EARTH SYSTEM RESEARCH LABORATORY

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What are we learning from Tall Tower and Vertical Profile Measurements over North America?

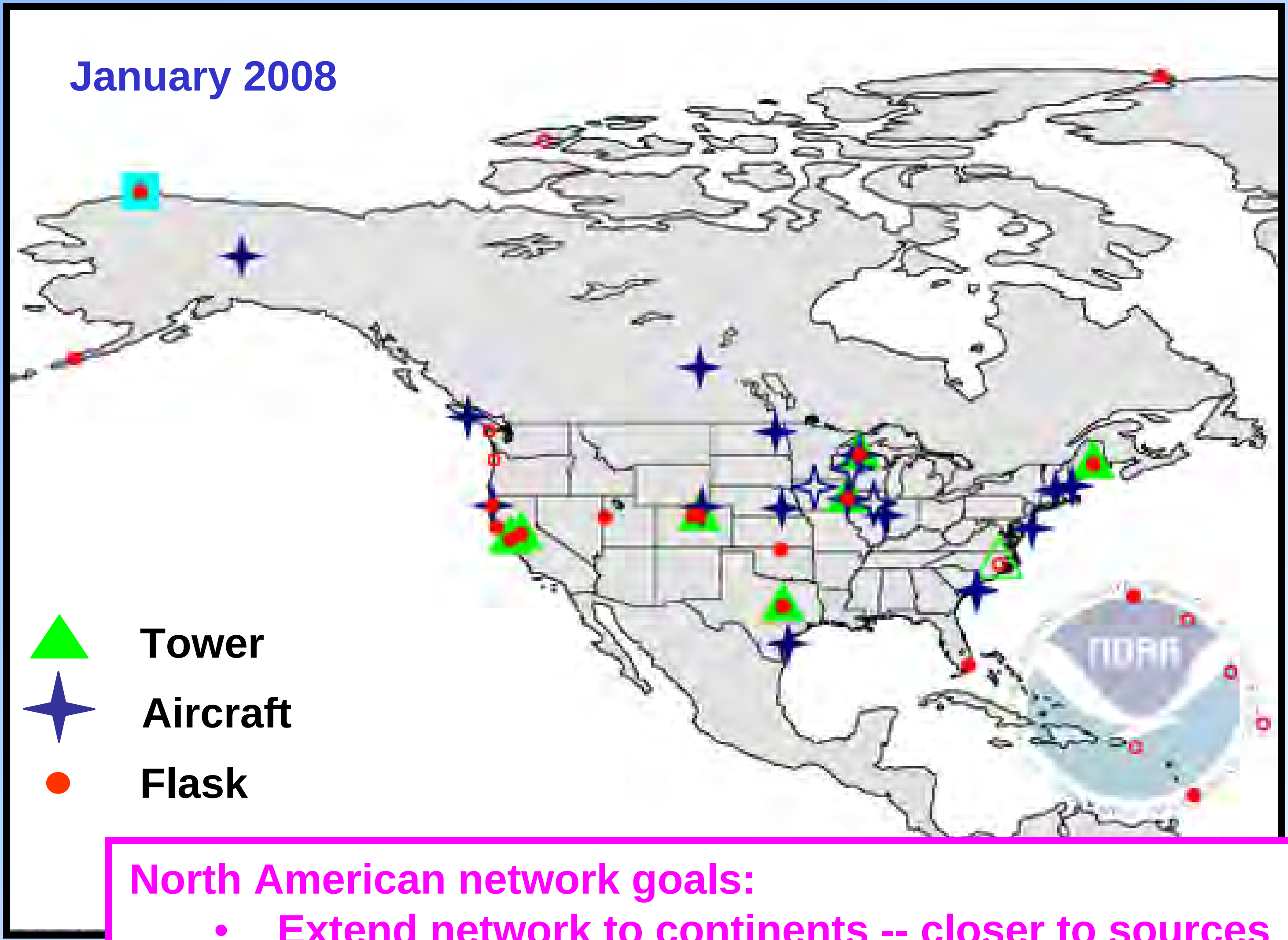
Arlyn Andrews, Colm Sweeney

ESRL Carbon Cycle Group

ESRL Atmospheric Chemistry Review

January 29-31, 2008 ~ Boulder, Colorado

NOAA ESRL's North American CarbonTracker Observing Network:

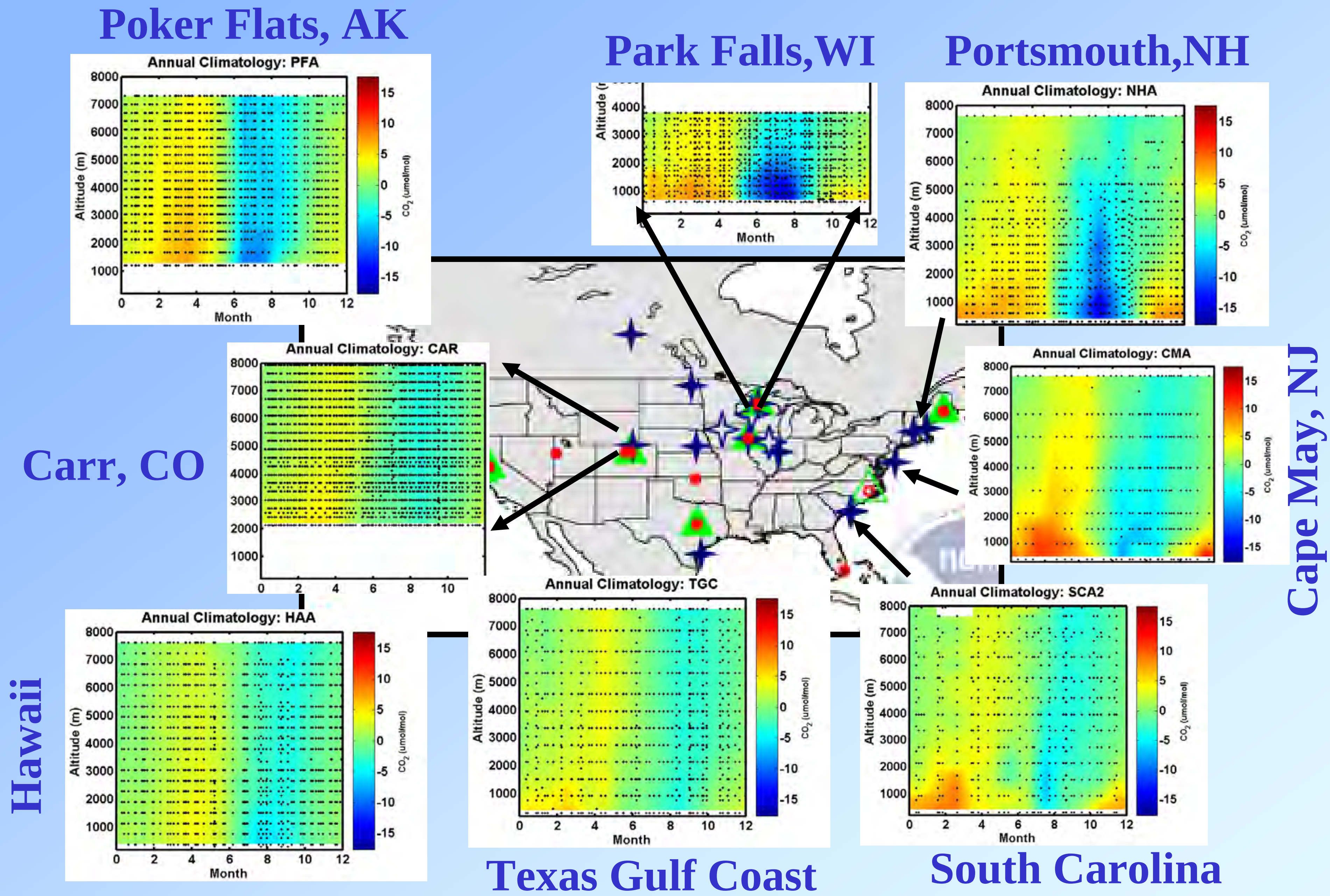


North American network goals:

- Extend network to continents -- closer to sources
- Sufficient density to do "mass-balance" estimate of CO_2 fluxes at regional scale
- Multiple species for source attribution

Automated Flask Sampling from Aircraft:

- One twelve-pack per flight
- Typical profile from 500 magl to 8000 masl
- Species: CO_2, CO, CH_4, N_2O, SF_6,
  stable isotopes, halocarbons, COS, hydrocarbons…
  $^{14}CO_2$ on a limited number of samples
- Next version will be FAA certified



Great resource for satellite evaluation: e.g. Orbiting Carbon Observatory

Recent Analyses Using Aircraft data to evaluate results from TRANSCOM model intercomparison:

Stephens et al., *Science*, 2007

- Annual mean vertical gradient is overestimated.
- Too much summertime vertical mixing in models.
- No model gets the vertical distribution correct in all seasons.
- Transcom model mean overestimates NH uptake.

Yang, et al., *GRL*, 2007

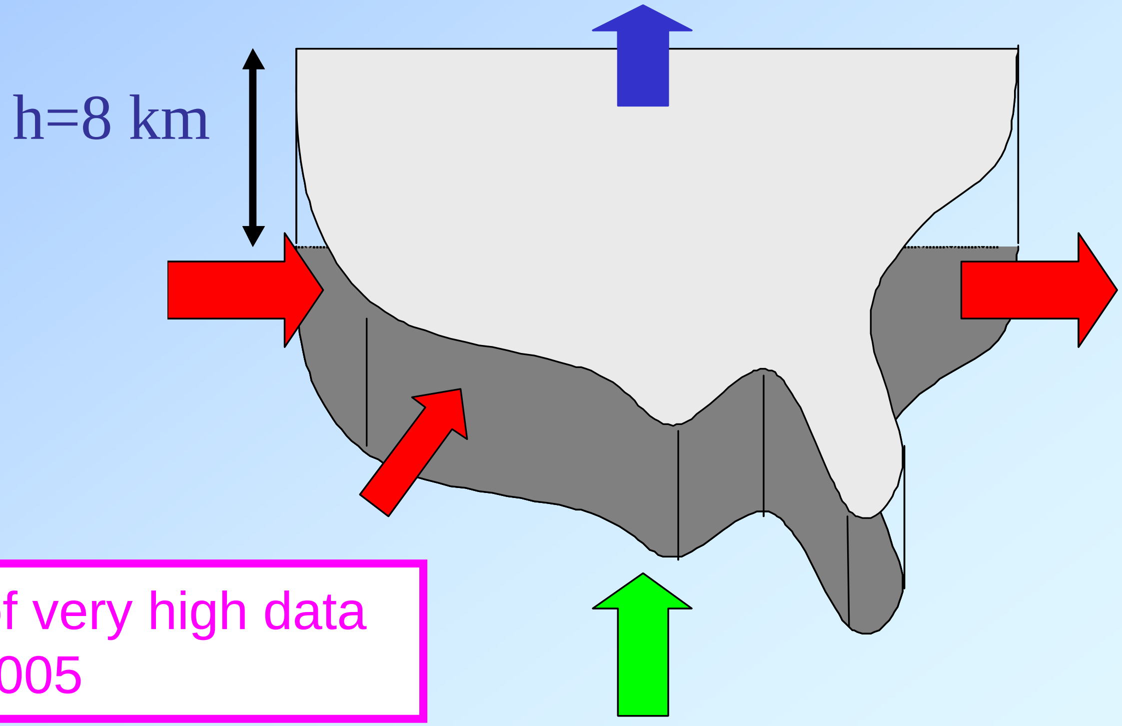
- Observed seasonal cycle of column integrated CO_2 has larger amplitude than predicted by models.
- Vertical mixing is too weak in models (seasonality not considered)
- Models likely to overestimate Northern Hemisphere carbon uptake.

- **Aircraft data are essential for diagnosing model transport errors.**
- **Accurate transport is required for accurate carbon flux estimates.**
- **Higher data density = less reliance on modeled transport.**

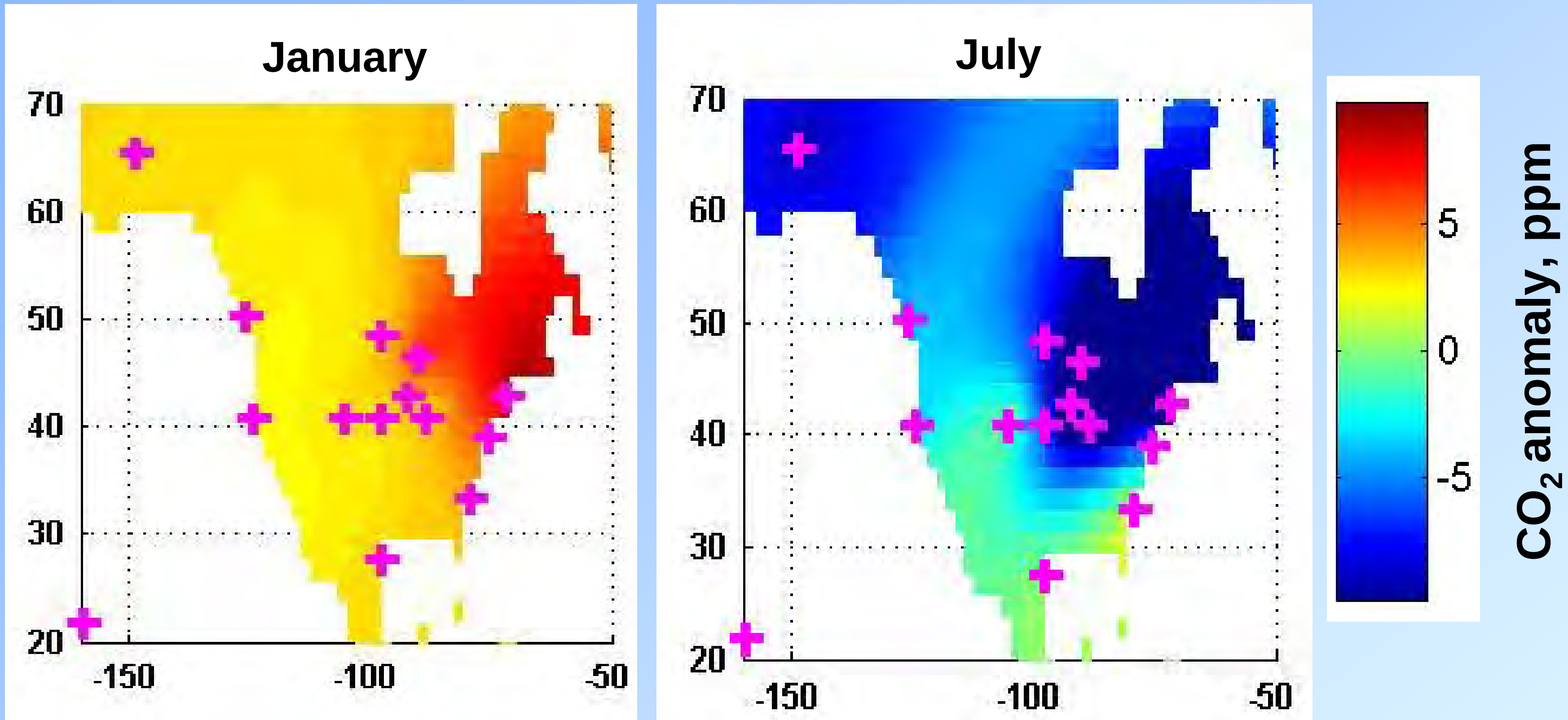
Direct Budgeting Approach:
(Crevoisier et al., manuscript in preparation)

$$F_{surf} = \iint_S \rho \chi \mathbf{u}.\mathbf{n} dS + \frac{\partial}{\partial t}\iiint_V \rho \chi dV \left(-\frac{\partial C}{\partial t}\Big|_{vertical} \right)$$

Edges — Volume — Convection



Takes advantage of very high data density during FY2005



Spatial interpolation of detrended data using Kriging to produce monthly maps

F_{surf} → 1.22 GtC.yr-1

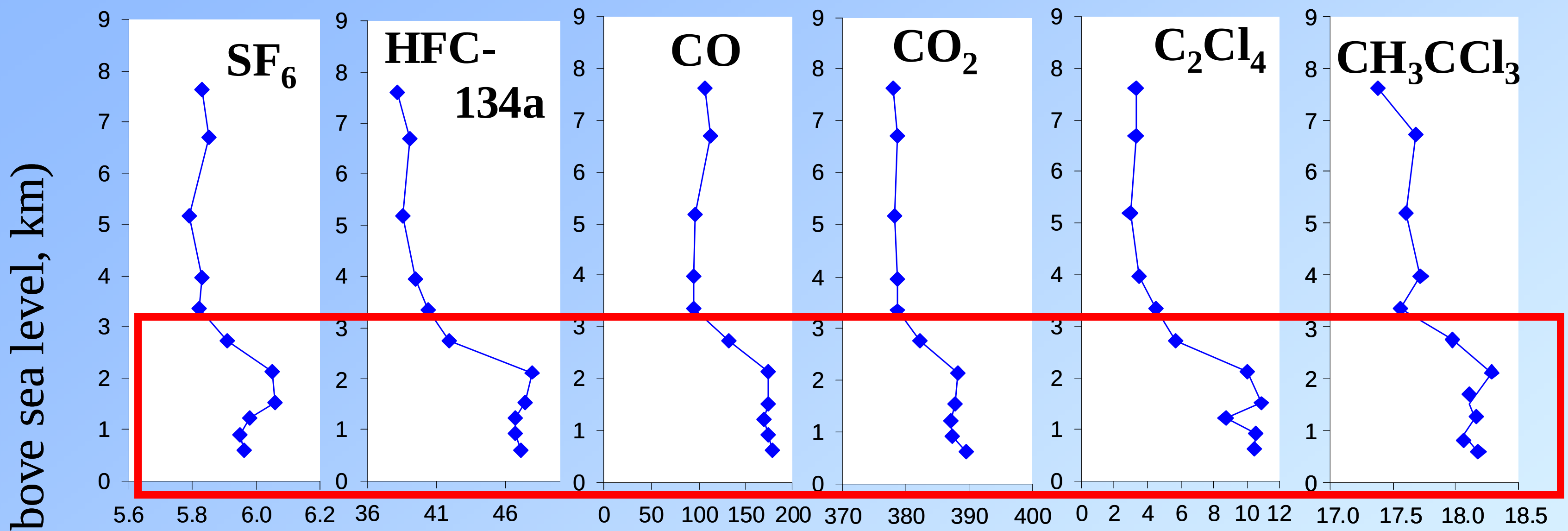
<u>Fossil fuel emission → 1.73 GtC.yr-1</u>

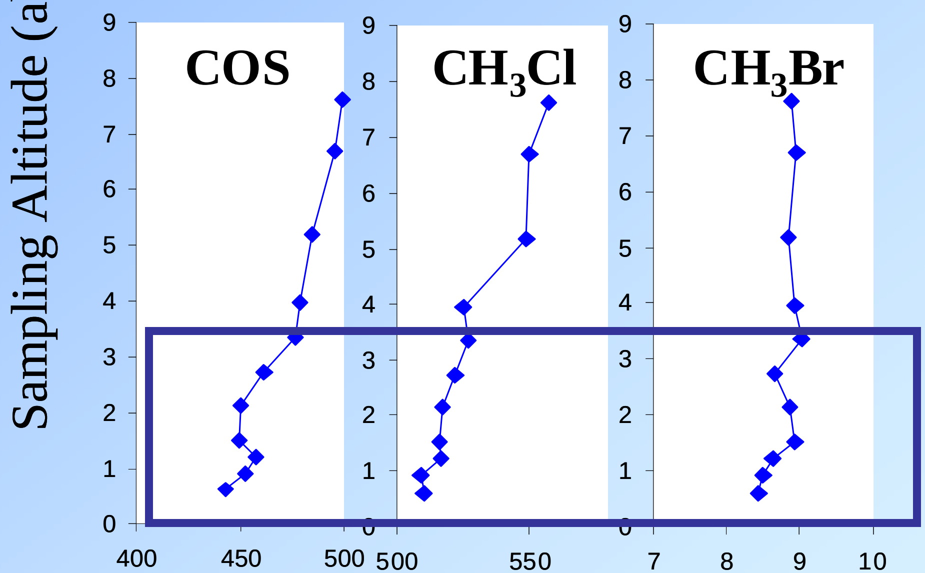
Coterminous US sink: → -0.51 ± 0.31 GtC.yr-1 (2004-2006)

CarbonTracker: -0.45 ± 0.19 Pg (2002 – 2006)

Multiple species analysis:

Eastern USA (NHA)
Nov 2005





Strong anthropogenic influence

Surface uptake

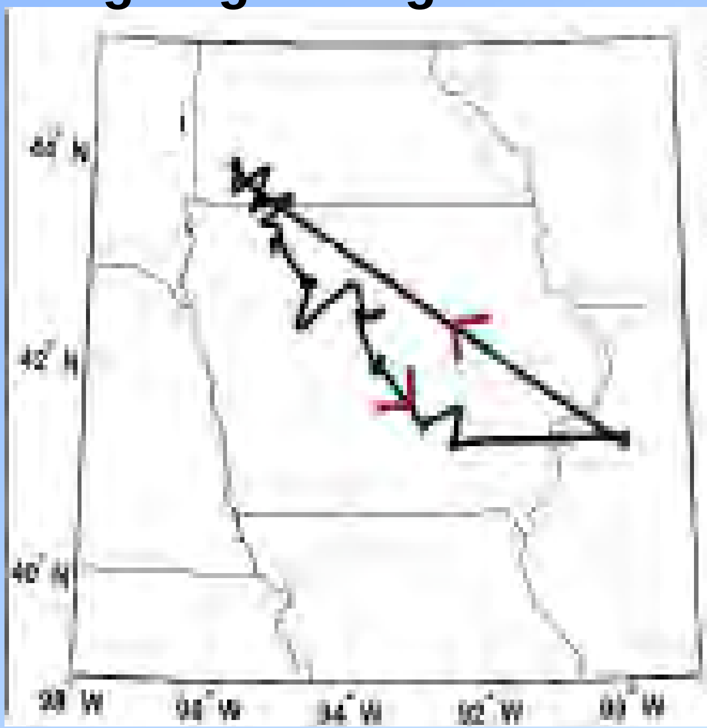
Multiple species aid in quantitative source attribution for carbon gases.

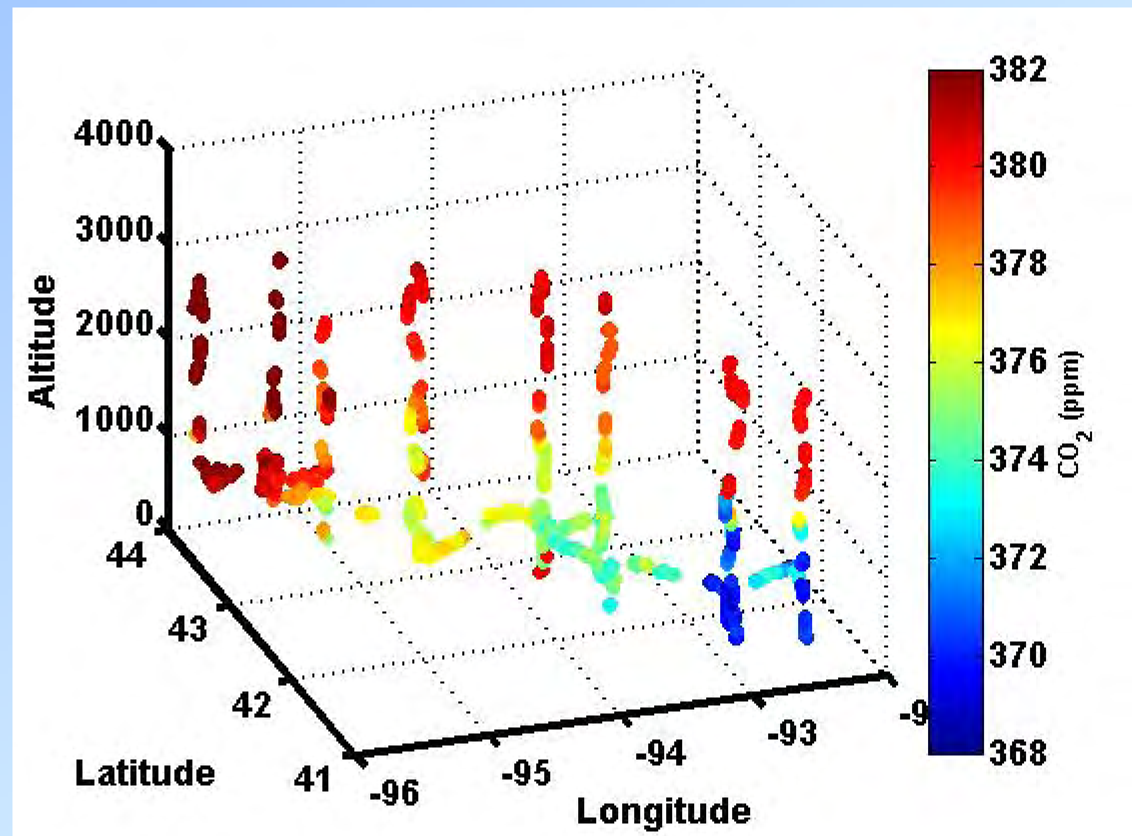
Courtesty of Steve Montzka

In-situ Observations

Mid-Continent Intensive NOAA/PURDUE Aircraft Experiment:
June 2007, Colm Sweeney and Paul Shepson

Lagrangian Flight Path



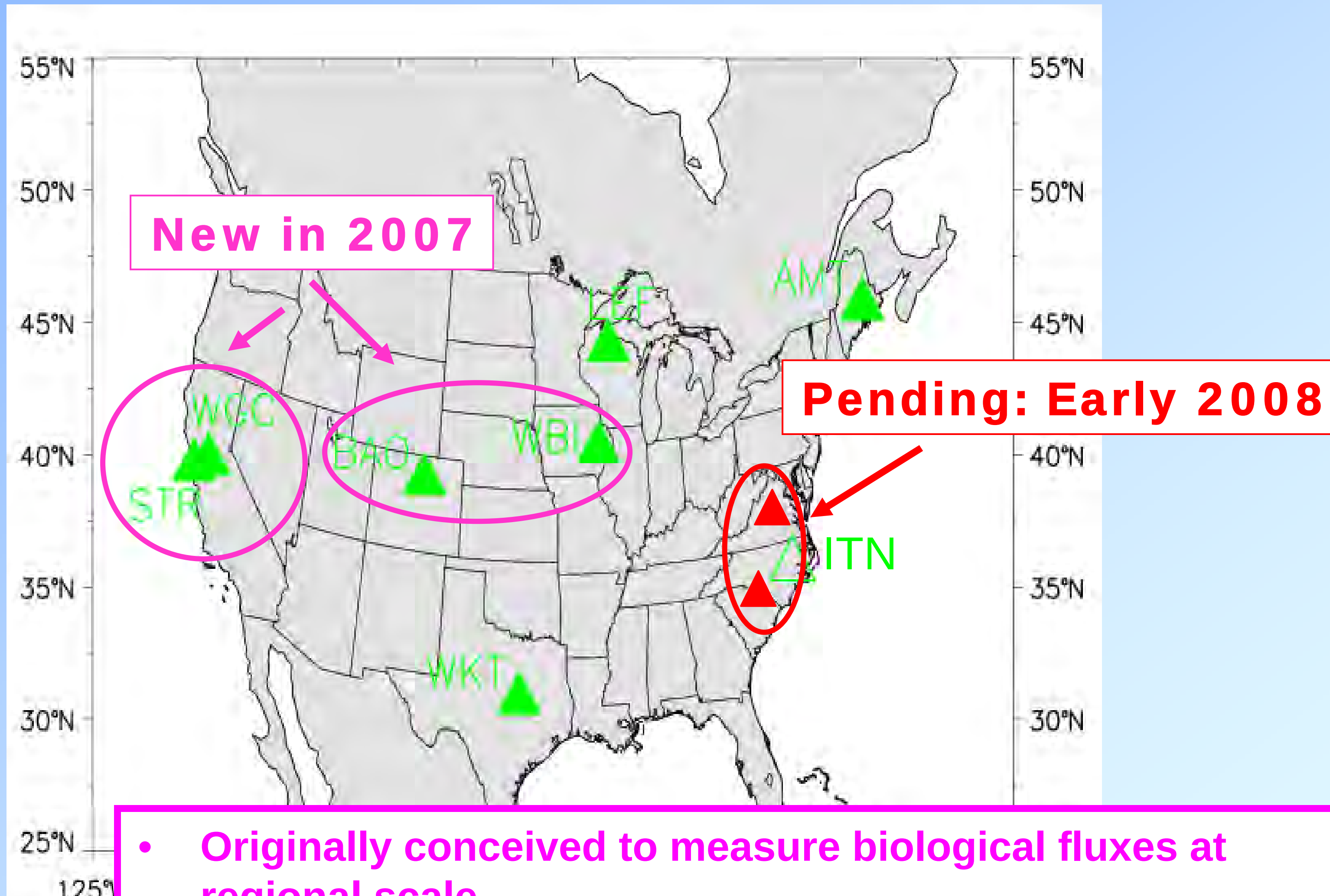


- **New direction for ESRL carbon cycle group**
- **Supports North American Carbon Program**

Flux = -46 umol/m^2/s

Source: Douglas Martins

NOAA Tall Tower Network



- Originally conceived to measure biological fluxes at regional scale
- Recently have added some more polluted sights
- Counting on multi-species approaches for source attribution

Why Tall towers?

- **Regionally representative boundary layer sampling**
  - **Don't want to alias near-field fluxes (biological or pollution) into large-scale flux estimates**
  - **Profile data provide information about relative contributions of regional and local fluxes**

- **Long-range transport of air in nocturnal jets above nighttime stable layer seems to be an important term in the carbon budget**

Tall = high enough to be minimally influenced by local fluxes and to be above nighttime stable layer (~300m)

Measurement Systems

Nominal 3 levels: 30, 100, >300m

- Semi-continuous CO_2
- Semi-continuous CO

CO_2 precision better than 0.1 ppm (30-sec average)
CO precision better than 3 ppb (2-min average)

Measurement Systems

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- Semi-continuous CO_2
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- Automated Flask Sampler: one 12-pack per week
  - -CO_2, CO, CH_4, N_2O, SF_6, Halocarbons, stable istotopes of CO_2, working to start $^{14}CO_2$ and $^{13}CH_4$ on select samples
  - -Important part of QA/QC strategy

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- Basic Meteorology: horizontal wind, air temperature,relative humidity,photosynthetically active radiation, rainfall, surface pressure

CO_2 precision better than 0.1 ppm (30-sec average)
CO precision better than 3 ppb (2-min average)

Measurement Systems

Nominal 3 levels: 30, 100, 500m

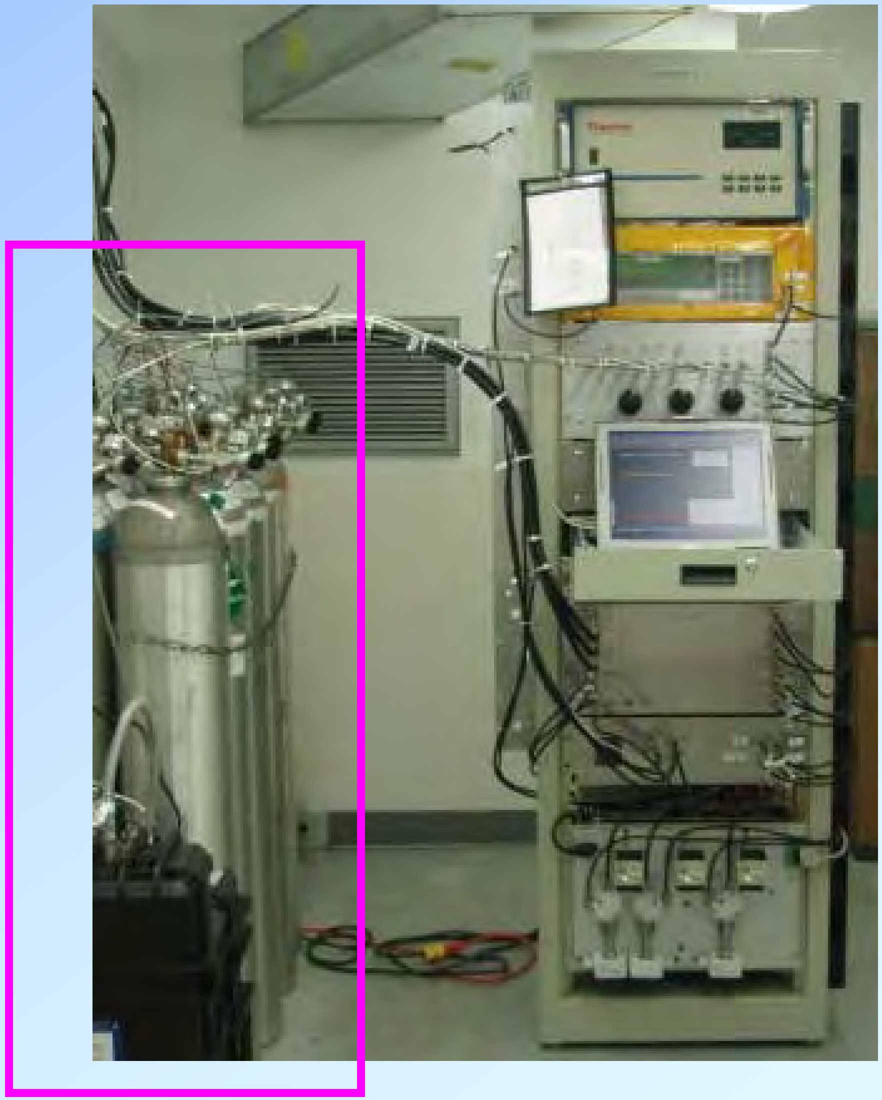
- Semi-continuous CO_2
- Semi-continuous CO
- Automated Flask Sampler: one 12-pack per week
  - CO_2, CO, CH_4, N_2O, SF_6, Halocarbons, stable isotopes of CO_2, working to start $^{14}CO_2$ and $^{13}CH_4$ on select samples
  - Important part of QA/QC strategy
- Basic Meteorology: horizontal wind, air temperature,relative humidity,photosynthetically active radiation, rainfall, surface pressure

- CH_4 & CO_2 (Picarro Cavity Ring Down): WGC only
- Radon-222: WKT, WGC only

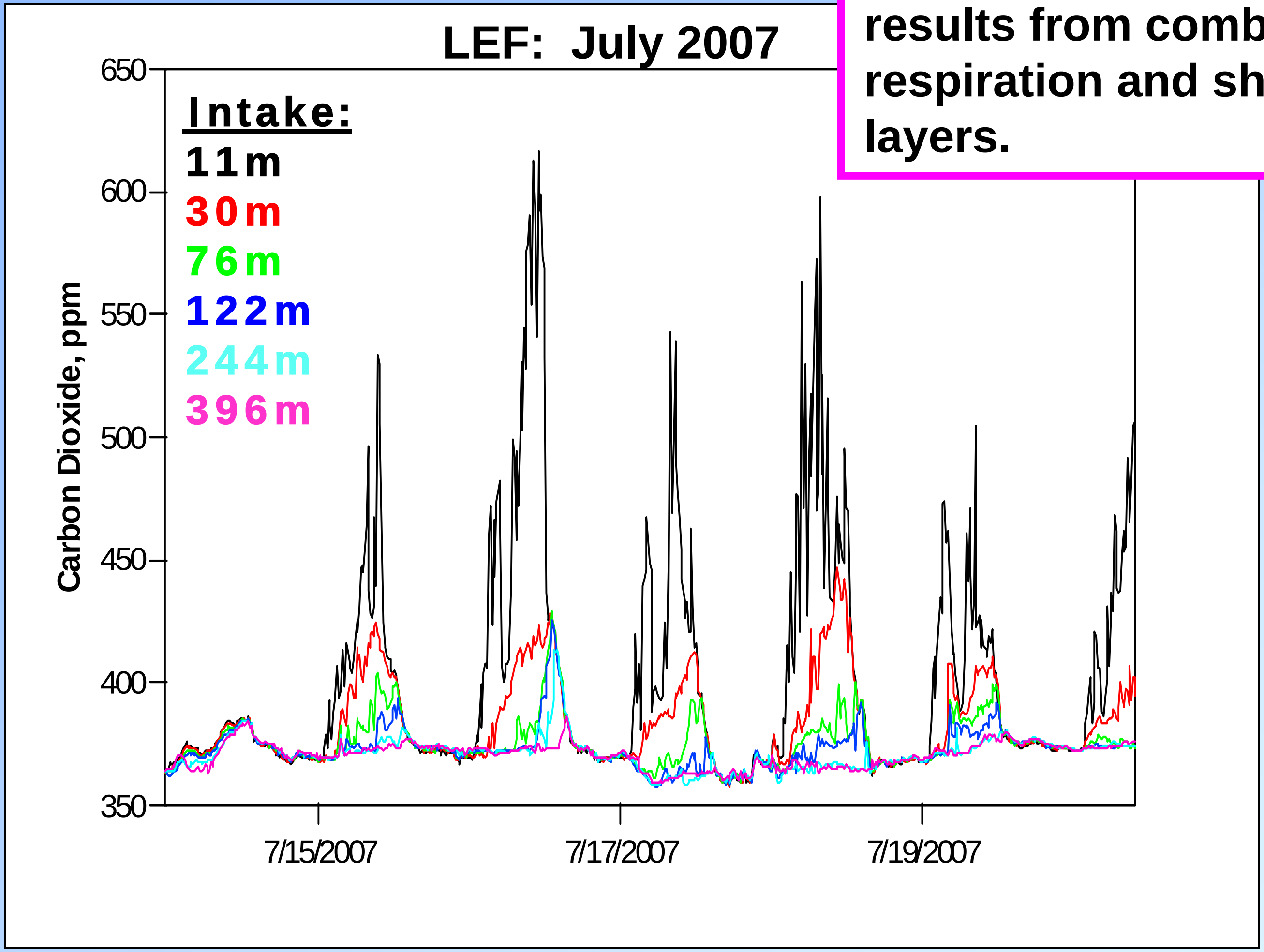
CO_2 precision better than 0.1 ppm (30-sec average)
CO precision better than 3 ppb (2-min average)

Trace gas measurements are rigorously calibrated on WMO scales maintained by NOAA ESRL.

Duane Kitzis
(Cylinder prep and handling)
Conglong Zhao (CO_2)
Paul Novelli (CO)
Ed Dlugokencky (CH_4)
Pat Lang (CH_4)

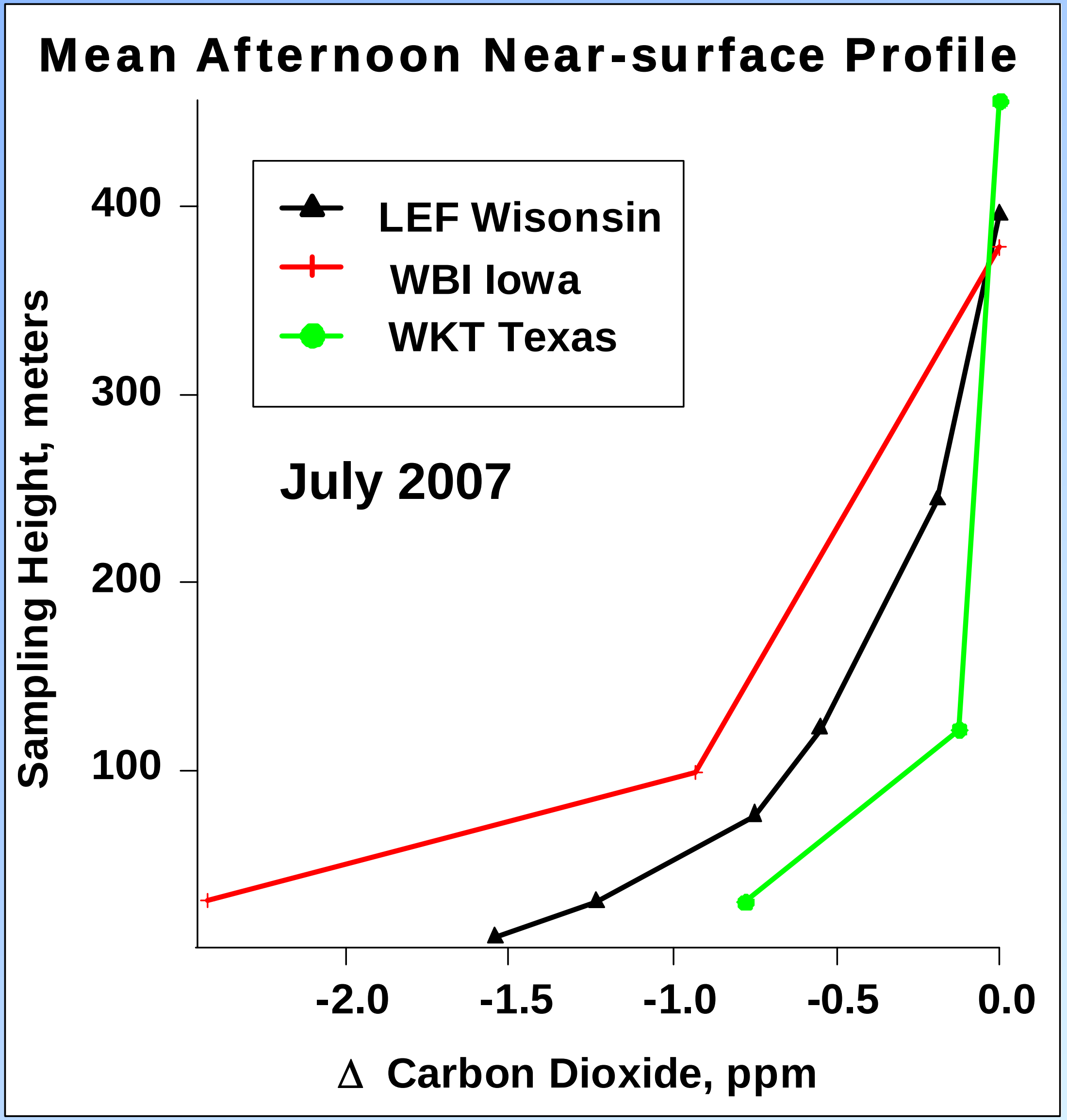


Quantitative signatures of biological CO_2 uptake and release:



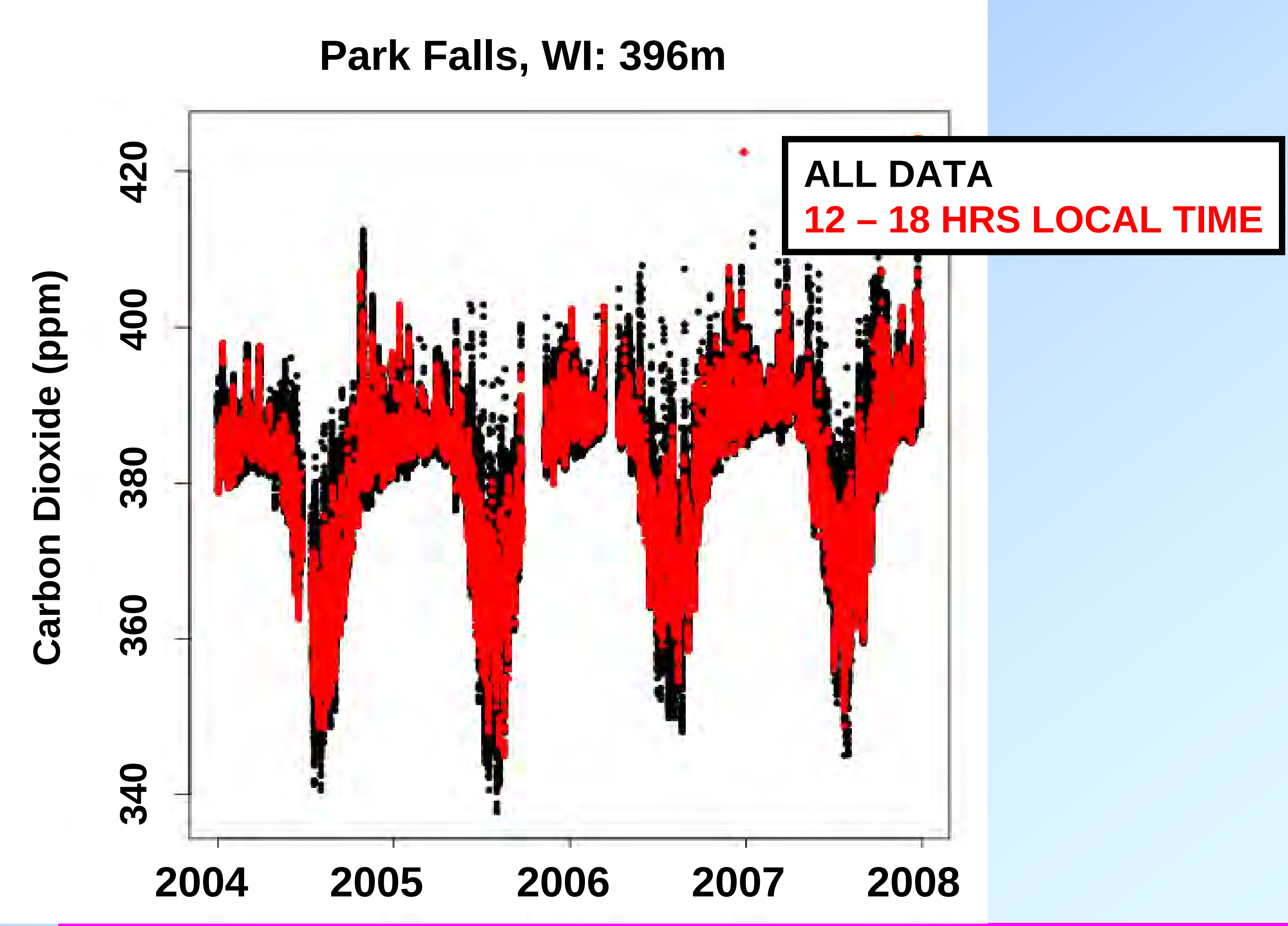
Large diurnal cycle at lowest levels results from combination of nighttime respiration and shallow boundary layers.

Quantitative signatures of biological CO_2 uptake and release…

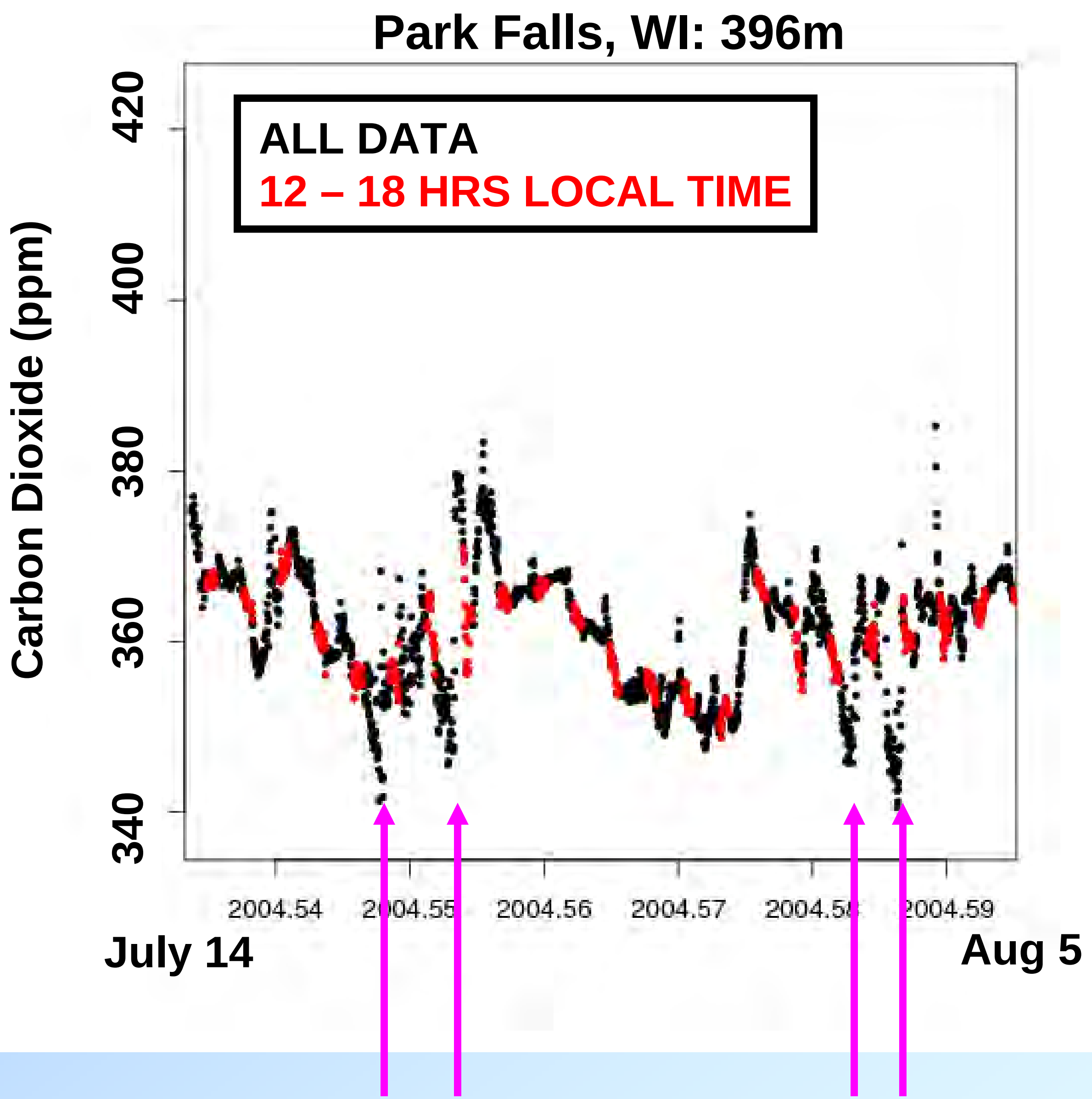


Mid-day vertical gradient is related to strength of local photosynthesis.

Regional transport of air in nocturnal jets:



Puzzle: Why don't lowest CO_2 values occur during local afternoon?

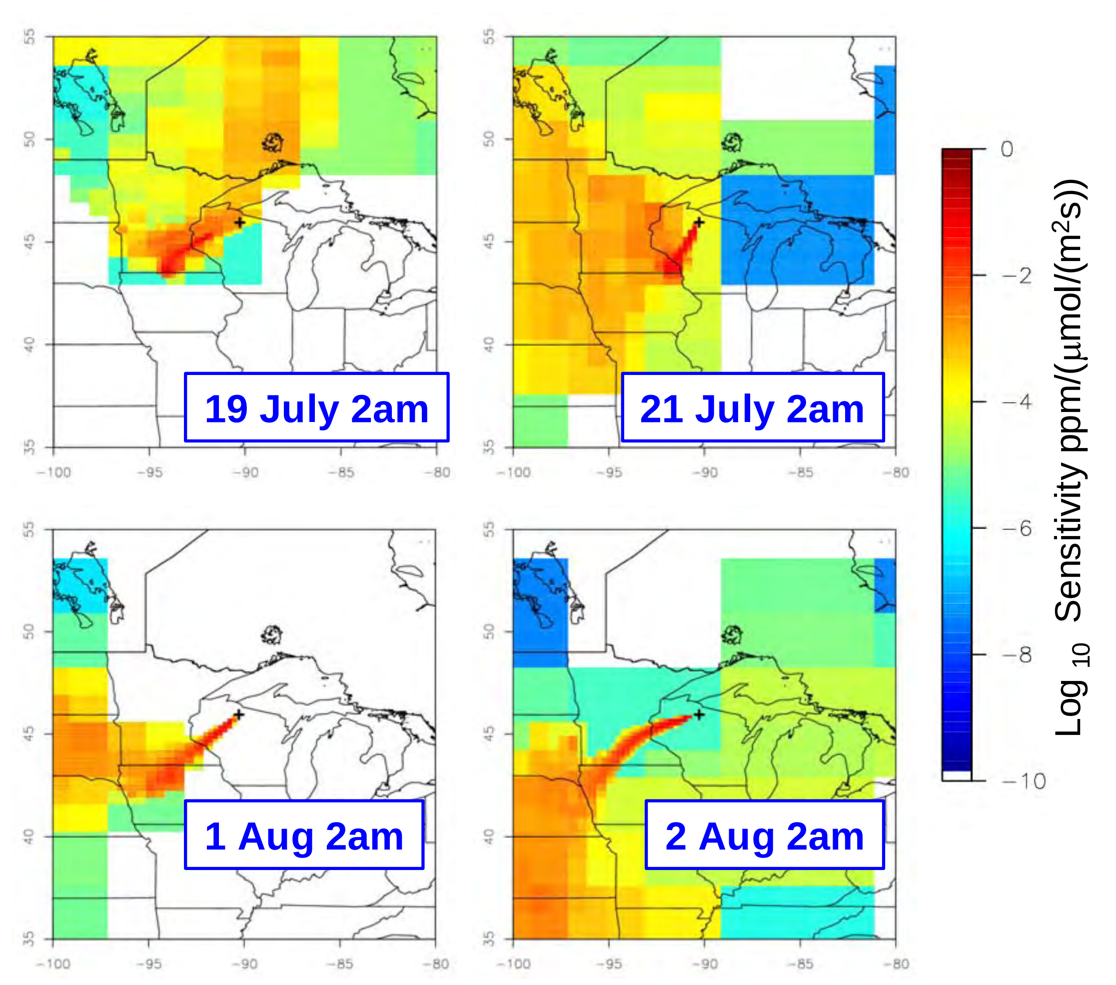


A closer look at four nighttime low-CO_2 events.

Lagrangian Particle Dispersion Models are good tool for investigating this question:

- Computes surface influence function (footprint)
- High-resolution for analyzing day-to-day variability typical of tall tower data.
- Not inherently subject to numerical diffusion
- Computationally efficient
- We use two separate LPDMs with variety of meteorological driver datasets
  - STILT (J. Lin and C. Gerbig)
  - Flexpart (A. Stohl)

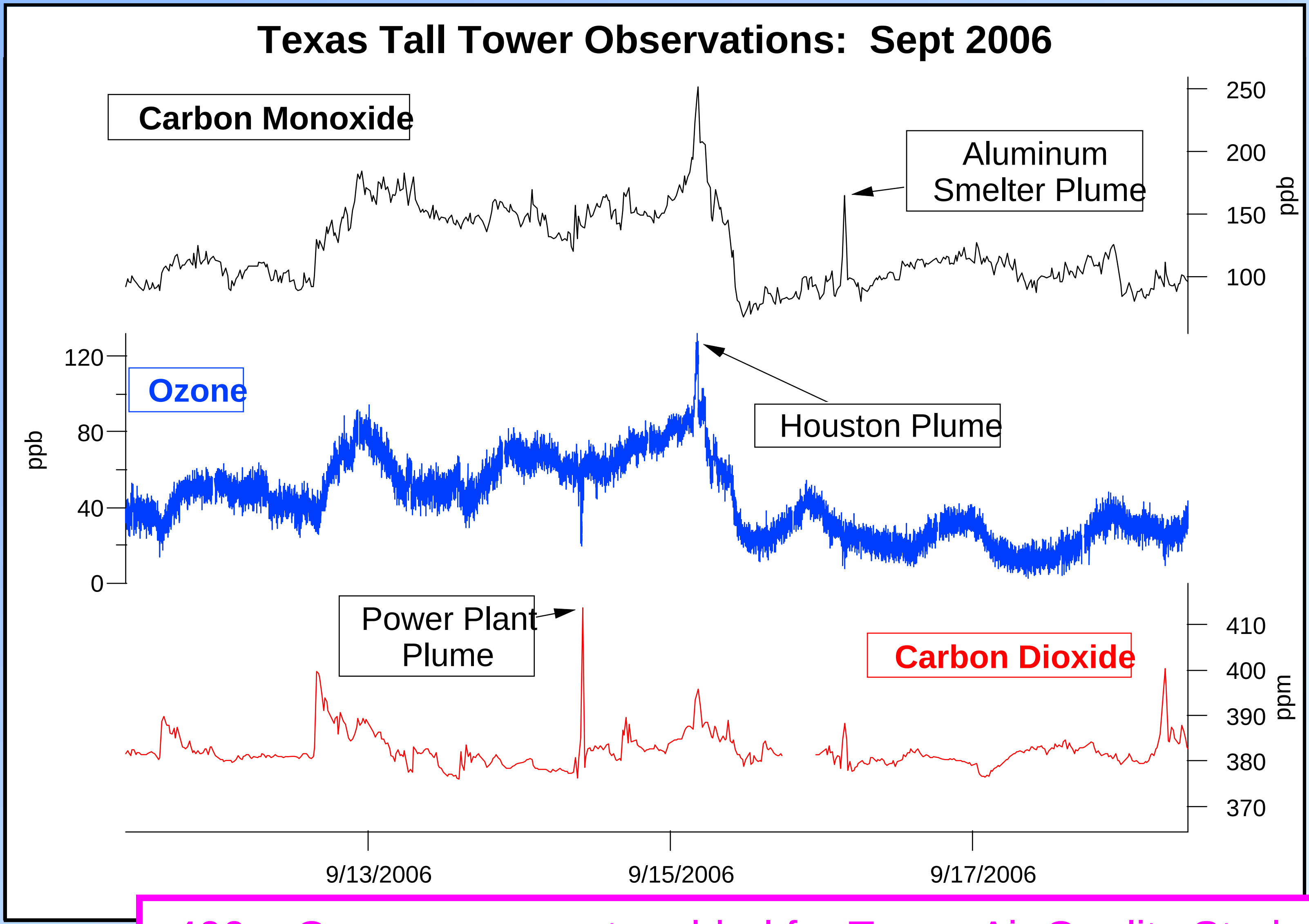
STILT model footprints



Note: STILT driven by customized BRAMS meteorology (courtesy of S. Wofsy & M. Longo)

- All 4 nocturnal low-CO_2 events occur with flow from SW
- Regional transport low-CO_2 air from agricultural regions (nocturnal jet?)
- $\delta^{13}CO_2$ data from 2007 flask samples indicate contribution from corn

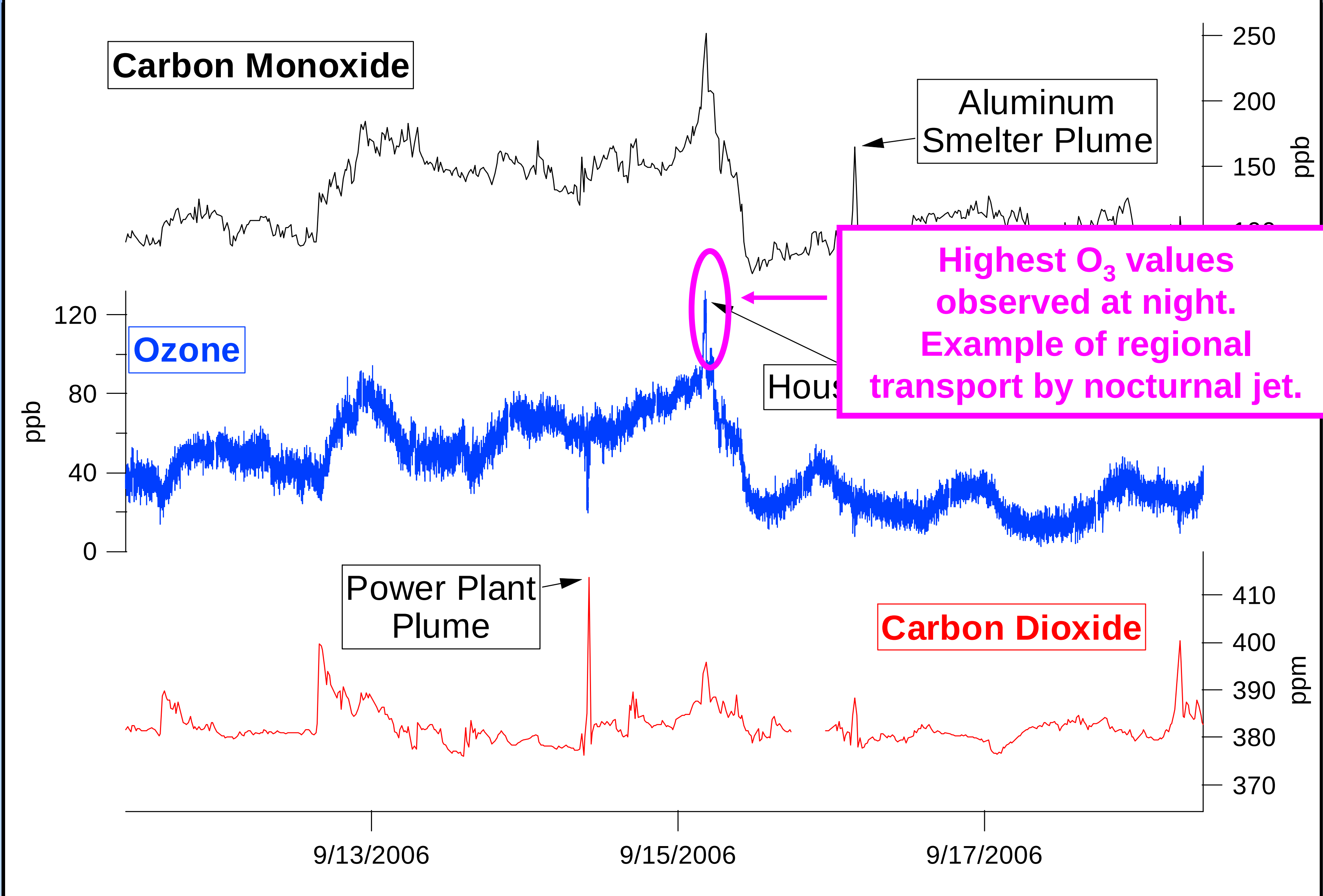
Multiple-species approaches for quantifying fossil fuel CO_2



- 400m O_3 measurements added for Texas Air Quality Study 2006 time period (example of cross-ESRL collaboration)

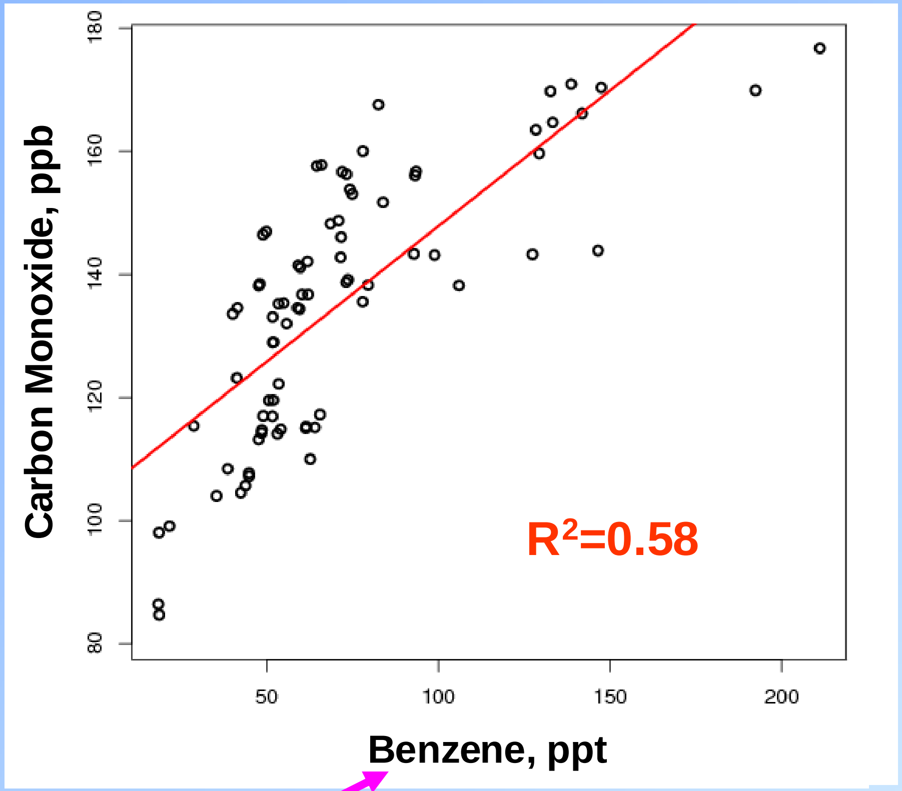
Multiple-species approaches for quantifying fossil fuel CO_2

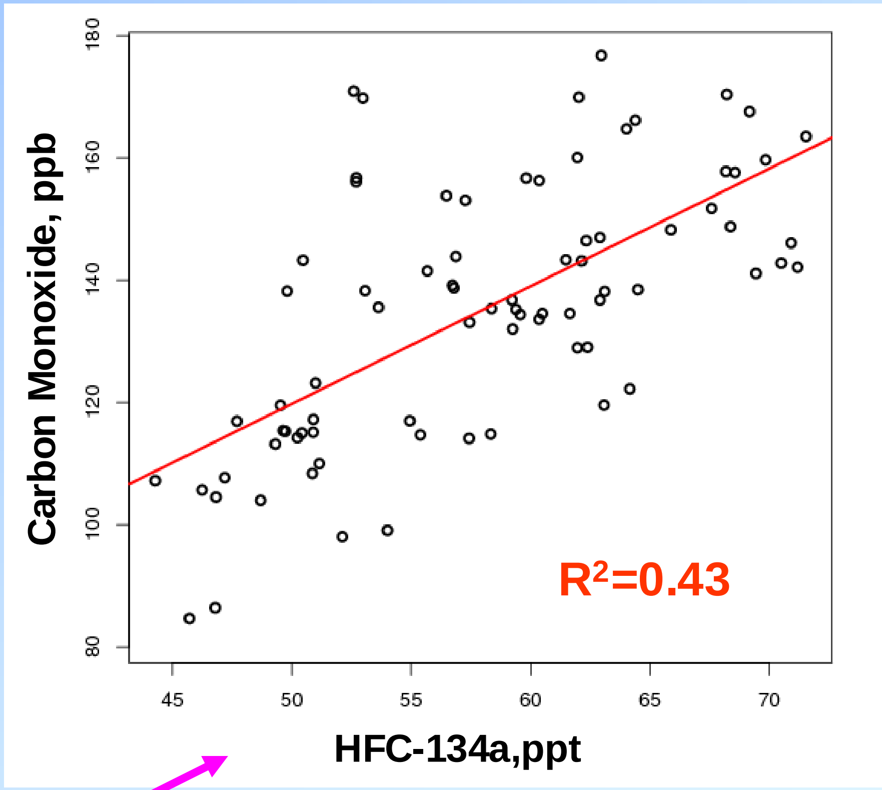
Texas Tower Observations: Sept 2006



Multiple-species approaches for quantifying fossil fuel CO_2

Flask data from Texas tall tower: Summer 2006





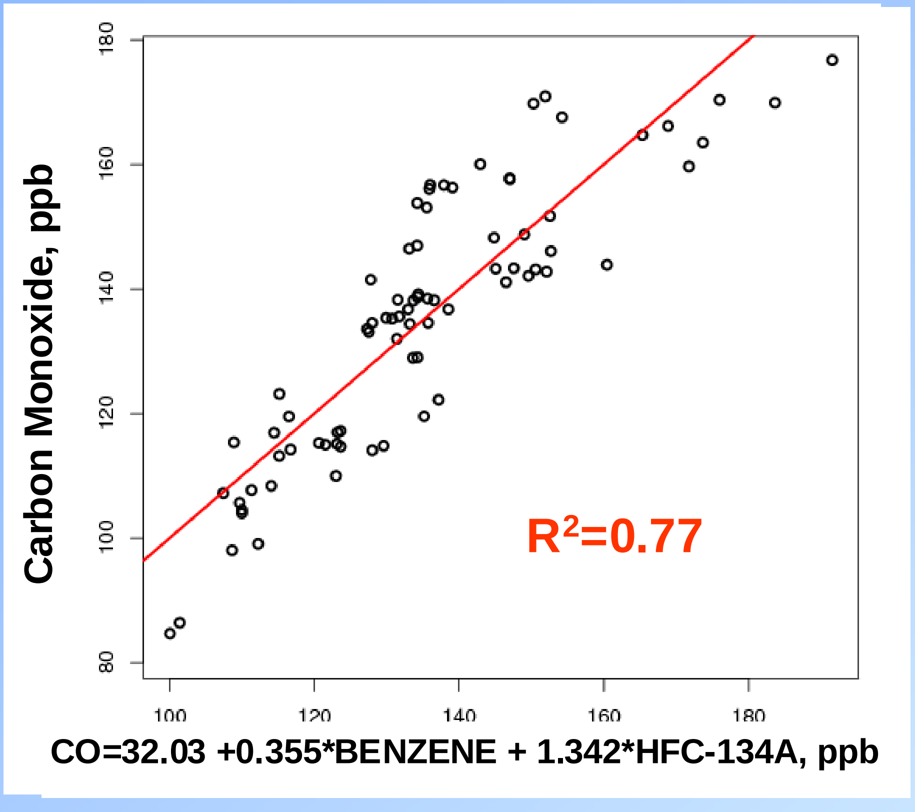
Fire or Urban

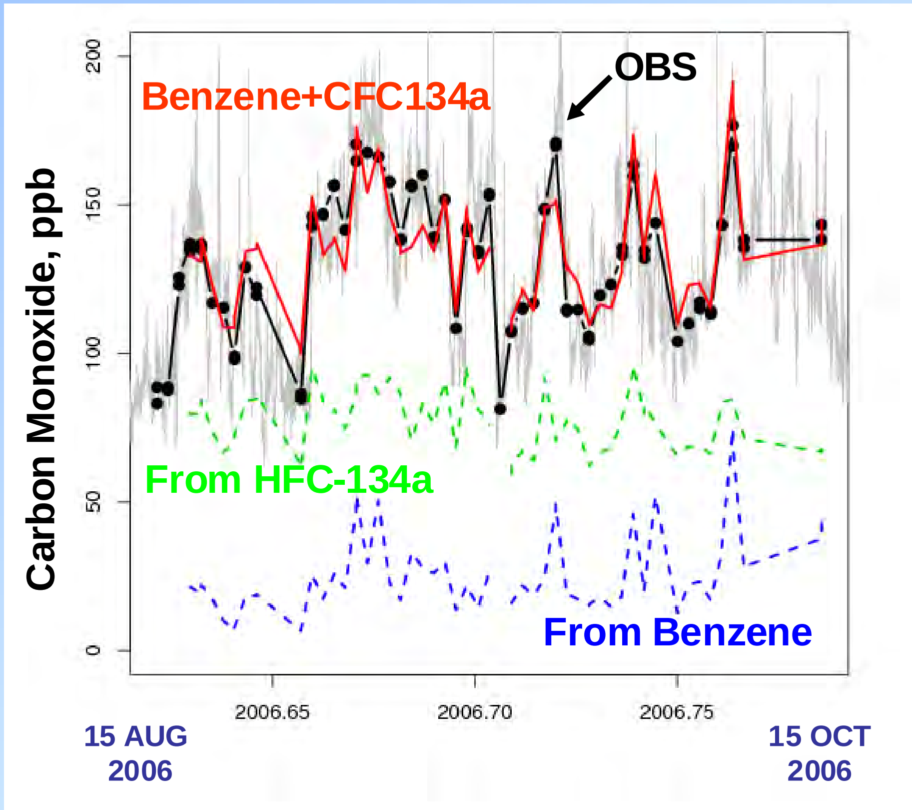
Traffic/Urban Tracer used in auto air-conditioners

CO is a tracer of combustion – but not selective

- Can't easily distinguish between biomass-burning and urban pollution.
- Multiple species can help.

Multiple-species approaches for quantifying fossil fuel CO_2





- Together, Benzene and HFC-134a describe 80% of the observed variability in observed CO
- Use this info to help partition inferred CO_2 flux among fires, urban pollution, and biological uptake/release

Conclusions

- **Data are of highest quality**
  - **Research-quality monitoring→multi-year process studies**
  - **More sights needed to monitor fluxes at regional scales**

- **Data are readily available**
  - **Tower in situ data directly from FTP server**
  - **Aircraft and Tower flask data on request as we resolve QA/QC procedures (FTP and Interactive Data Viewer access coming soon)**

- **Expected improvements**
  - **New sites**
  - **More species (e.g., adding continuous CH_4, more $\Delta^{14}CO_2$)**
  - **Use of CarbonTracker and Lagrangian Particle Dispersion Models for network design studies**