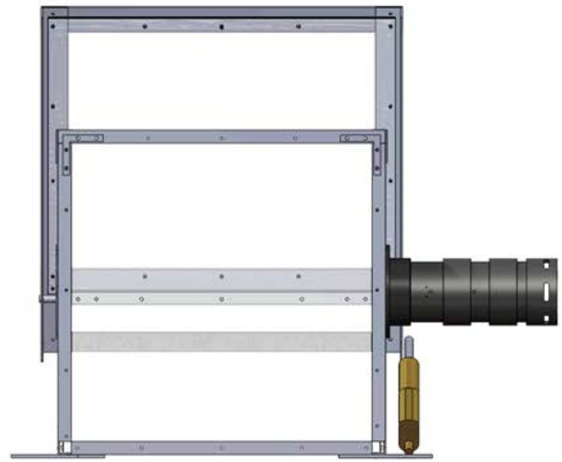
Development of the Next Generation of Flux-Measurement Tools



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Dry Deposition is an important contributor to acidification

- The EPA is considering changing future secondary National Ambient Air Quality Standards (NAAQS) for SO_2 and NO_2 based on acidification
- SO_2 dry deposition accounts for up to 50% of total sulfur deposition
- Dry deposition accounts for up to 40% of total nitrogen deposition
- There is a lot of uncertainty regarding dry deposition measurements and modeling

Flux-measurement methods are costly or indirect

Inferential Method:

Advantages:

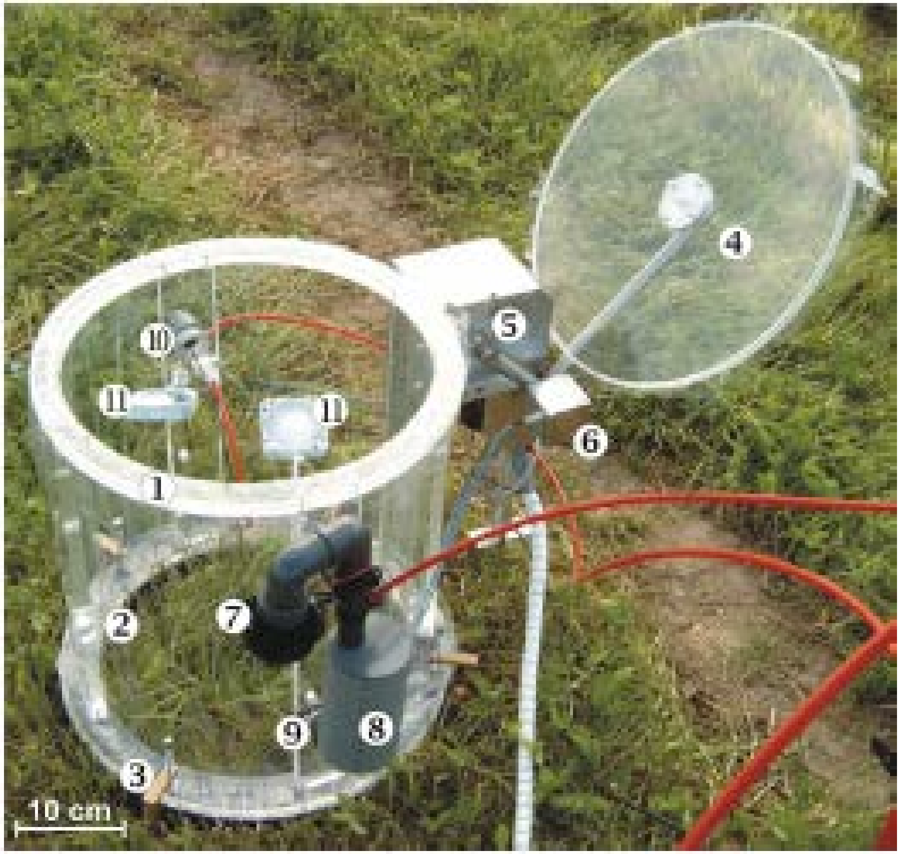
- Less expensive than eddy covariance
- Less technically difficult
- Direct measurement
- Most accurate method available

Disadvantages:

- Based on models that don’t always agree with direct measurements, or other models
- Flux estimates between models can vary by a factor of 2 to 3
- Expensive (> $500,000)
- Technically difficult and computationally expensive

Burba (2005)

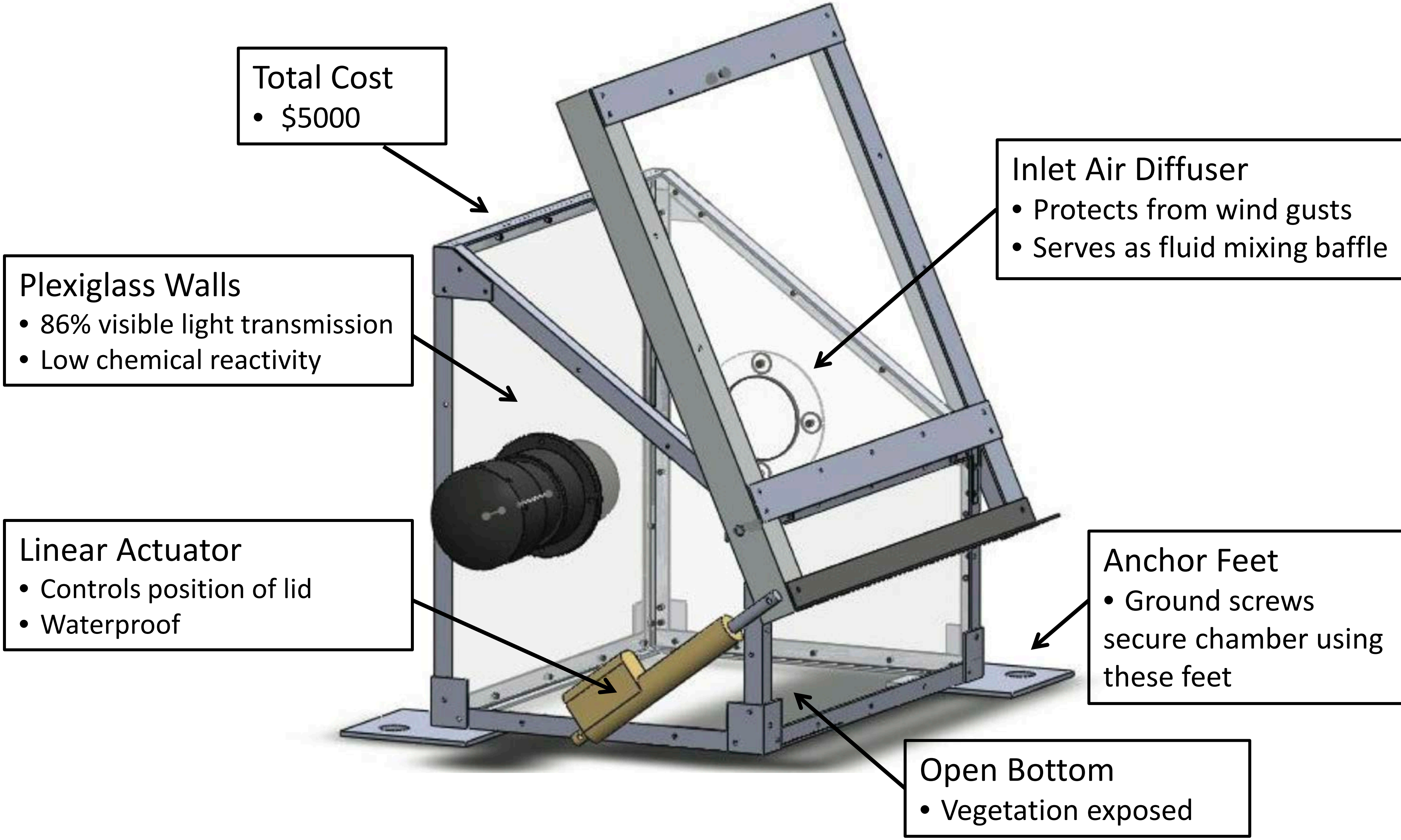
Pape et al. demonstrated that flux chambers are an accurate tool for measuring dry deposition



- Dynamic flux chambers were used in combination with traditional pollutant monitors
- Measured CO_2 and methanol surface flux over grassland
- Demonstrated good agreement with eddy covariance systems

Pape (2005)

Dynamic Flux Chambers could provide direct dry-deposition measurements



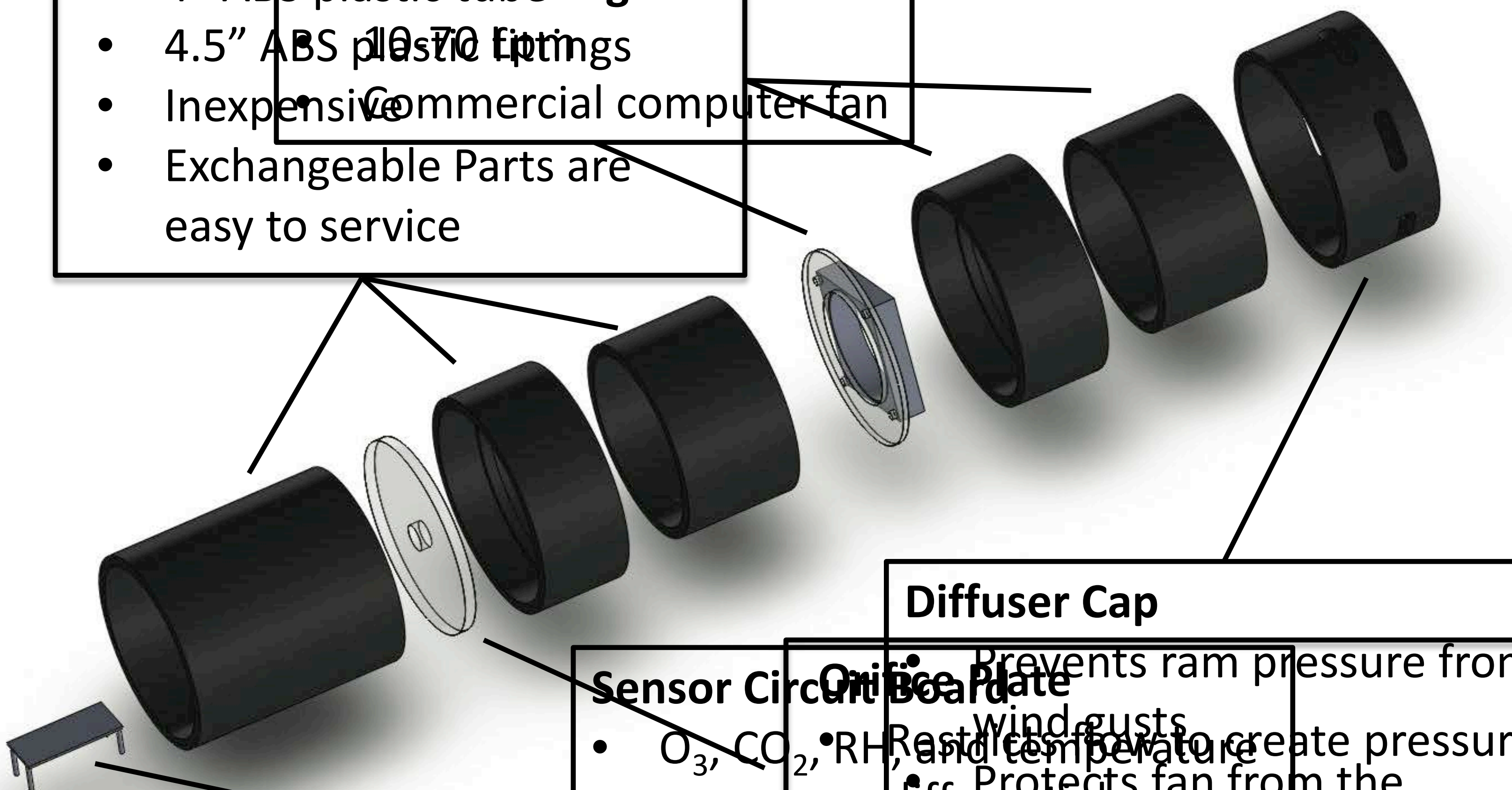
Chamber outlet houses sensors and flow controls

Standard Components

- 4” ABS plastic tube
- 4.5” ABS plastic fittings
- Inexpensive
- Exchangeable Parts are easy to service

Fan & Mounting Plate

- 10-70 Lpm
- Commercial computer fan



Diffuser Cap

- Prevents ram pressure from wind gusts
- Protects fan from the elements

Orifice Plate

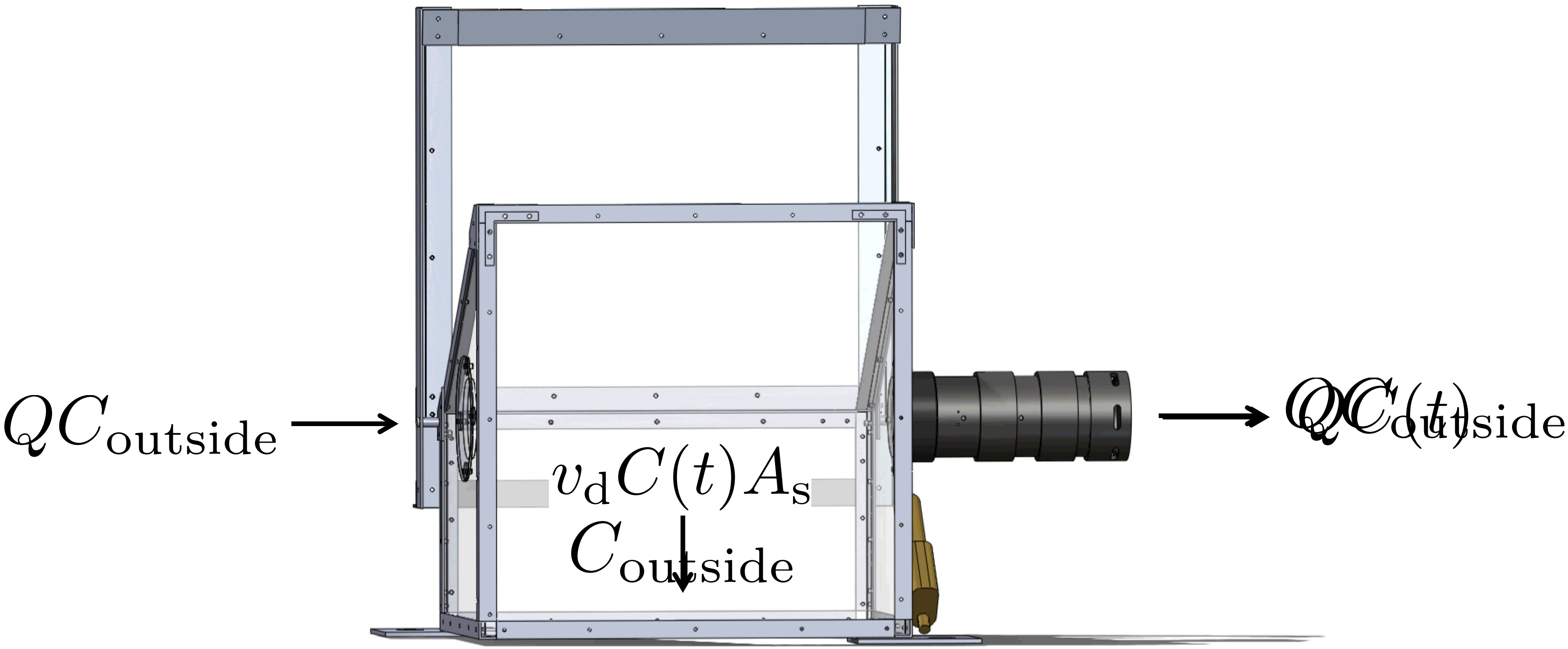
- Restricts flow to create pressure differential
- Enables the pressure transducer to measure flow rate

Sensor Circuit Board

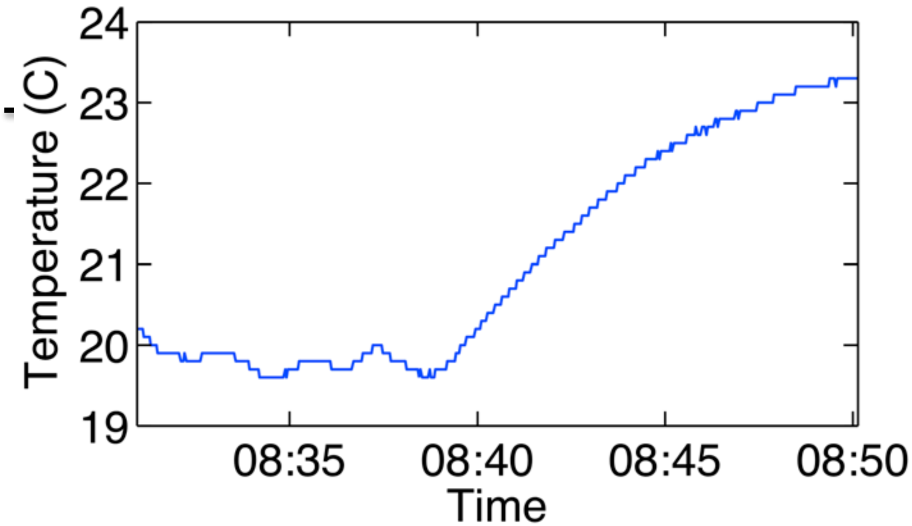
- O_3, CO_2, RH, and temperature sensors
- mounted on standoffs to place sensors in center of flow path

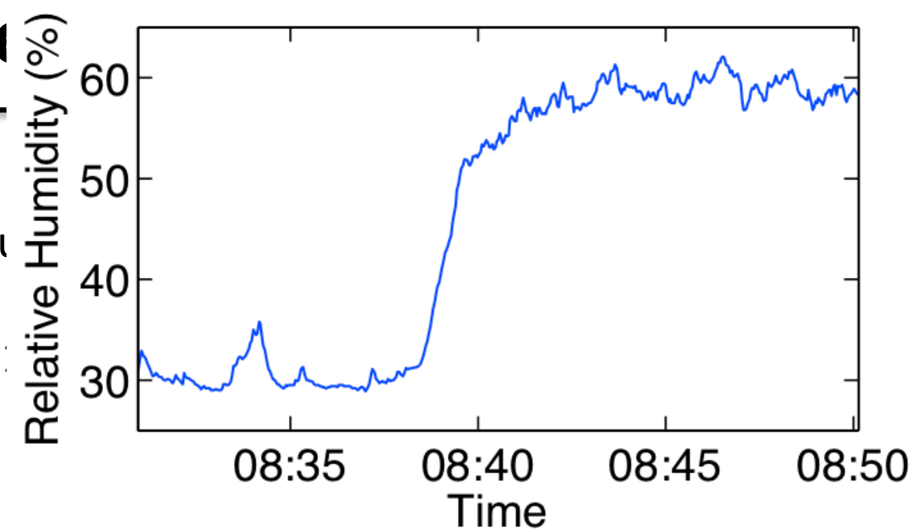

Ozone Monitor

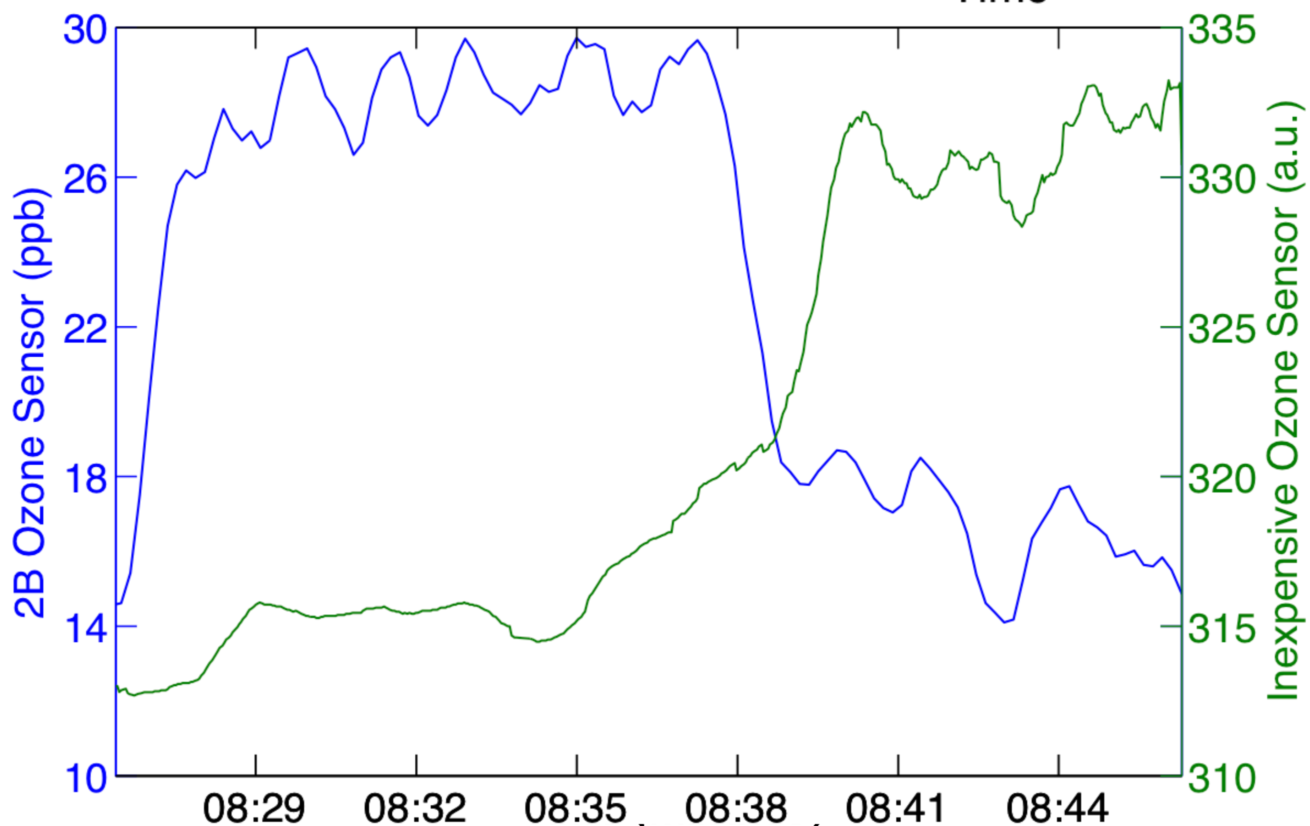
Dry deposition flux is calculated via a mass balance



$$C(t) = \frac{QC_{\mathrm{out}}}{Q - v_{\mathrm{d}}A_{\mathrm{s}}} + (C_{\mathrm{out}} - \frac{QC_{\mathrm{out}}}{Q - v_{\mathrm{d}}A_{\mathrm{s}}})e^{\frac{-(Q - v_{\mathrm{d}}A_{\mathrm{s}})t}{V}}$$



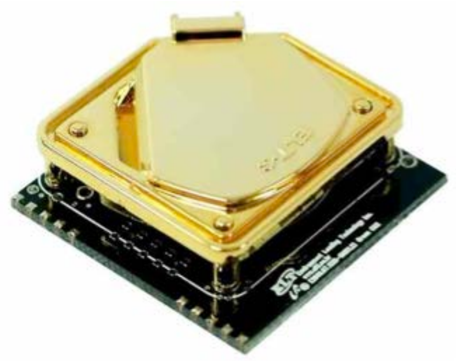




Plot Parameters

- C_{ozone} = 30 ppb
- v_d= - 0.1 cm/s

Inexpensive sensors enable low-cost measurements

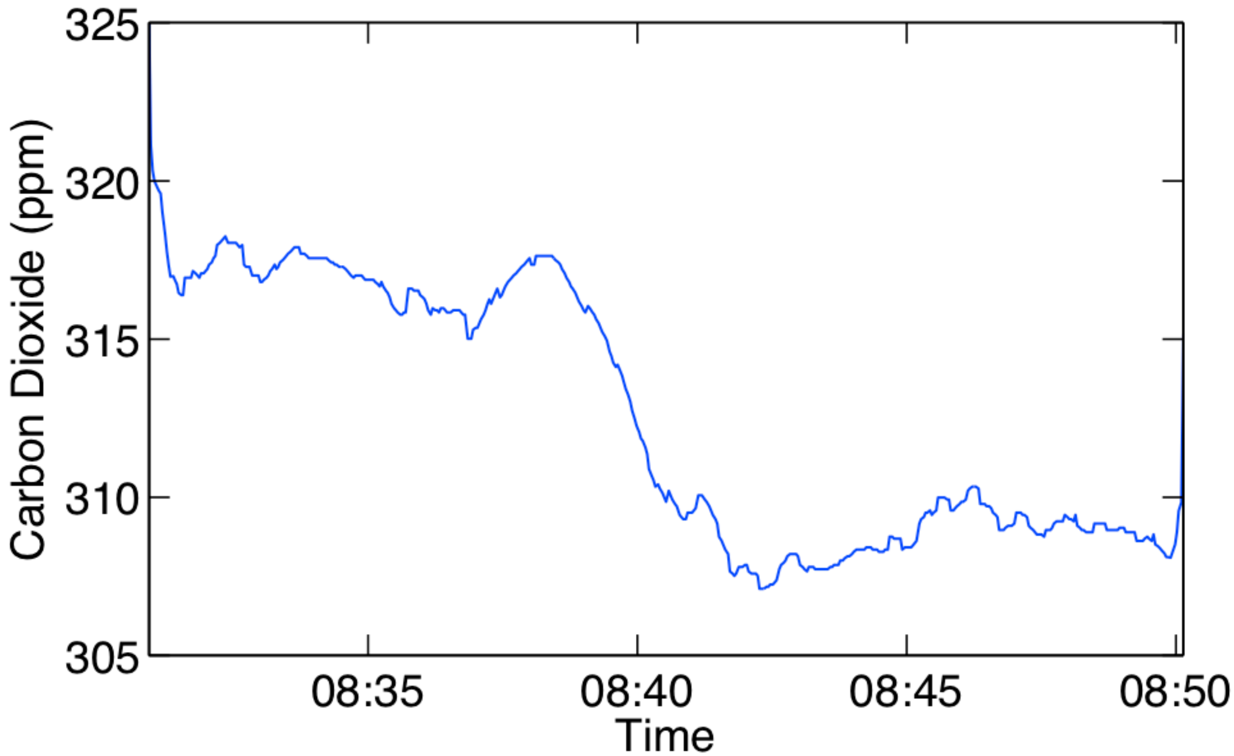


CO_2 Sensor

- Non-dispersive infrared
- Costs about $60
- Detection range of 0-5000 ppm
- 30 ppm resolution

Concerns

- Sensitive to temperature



Inexpensive sensors enable low-cost measurements

NO_2 Sensor

- Electrochemical Sensor
- Costs about $80
- Detection range of 0-20,000 ppb
- < 20 ppb resolution

Concerns

- Sensor resolution (ideally 1 ppb)
- NO emissions react with O_3 and rapidly produce NO_2. This can diminish the magnitude of NO_2 deposition reading

SO_2 Sensor

- Electrochemical Sensor
- Costs about $80
- Detection range of 0-50,000 ppb
- < 100 ppb resolution

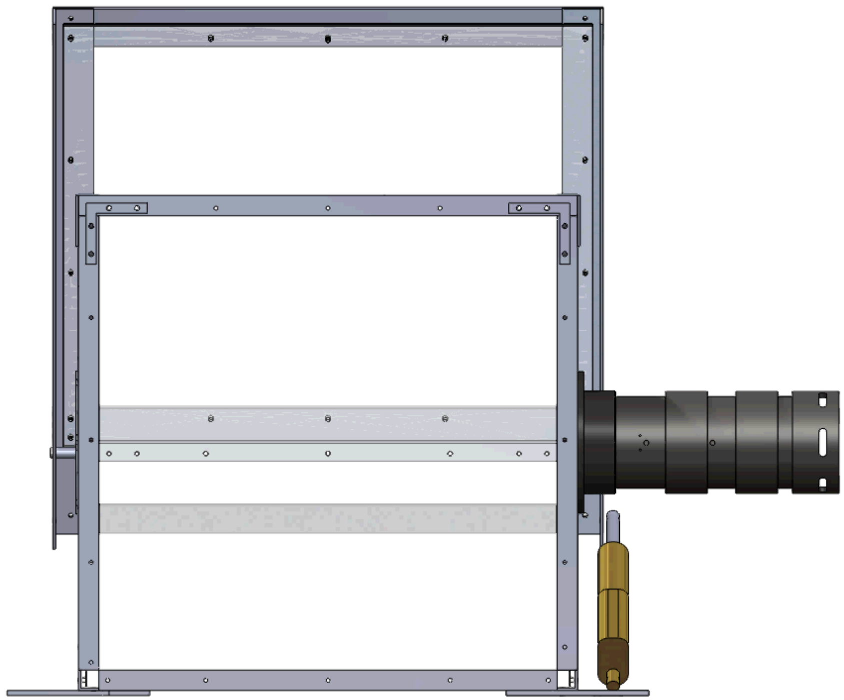
Concerns

- Sensor resolution (ideally 1 ppb)
- SO_2 levels in the western US are low, so SO_2 deposition will be very difficult to measure

Summary & Future Plans

- We developed a flux chamber that measures CO_2, O_3, RH, temperature, rainfall, and soil moisture.
- The crux of our project is finding inexpensive ways to take high-resolution NO_2 and SO_2 measurements.
- We will develop electronics and install the NO_2 and SO_2 sensors. We will also install high-resolution NO_2 measurement devices, which will enable us to calibrate and evaluate the inexpensive sensors.
- We will perform calibrations to explore the effects of temperature, RH, and cross-sensitivity on the O_3 sensors.
- We will compare our flux-chamber results to an eddy-covariance system.

Questions?



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References

EPA, *Policy Assessment for the Review of the Secondary NAAQS for Oxides of Nitrogen and Oxides of Sulfur,* United States Environmental Protection Agency, 2011.

Burba, G; Anderson, D. *A Brief Practical Guide to Eddy Covariance Flux Measurements,* Version 1.0.1; Licor, Inc.: Lincoln, 2005.

Driscoll, C.T.; Lawence, G.B.; Bulger, A.J.; Butler, T.J.; Cronan, C.S.; Eagar, C.; Lambert, K.F.; Likens, G.E.; Stoddard, J.L.; Weathers, K.C. Acidic Deposition in the Northeastern United States: Sources and Inputs, Ecosystem Effects, and Management Strategies. *Bioscience.* **2001,** *51,* 180-198.

Clean Air Status and Trends Network; *2010 Annual Report*; U.S. Environmental Protection Agency: Washington, DC, 2010.

Seinfeld, John H. ; Pandis, Spyros N. *Atmospheric Chemistry and Physics - From Air Pollution to Climate Change,* 2nd ed.; John Wiley and Sons: Hoboken, 2006.

Turnipseed, A.A; Burns, S.P.; Moore, D.J.P.; Hu, J.; Guenther, A.B.; Monson, R.K. Controls over ozone deposition to a high elevation subalpine forest. *Agricultural and Forest Meteorology.* **2009,** *149,* 1447-1459.

Baldocchi, D. D.; Hincks, B. B.; Meyers, T. P. Measuring Biosphere-Atmosphere Exchanges of Biologically Related Gases with Micrometeorological Methods. *Ecology.* **1988,** *69*, 1331-1340.

Schwede, D.; Zhang, L.; Vet, R.; Lear, G. An intercomparison of the deposition models used in CASTnet and CAPMoN networks. *Atmospheric Environment.* **2011,** *45*, 1337-1346.

Wesely, M. L.; Hicks, B. B. A review of the current status of knowledge on dry deposition. *Atmospheric Environment.* **2000,** *34*, 2261-2282.

Zhang, L.; Brook, J. R.; Vet, R. A revised parameterization for gaseous dry deposition in air-quality models. *Atmos. Chem. Phys.* **2003,** *3*, 2067-2082.

Pape, L.; Ammann, C.; Nyfeler-Brunner, A.; Spirig, C.; Hens, K.; Meixner, F.X. An automated dynamic chamber system for surface exchange measurement of non-reactive and reactive trace gases of grassland ecosystems. *Biogeosciences Discuss.* **2008,** *5,* 3157-3219.

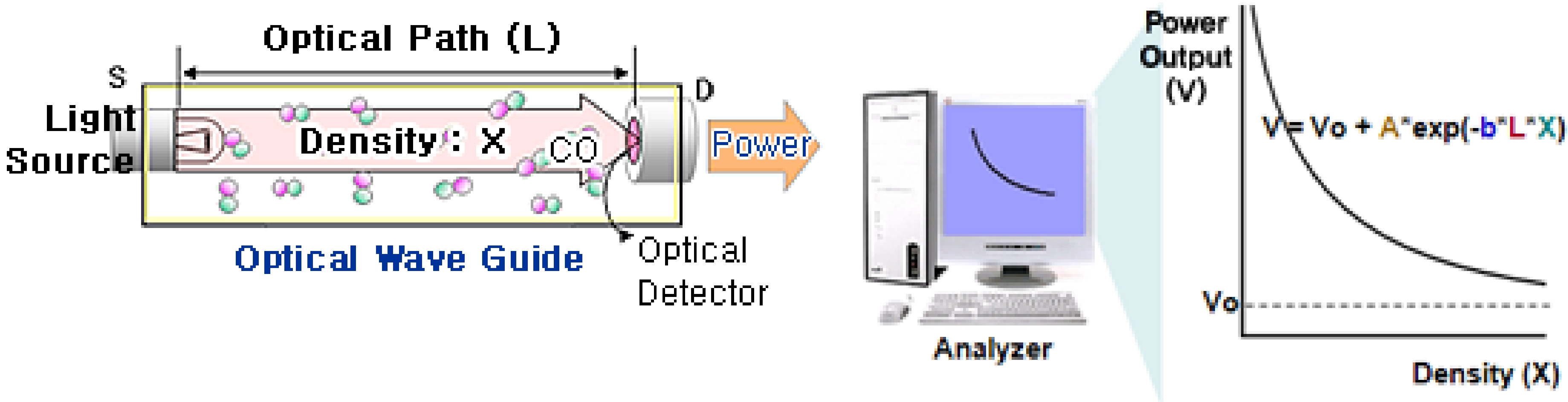
Jiang, Y.; Li, K.; Tian, L.; Piedrahita, R.; Yun, X.; Mansata, O.; Lv, Q.; Dick R.P.; Hannigan, M.P.; Shang, Li. *Papers and Notes,* 13th International Conference on Ubiquitous Computing, Beijing, China, September 17-21, 2011.

Myles, L.; Heuer, M.W.; Meyers, T.P.; Hoyett, Z.J. A comparison of observed and parameterized SO_2 dry deposition over a grassy clearing in Duke Forest. *Atmospheric Environment.* **2012,** *49,* 212-218.

Wu, Z.; Wang, X.; Chen, F.; Turnipseed, A.A.; Guenther, A.B.; Niyogi, D.; Charusombat, U.; Xia, B.; Munger, J.W.; Alapaty, K. Evaluating the calculated dry deposition velocities of reactive nitrogen oxides and ozone from two community models over a temperate deciduous forest. *Atmospheric Environment.* **2011,** *45,* 2663-2674.

D. Vaugn et al., *Characterization of Low-Cost NO_2 Sensors;* Sonoma Technology, Inc., 2010.

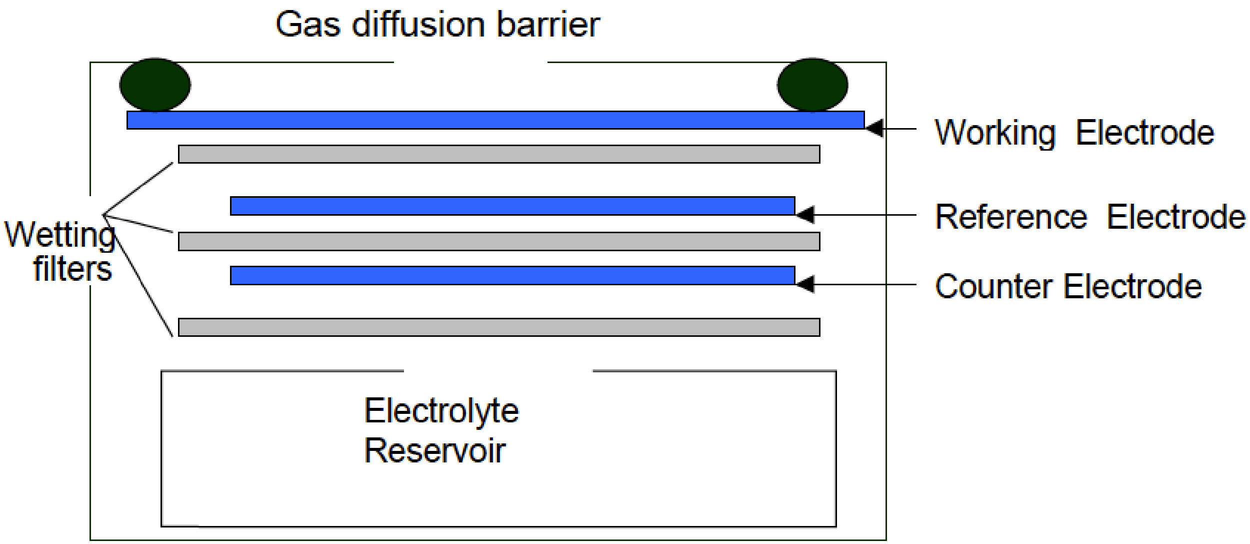
Non-dispersive infrared radiation (NDIR)



- NDIR: Infrared light is directed through a sample chamber toward a detector.
- Each gas absorbs infrared radiation at a different wavelength (CO_2 absorbs 4.26μm).
- Concentration (density) can be calculated from measured voltage and optical path length.

[2] Environment Leading Technology Website, http://tccelt.co.kr/

Electrochemical Sensors



- Measure concentration by oxidizing or reducing gas and measuring current.

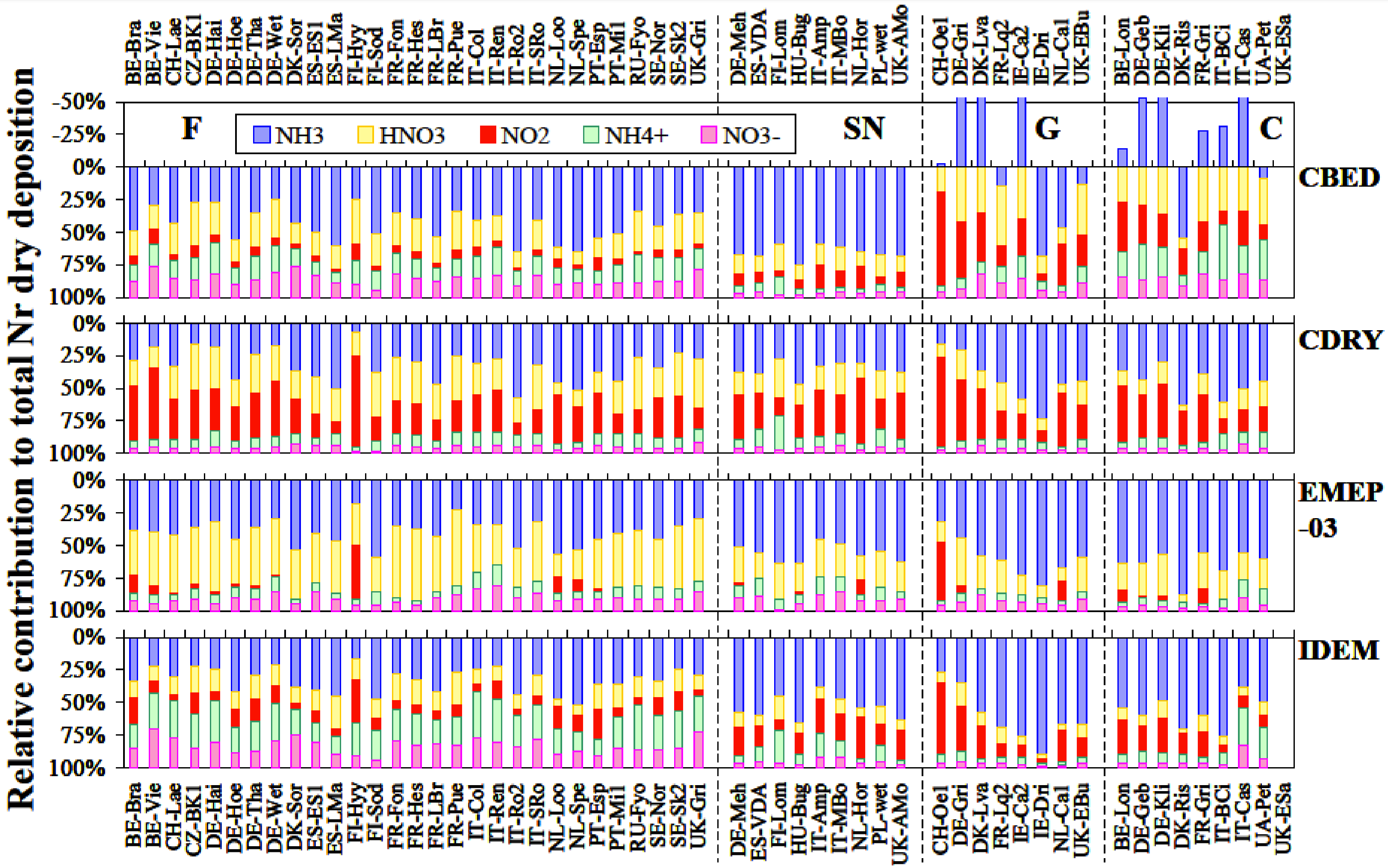
Advantages:

- Output is linearly proportional to concentration
- Stable over time (less re-calibration)

Disadvantages:

- Cross-sensitive

Relative contributions of N_r species to total inorganic N dry deposition



*Negative percentages for NH3 denote net NH3 emissions, which are expressed relative to the sum of dry deposition fluxes for the other four Nr species.

Flechard et al. (2011)

Chemiluminescence

Nitrogen Chemistry