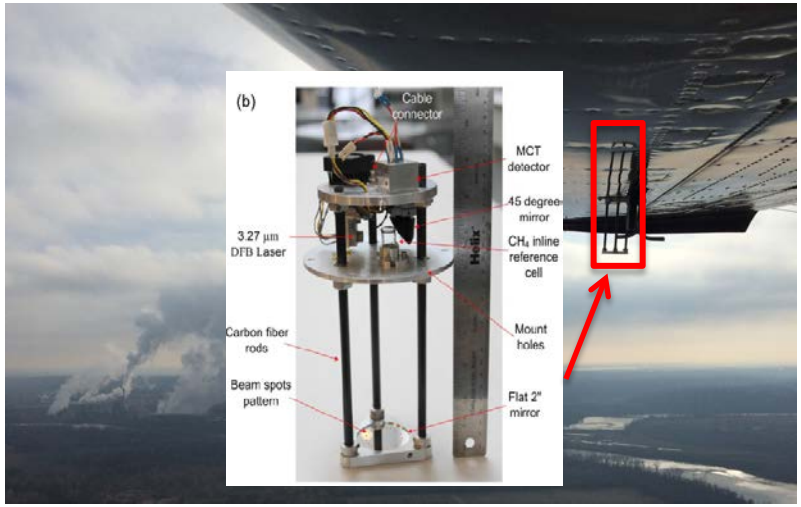
Fugitive methane from petrochemical activities



A compact, drone-based CH_4 sensor was successfully flight tested

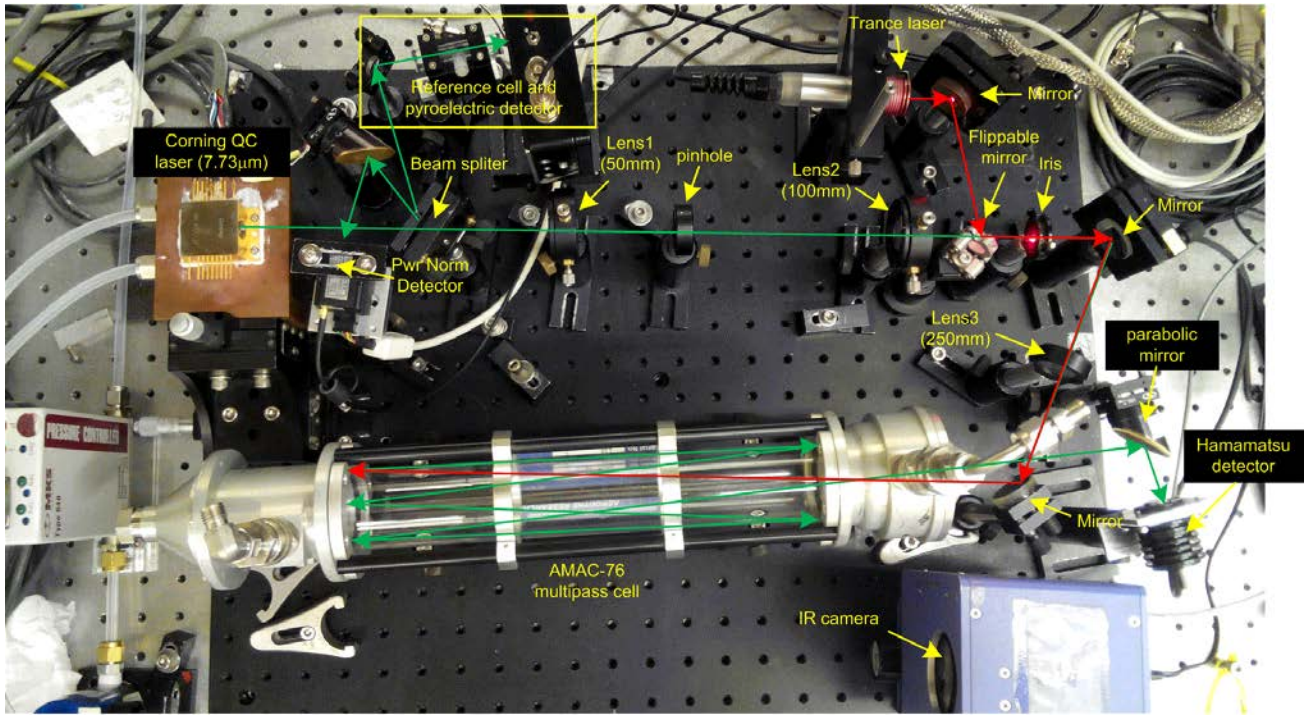
- laser: 3.27 micron GaSb DFB
- precision: 2 ppbv at 10 Hz
- total mass: 1.81 kg (sensor + electronics)
- flight stability < 30 ppbv over 2 h
- agreement ±(0.5% + 5 ppbv)

drone-based flights along pipeline in May 2015



Sensor for Atmospheric Hydrogen Peroxide (H_2O_2)

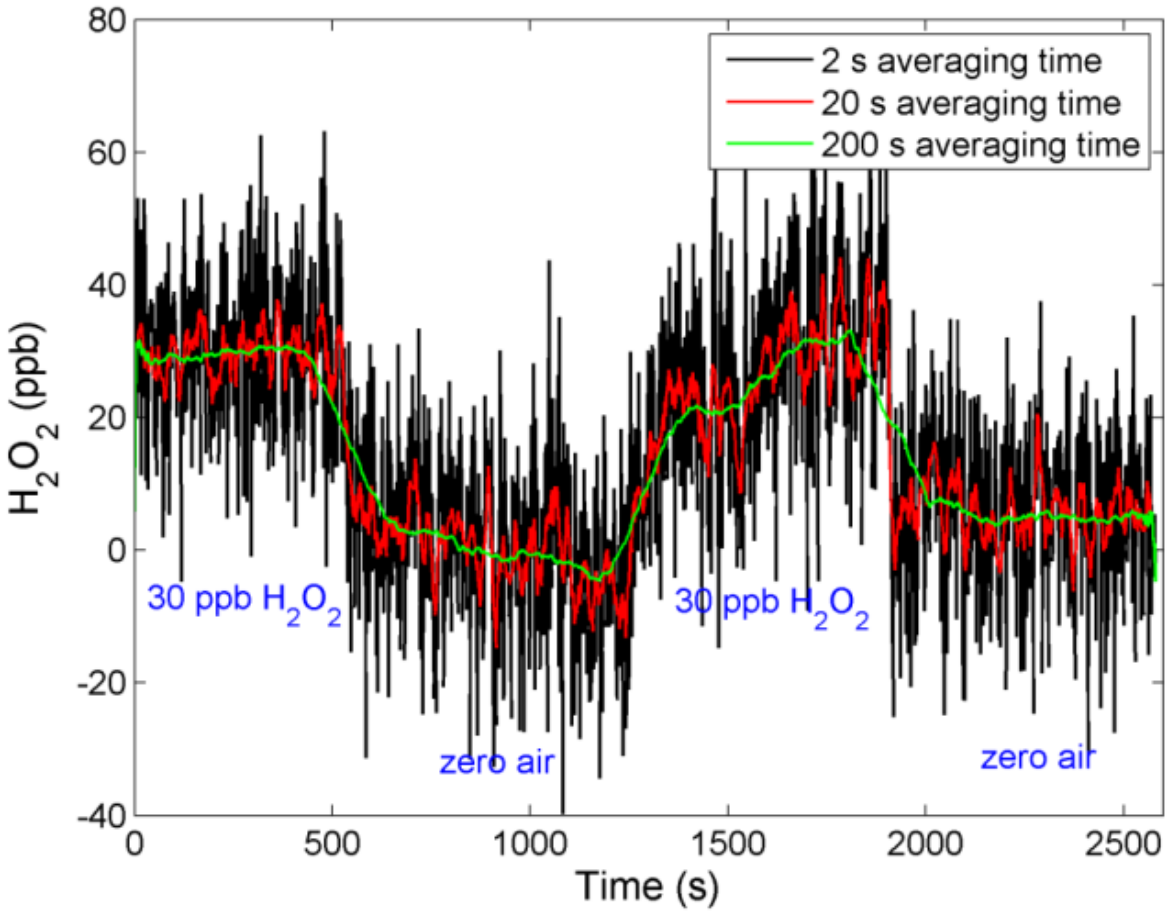
- Sensor system based on multi-pass absorption using CW DFB-QCL and targeting H_2O_2 absorption line at 1296.2 cm^{-1} was built .
- System deployed at Rice University campus and compared with commercial fluorescence-based instrument (AeroLaser AL2021).
- Further reduction of detection limit is needed for atmospheric monitoring of H_2O_2 (sub-ppbv level).
- Significant interference from other atmospheric constituents (e.g., H_2O, N_2O and CH_4) at the targeted spectral region was identified.



Multi-pass absorption-based sensor system for atmospheric H2O2 detection

Sensor for Atmospheric Hydrogen Peroxide (H_2O_2)

- Minimum H_2O_2 detection limit (MDL): 13.4 and 1.5 ppb (200 and 2 sec integration time respectively)
- Improved MDL compared with previous QEPAS-based sensor (75 ppb at 1 sec integration time)
- Improved detection will be achieved by targeting a new spectral region with minor interference from other atmospheric species (1249.45 cm^{-1})



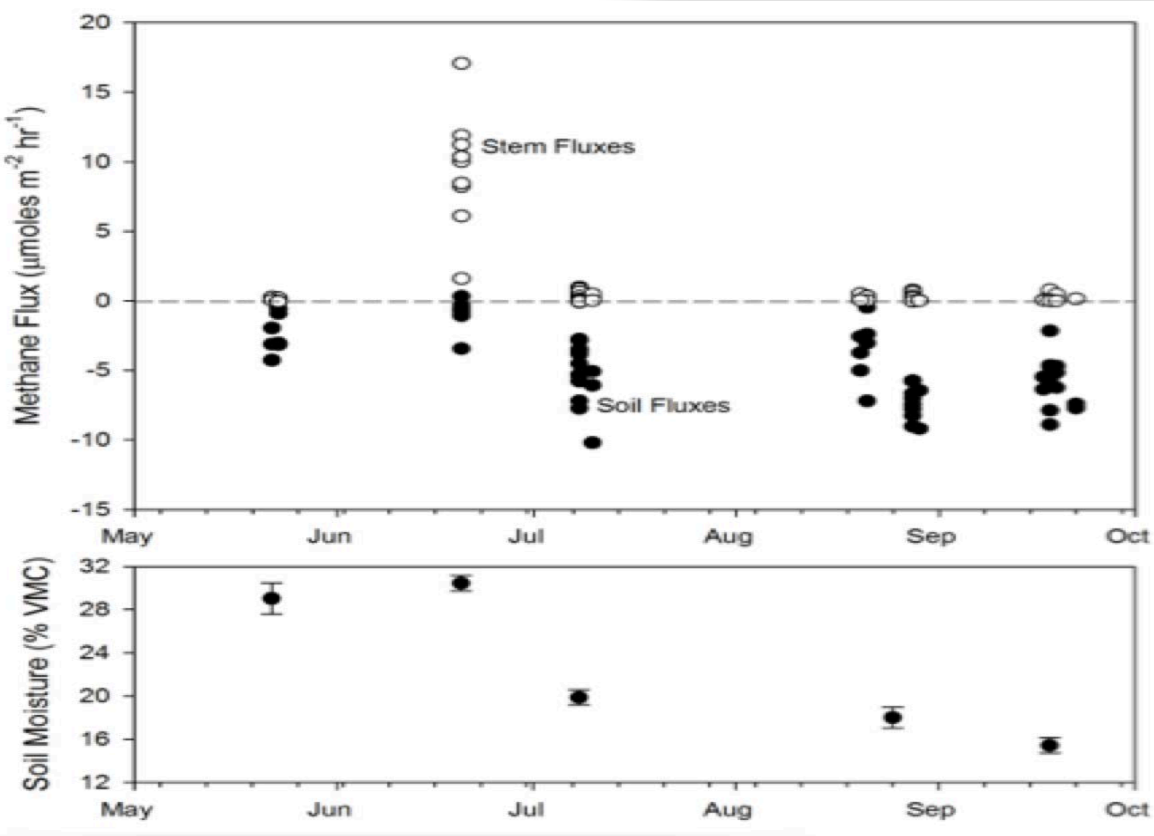
Detection of gas-phase H2O2 at the ppb level using the multi-pass absorption-based sensor system

Understanding the Carbon Cycle: the Contribution of Soil and Vegetation

Methane fluxes across tree stem and soil surfaces in during the 2014 growing season. Points above 0 indicates source, points below are sinks. Each point represents a significant flux (R^2>0.8).

Upland forests may not be the uniform CH_4 sinks as previously thought.

I*n situ* data demonstrate that CH_4 is emitted from the stems of dominant tree species, and that tree emissions occur throughout the growing season while soils adjacent to the trees are consuming CH_4

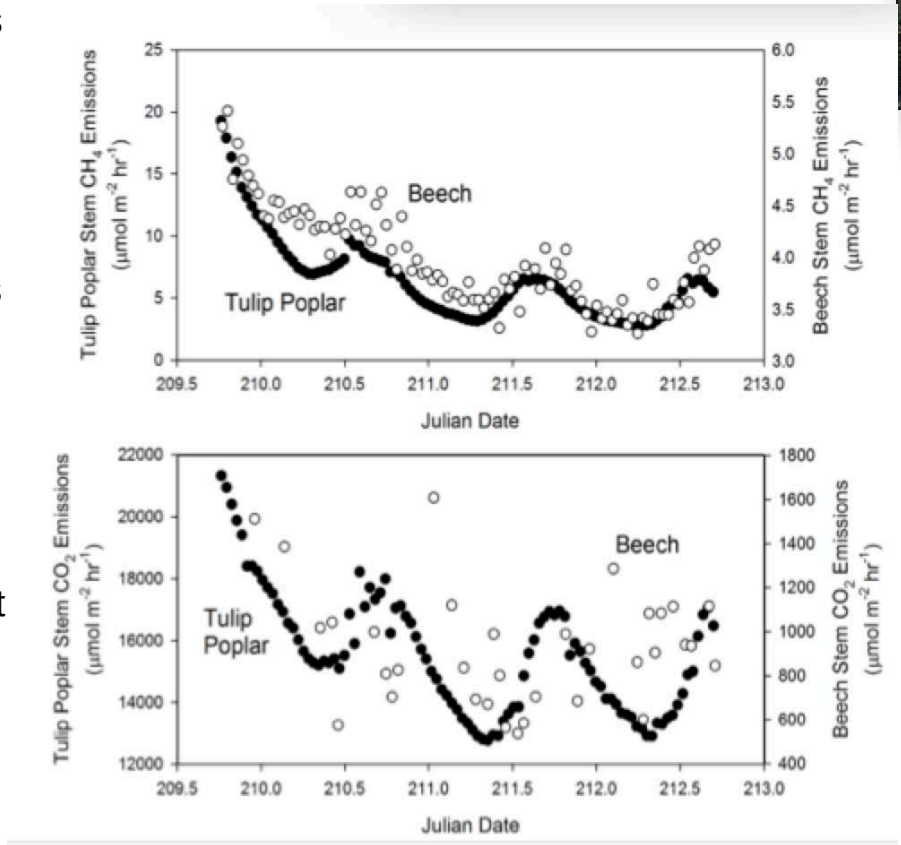


Understanding the Carbon Cycle: the Contribution of Soil and Vegetation

High frequency measurements revealed diurnal cycling in the rate of CH_4 emissions, pointing to soils as the CH_4 source and transpiration as the most likely pathway for CH_4 transport.

Findings may reduce global estimates for temperate forests as CH_4 sinks.

Stem emissions can be particularly significant in upland tropical forests, characterized by high rainfall and transpiration. Transpiration-driven CH_4 transport may help explain observations of unexpectedly high pools of atmospheric CH_4 over tropical forests and help resolving differences between models and measurements.

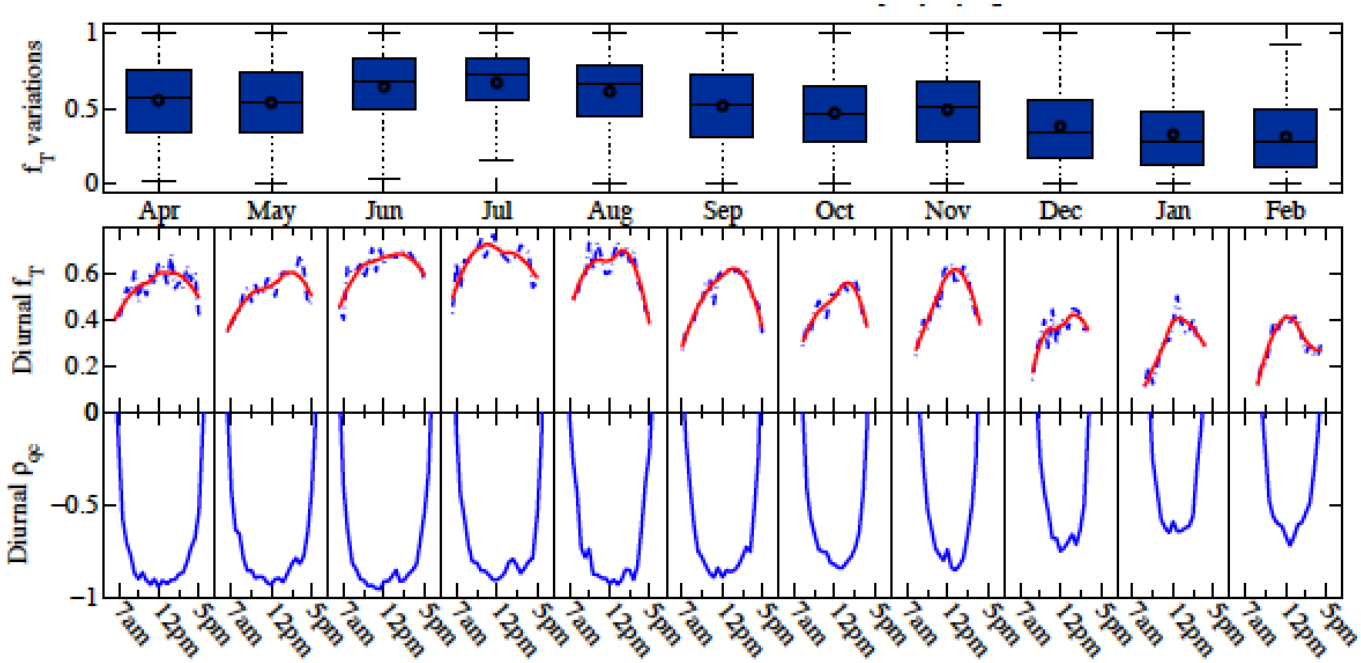


Coupled Water, Carbon and Nitrogen Cycles in Urban Environments

Water Vapor – CO2 correlation

Partitioning of evaporation between plant transpiration and soil evaporation exhibits pronounced seasonal and diurnal cycles.

Validation of QCL-based water vapor isotopes analyzer.



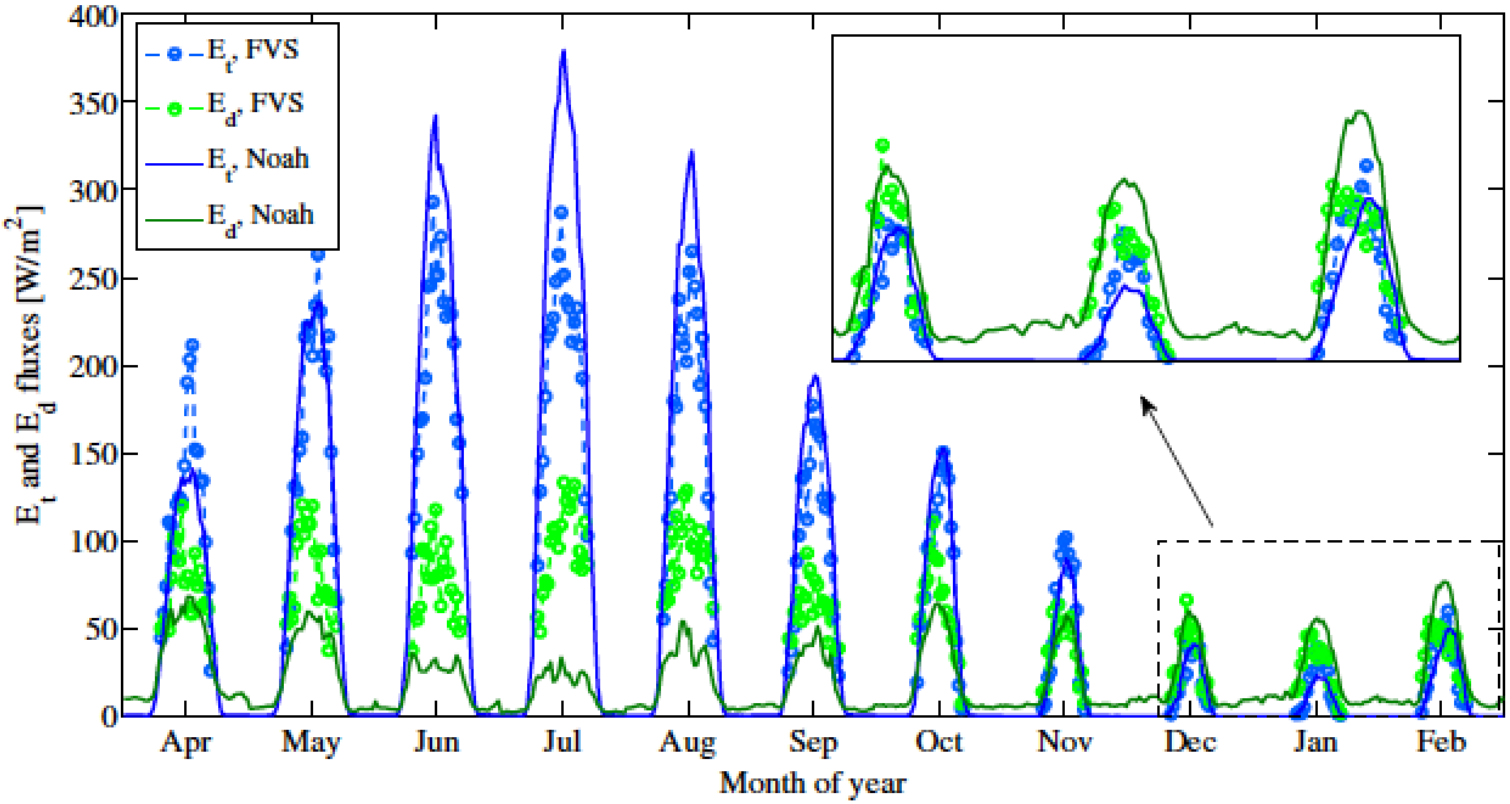
Princeton Testbed

Environmental Sensors

Coupled Water, Carbon and Nitrogen Cycles in Urban Environments

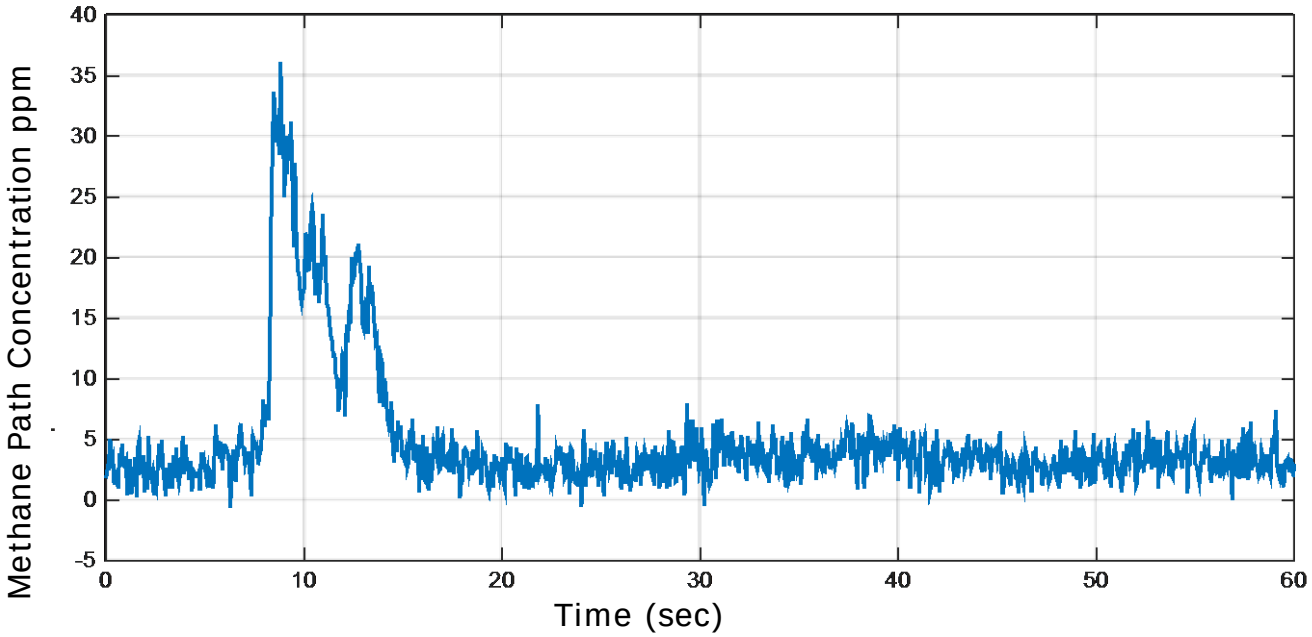
Climatology of transpiration and direct soil evaporation – seasonal and diurnal cycles

Validation of regional climate models used to assess urban impacts on climate



Monitoring Trace Gas and Aerosol Properties in the Urban Environment

* QCL Open-path fence-line system to monitor methane and nitrous oxide with 1% accuracy over a 250 meter path.
* Two Channel aerosol and cloud micro-pulse IR lidar and field testing is ongoing.
* Demonstrated the high stability and reputability of a pulsed SG-DBR QCL system for spectroscopic applications

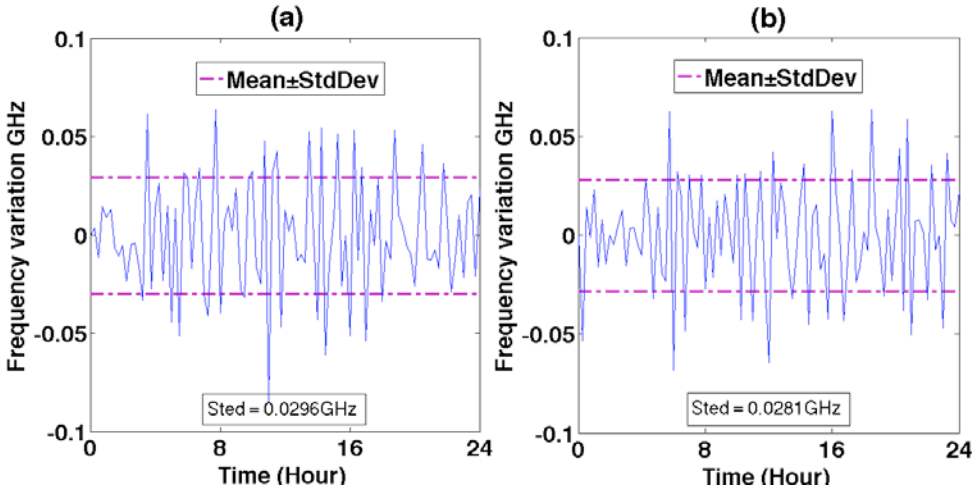


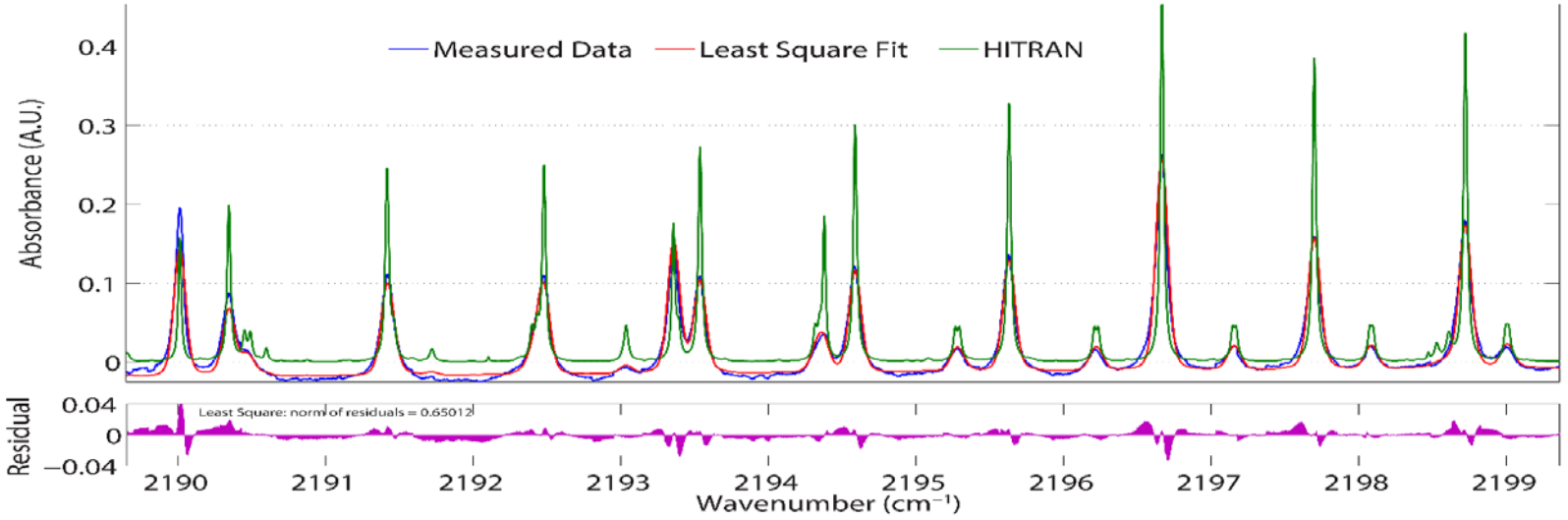
Stand-off Detection of Methane Leak.

Two Channel portable IR Micropulse Lidar at 1.5 and 4.5 microns for Clouds and Aerosols Observations

Monitoring Trace Gas and Aerosol Properties in the Urban Environment

A stable and repeatable system: Relative pulsed SG-DBR frequency fluctuations measured using two different N2O absorption line peaks at 150 Torr. (a) 2198.7 cm^{-1} and (b) at 2197.7cm^{-1} respectively.



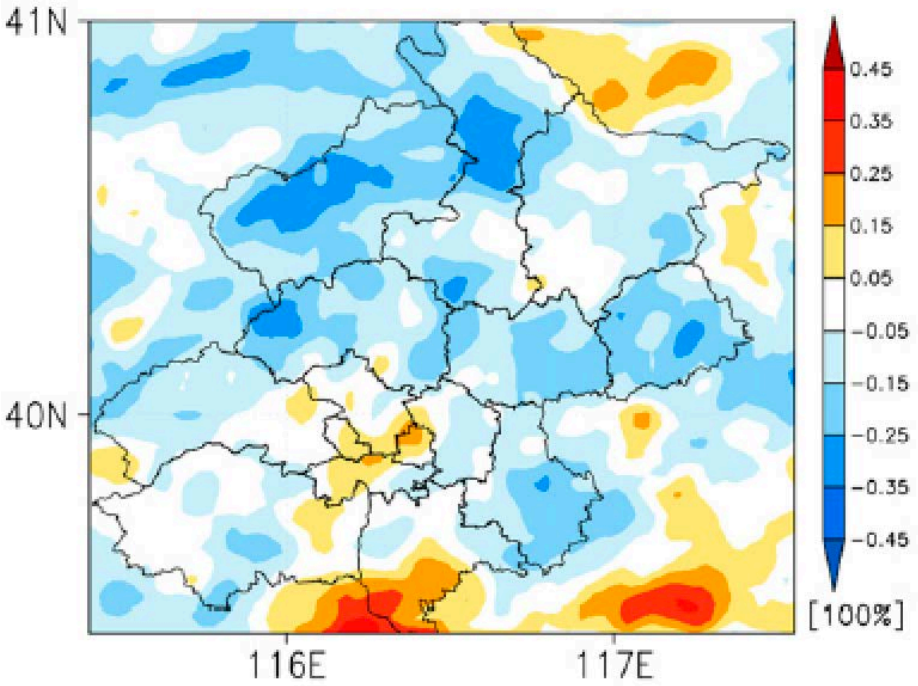


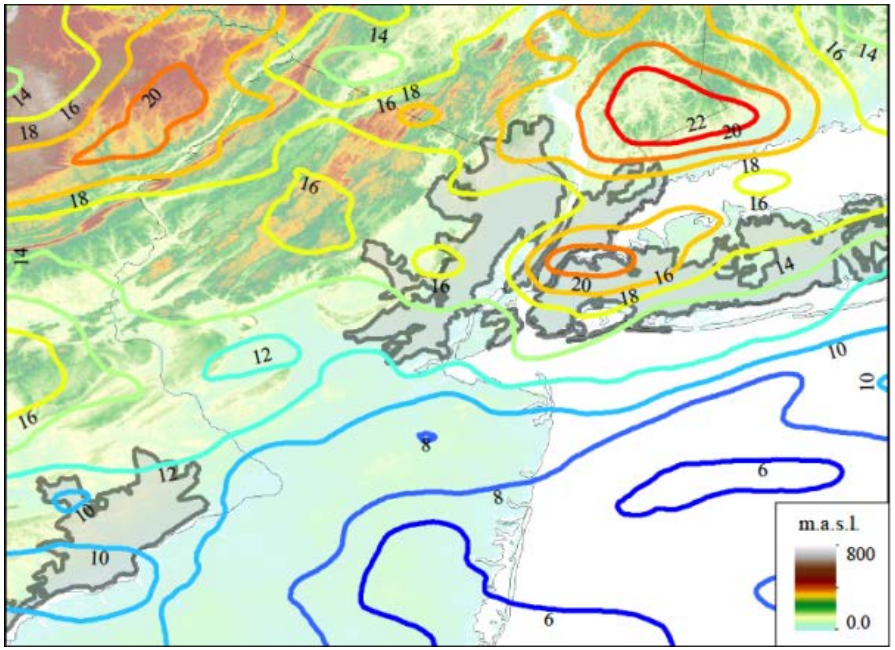
Broad electronic tunability at high resolution: Spectrum of simultaneous detection of H_2O, CO, N_2O .

Urban Climate Modeling

Urban Modeling of regional climate: New York, Beijing and Baltimore testbeds.

Changes in the decadal-averaged (2000-2009) rainfall during August for the Beijing metropolitan region, associated with urban growth from 1993 – 2004.





Mean rainfall (mm) for the 50 most intense thunderstorm systems over the New York – New Jersey metropolitan region during the period from 2001 – 2009.

Quantum Cascade Lasers for Breath Analysis

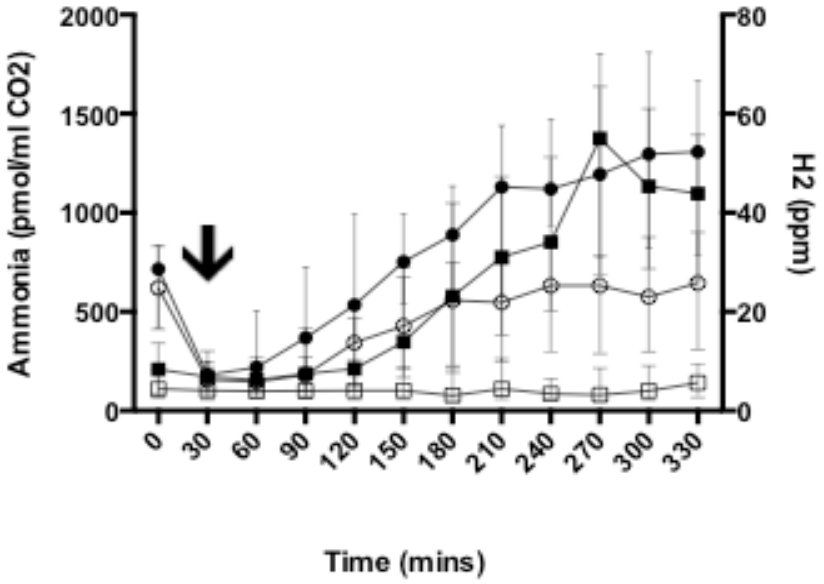
Simultaneous multi-metabolite breath analysis provides a unique and powerful approach to evaluate gut metabolism and nutrition physiology in vivo.

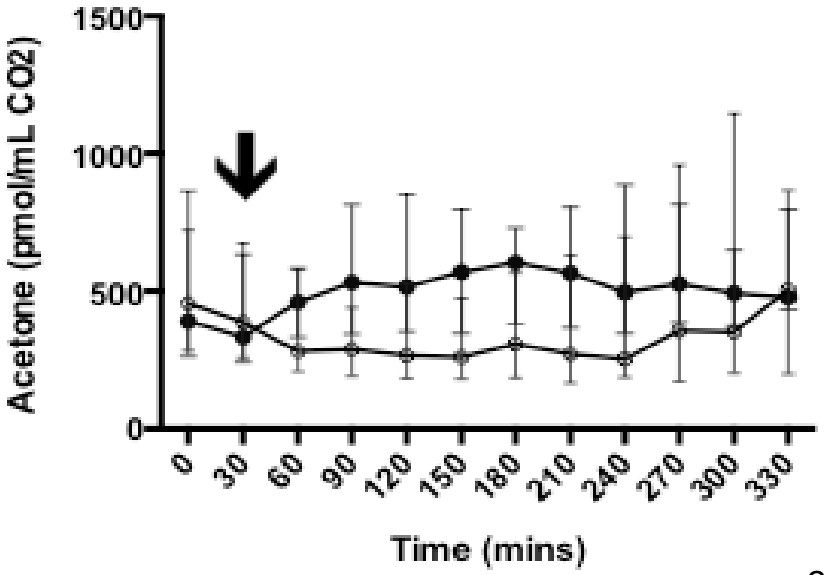
In 30 healthy subjects, we measured ammonia, acetone, and hydrogen serially for 6 hours in a control trial (glucose) and after a 60 gm high protein intervention.

Ammonia levels increase above baseline in response to a high protein intervention but not to control.

Acetone increase in intervention compared to decrease in control suggests that increased ammonia may be due to amino acid degradation.

Hydrogen peak marks time when the oral challenge enters the distal small bowel and colon





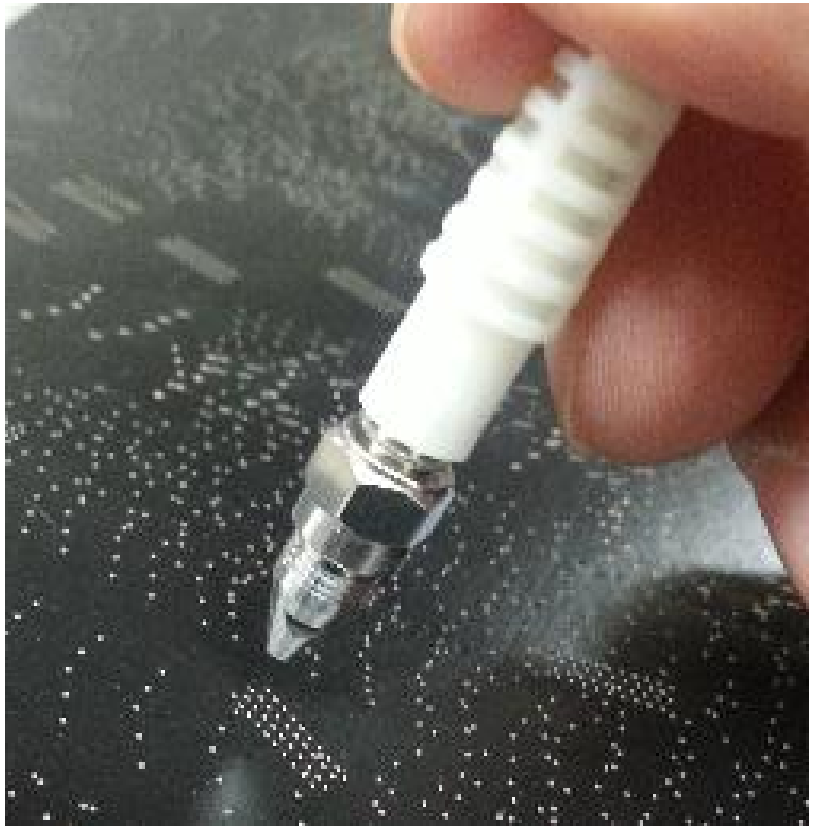
Laser Therapy Using 6 μm Quantum Cascade Lasers

Capulorhexis is the most difficult part of cataract surgery and freehand laser incision could be a cost-effective alternative to femtosecond capulorhexis.

We performed studies to develop a freehand laser Capsulorhexis technique.

To achieve that goal, we first measured the absorption spectra of lens capsules.

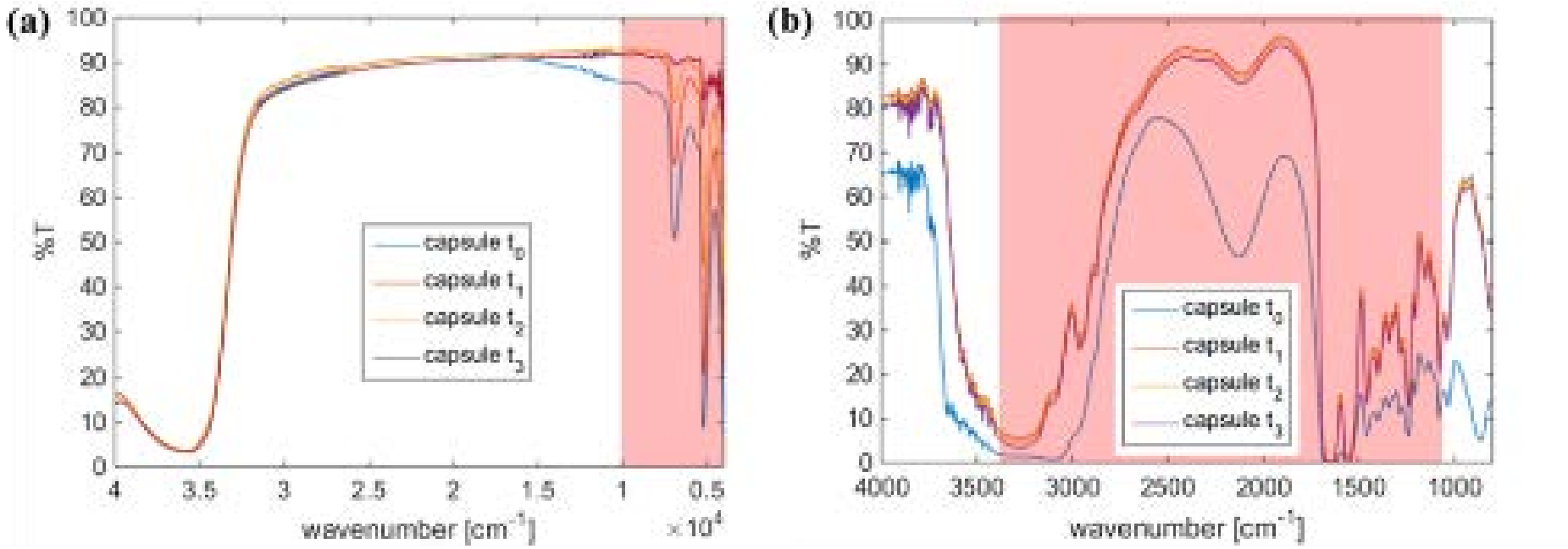
In parallel we designed and fabricated ball lens based laser cutters and demonstrated free-hand laser capulorhexis of ex vivo cow eyes.



Stainless laser cutting tip using ball lens for freehand laser capulorhexis

Laser cutting of lens capsule, Below: lens removed

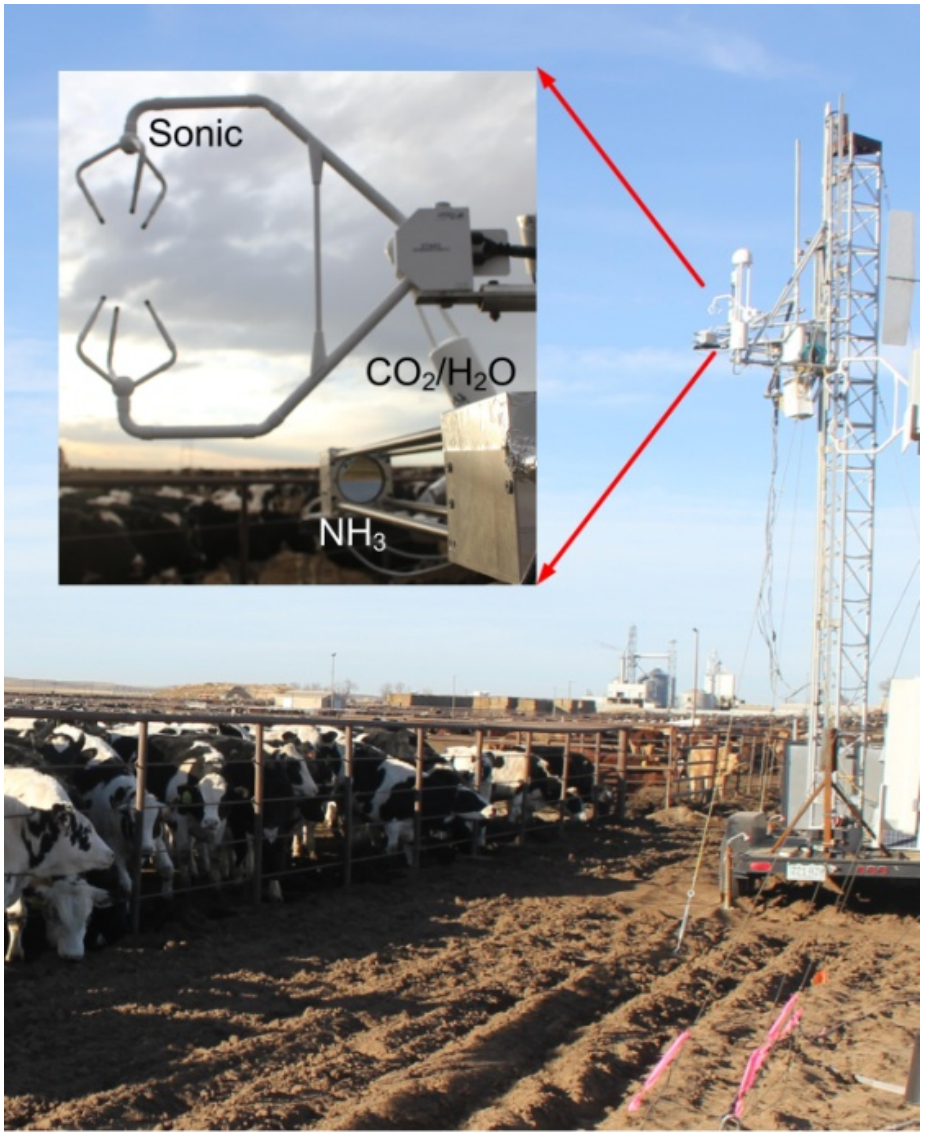
Laser Therapy Using 6 µm Quantum Cascade Lasers



Transmittance measurement in (a) UV-visible-near IR region and (b) infrared region. Red regions indicates where water vaporization occurs during the temporal measurement over 2 hours between t_o to t_3..

SLIP I: Multi-Sensor Deployment for Assessing Spatiotemporal Variability of Carbon, Nitrogen and Water Fluxes

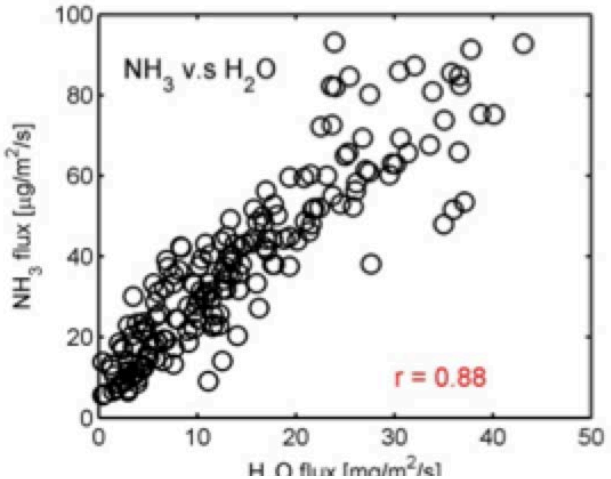
- Open-path NH_3 EC flux measurements were demonstrated at a cattle feedlot
- A new open-path, quantum cascade laser-based sensor was used in the EC setup and showed advantage over commercial sensors
- A detection limit of 1.3±0.5 ng m^{-2} s^{-1} NH_3 flux was achieved

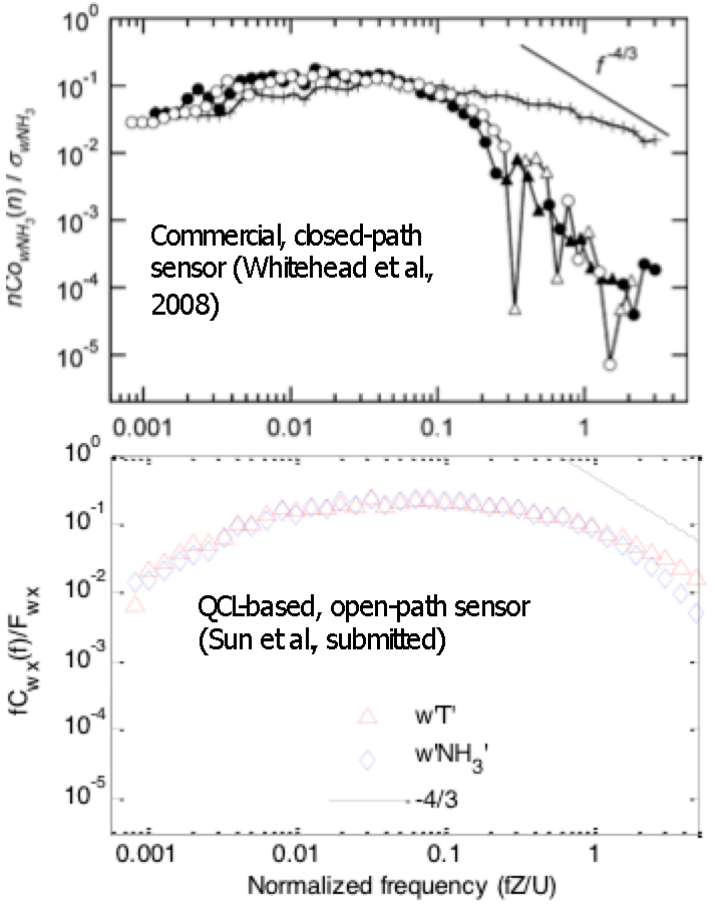


Experimental setup of the eddy covariance measurements above a 25,000-animal cattle feedlot

SLIP I: Multi-Sensor Deployment for Assessing Spatiotemporal Variability of Carbon, Nitrogen and Water Fluxes

NH_3 fluxes showed a strong diurnal cycle and correlated well with latent heat; CH_4 fluxes correlated with CO_2 fluxes:





Cospectra of NH_3 fluxes measured by closed-path sensors (top) and by open-path sensor (bottom)

Summary

- Continued expansion in field deployment of environmental sensors have lead to important scientific advances in air quality and regional climate.
- Rapid growth in deployment of sensors on mobile platforms.
- Testbeds continue to provide key resources for development, testing and demonstration of QCL-based environmental and public health sensor systems.
- Field deployments have demonstrated ability of Thrust 5 projects to contribute cutting-edge advances to sensor technologies.