What can we learn from measurements of $^{13}C:^{12}C$ and $^{14}C:C$ in atmospheric CO_2?

… or, Other tracers that are hard to measure well and tell you about the carbon cycle

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Outline

1. ^{14}C
    1. Background
    2. Signals in the data
    3. Global inverse modeling
    4. Urban
2. ^{13}C
    1. Evolution of use
    2. Region signals
    3. Global signals

Radiocarbon basics

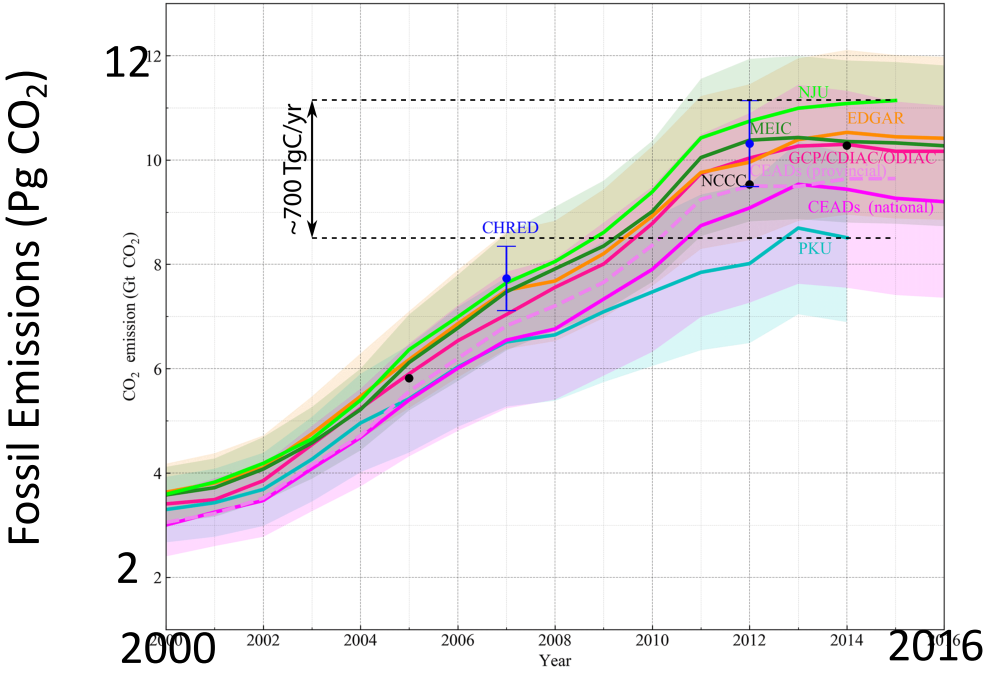
- ^{14}C is produced in the upper atmosphere and oxidized to CO_2 which is incorporated into the atmosphere-land-ocean system.
- Fossil fuels have no ^{14}C, because its half-life is ~6000 yrs. This makes $^{14}CO_2$ an ideal tracer for fossil CO_2.
- As with stable isotopes, we report ^{14}C abundance (~10^{-12} of CO_2) using "delta" notation:

$$\Delta \approx \left(\frac{R_{sample}}{R_{standard}} - 1\right) \times 1000\ ‰$$

→ ***as Delta decreases, ^{14}C:C decreases, indicating more fossil***

Why Top-Down $^{14}CO_2$?
Significant spread in national inventories.

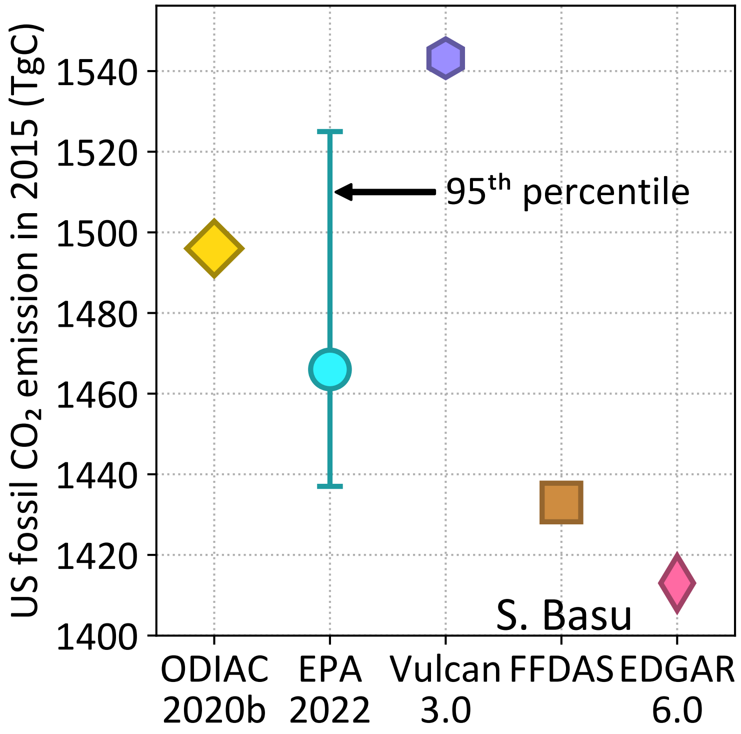
China: ~ 700 Tg C/yr



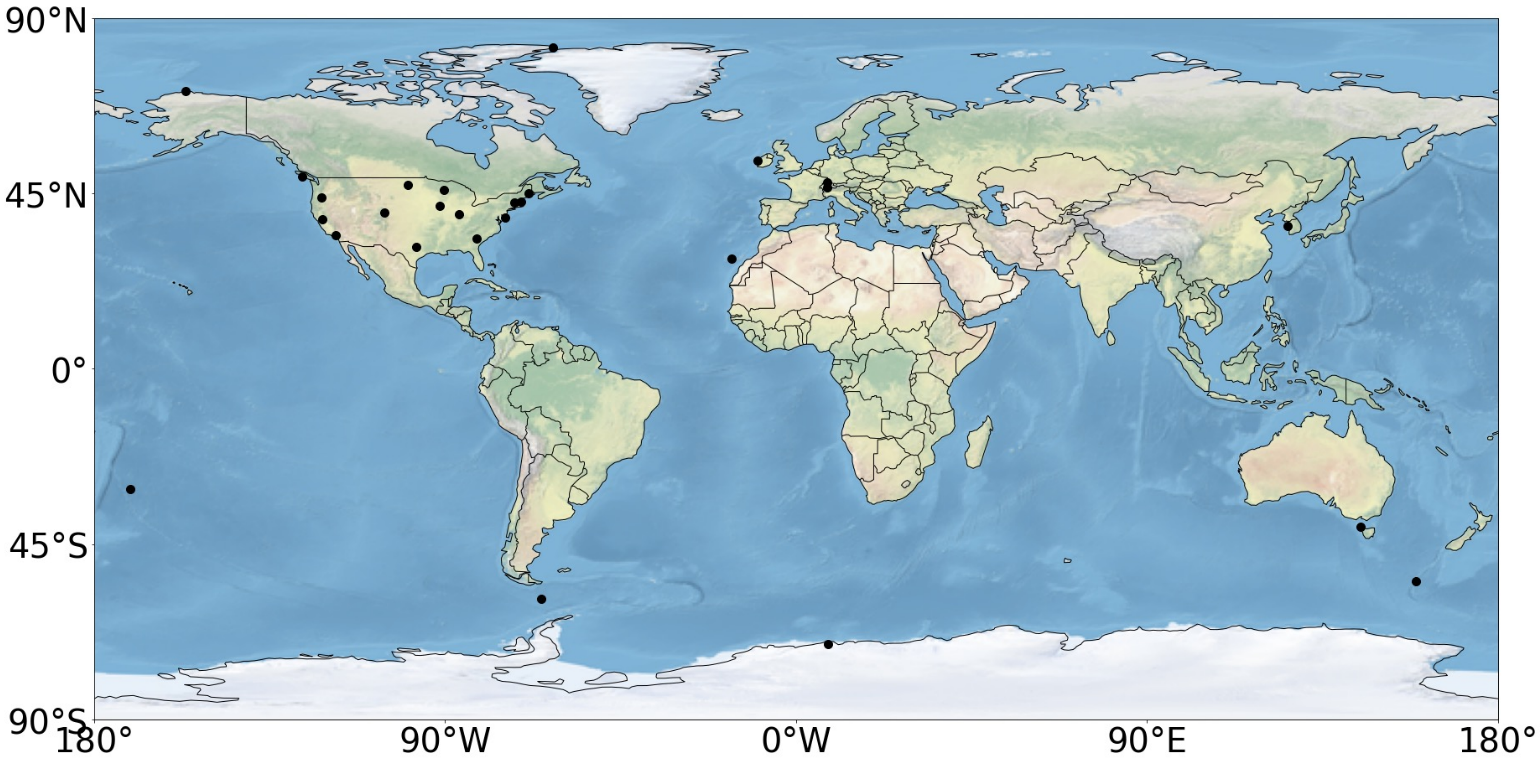
Evaluating China's fossil-fuel CO_2 emissions from a comprehensive dataset of nine inventories

Pengfei Han[1], Ning Zeng[2], Tom Oda[3], Xiaohui Lin[4], Monica Crippa[5], Dabo Guan[6,7], Greet Janssens-Maenhout[5], Xiaolin Ma[8], Zhu Liu[6,9], Yuli Shan[10], Shu Tao[11], Haikun Wang[8], Rong Wang[11,12], Lin Wu[4], Xiao Yun[11], Qiang Zhang[13], Fang Zhao[14], and Bo Zheng[15]

USA: ~130 Tg C/yr

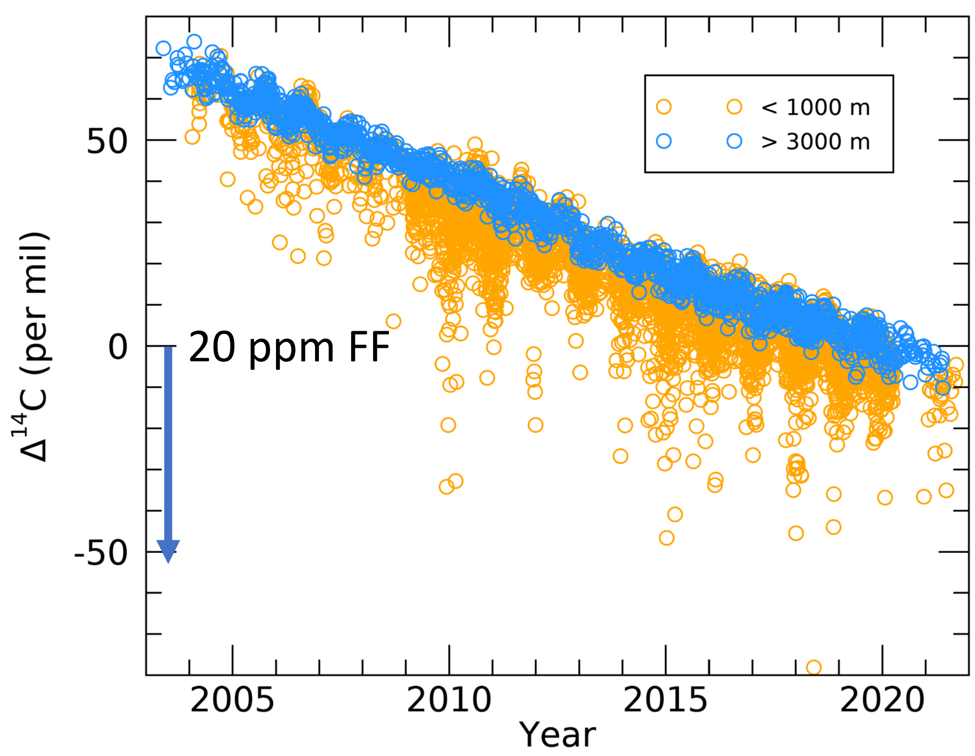


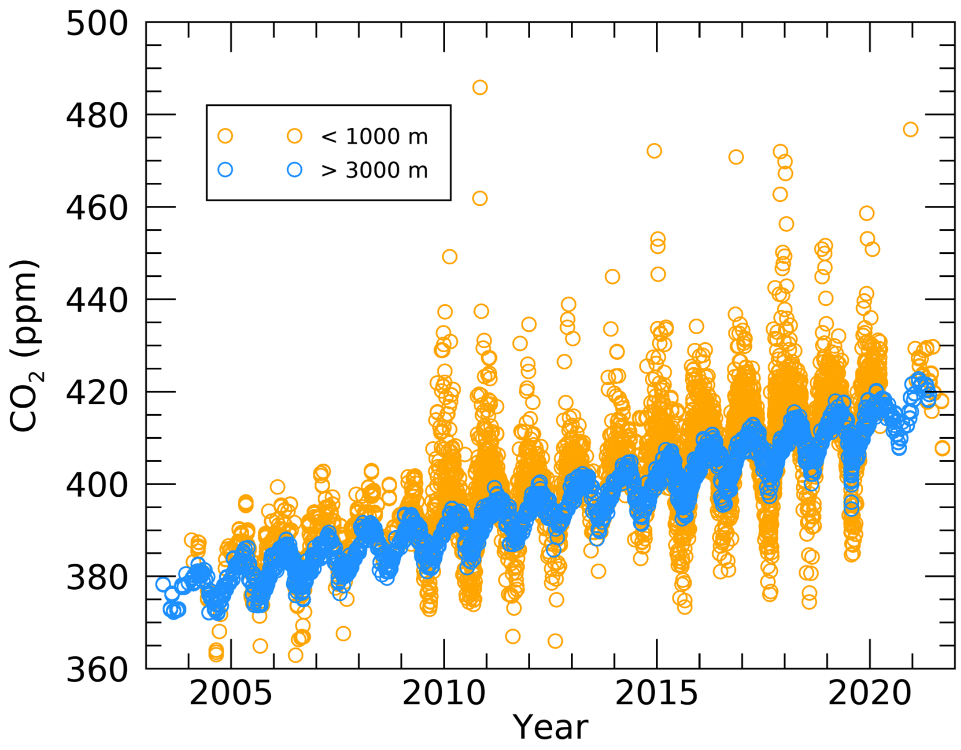
Measurement sites are global but mainly in North America



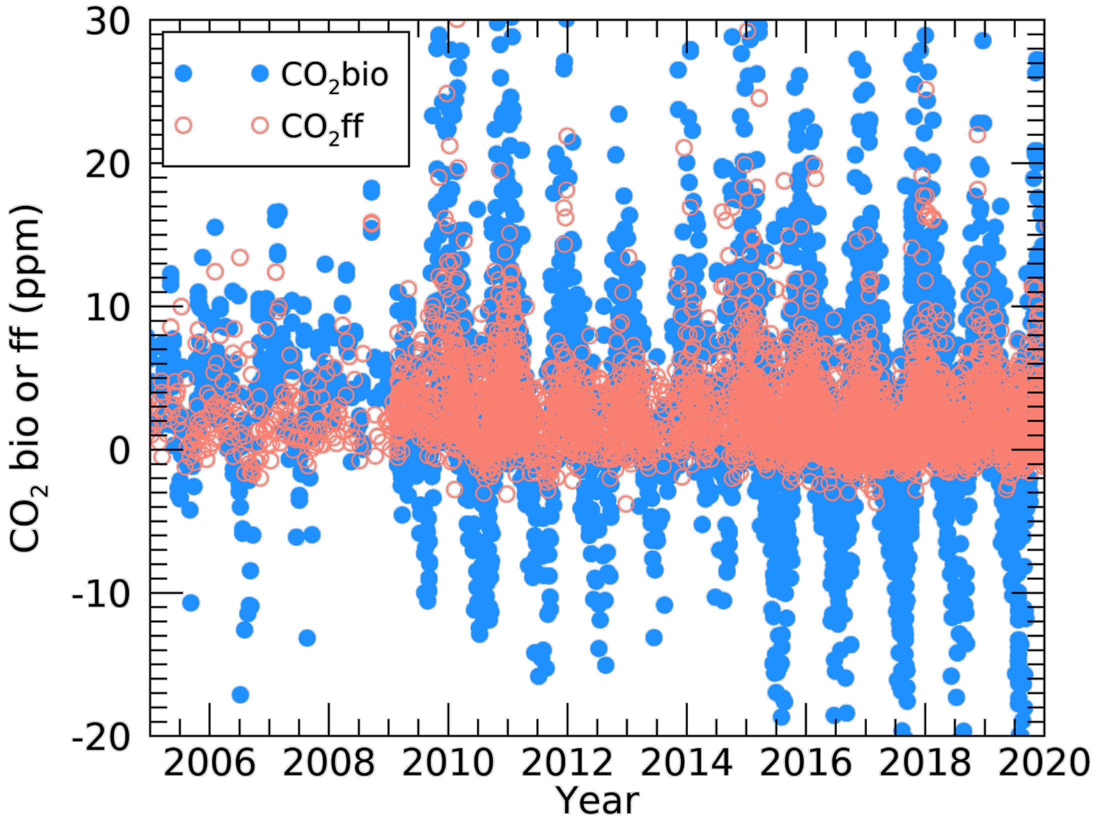
- ~ 1000 measurements per year.
- US sites 1 – 3 x per week.
- Most from U.S. tall towers (NOAA)
- Also aircraft sites
- Many global background sites from U. Heidelberg.

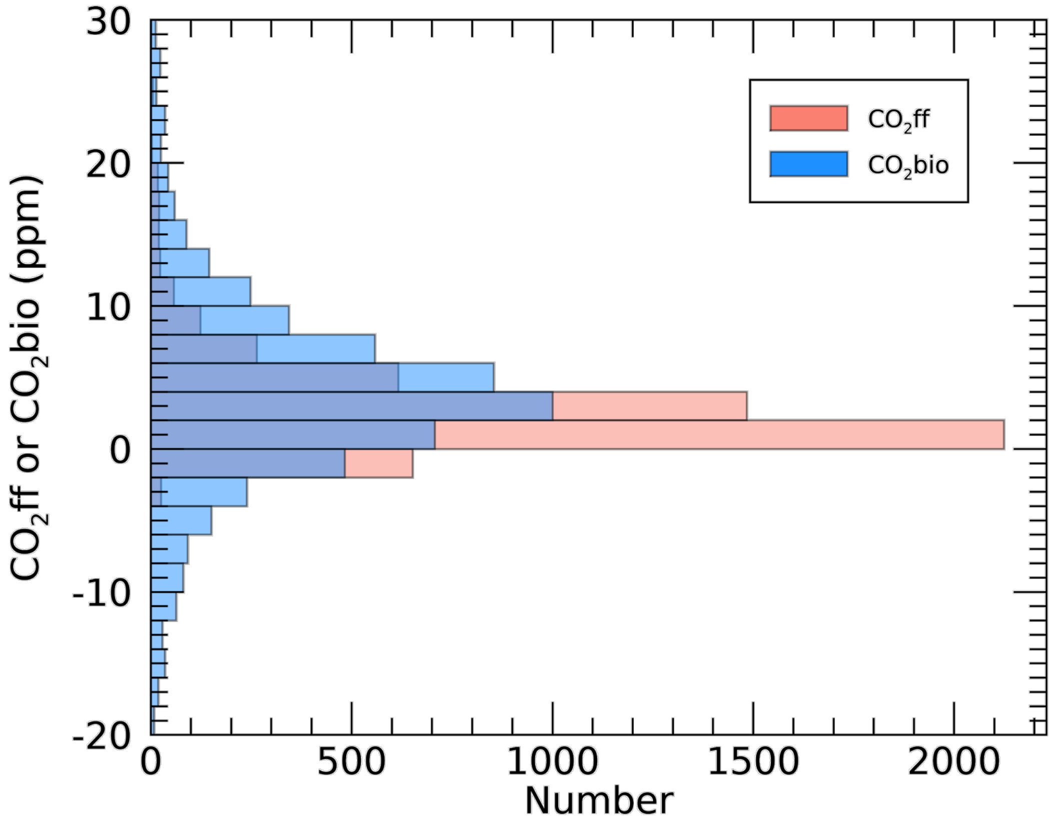
$\Delta^{14}C$ and CO_2 variations over U.S. are dominated by biology and fossil emissions, respectively



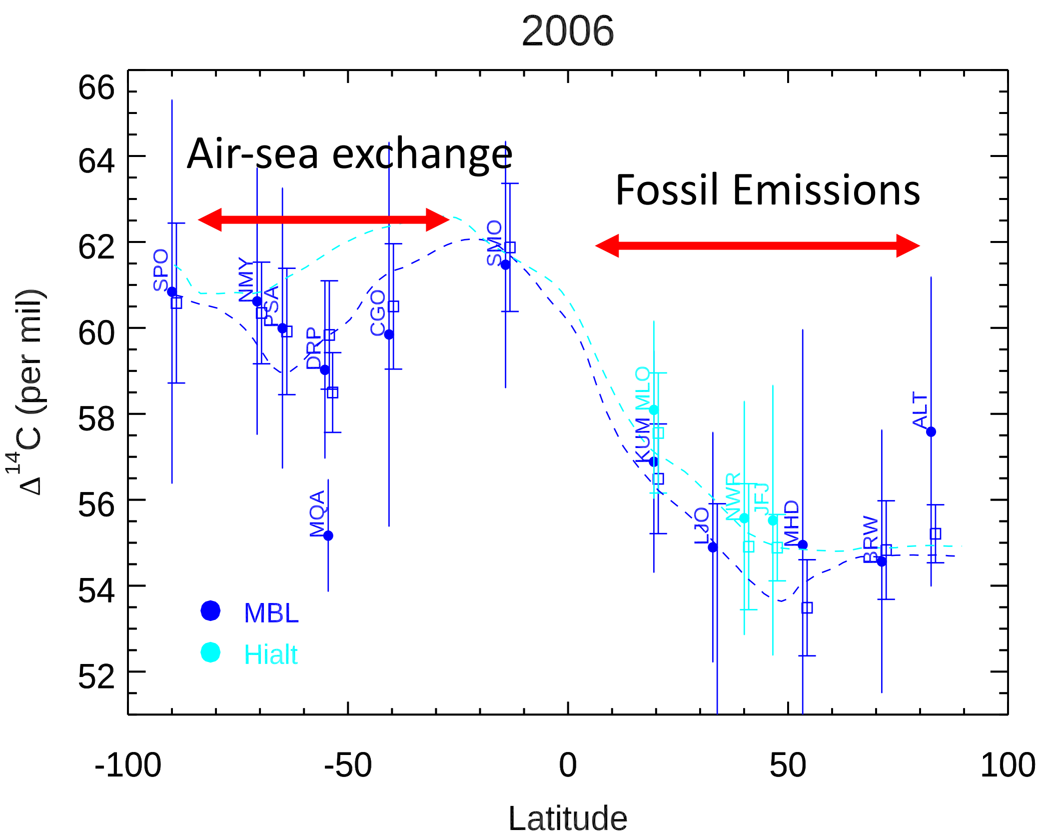


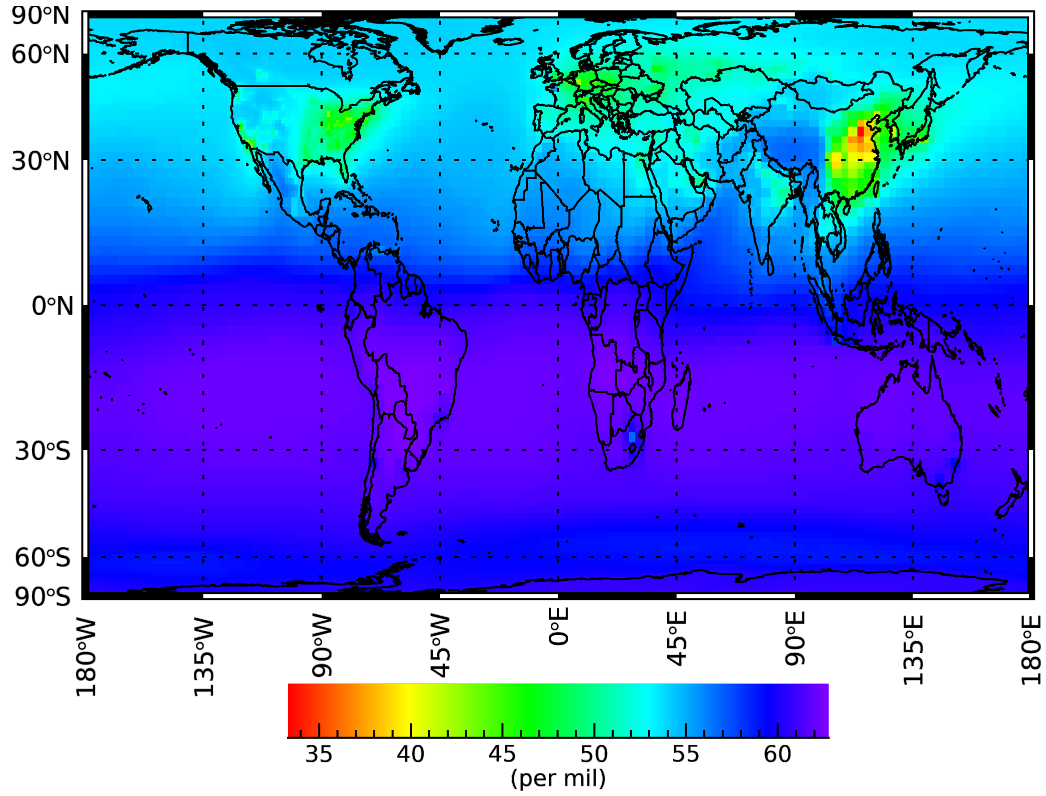
$\Delta^{14}C$ can separate fossil and biological components of continental CO_2





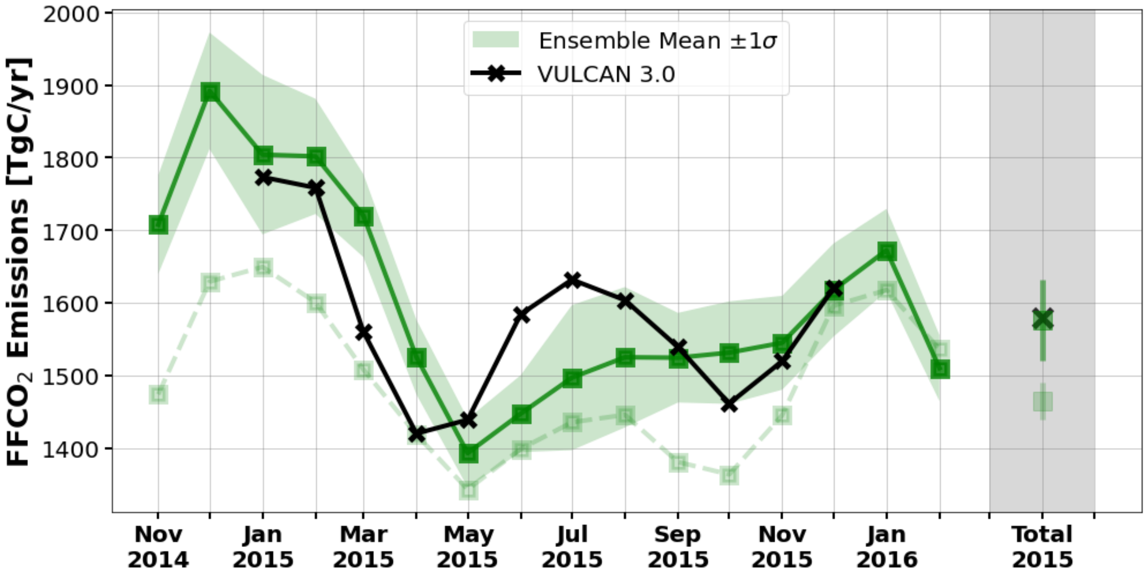
Forward model comparisons with data gives confidence ahead of inversion: 1) large scale lat. gradient

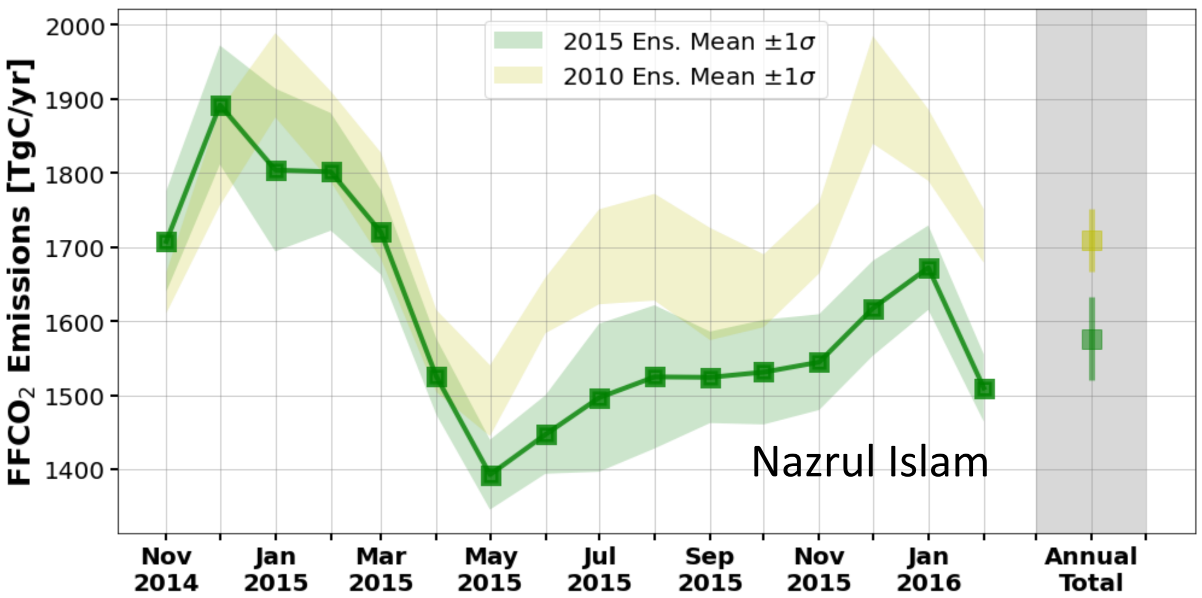




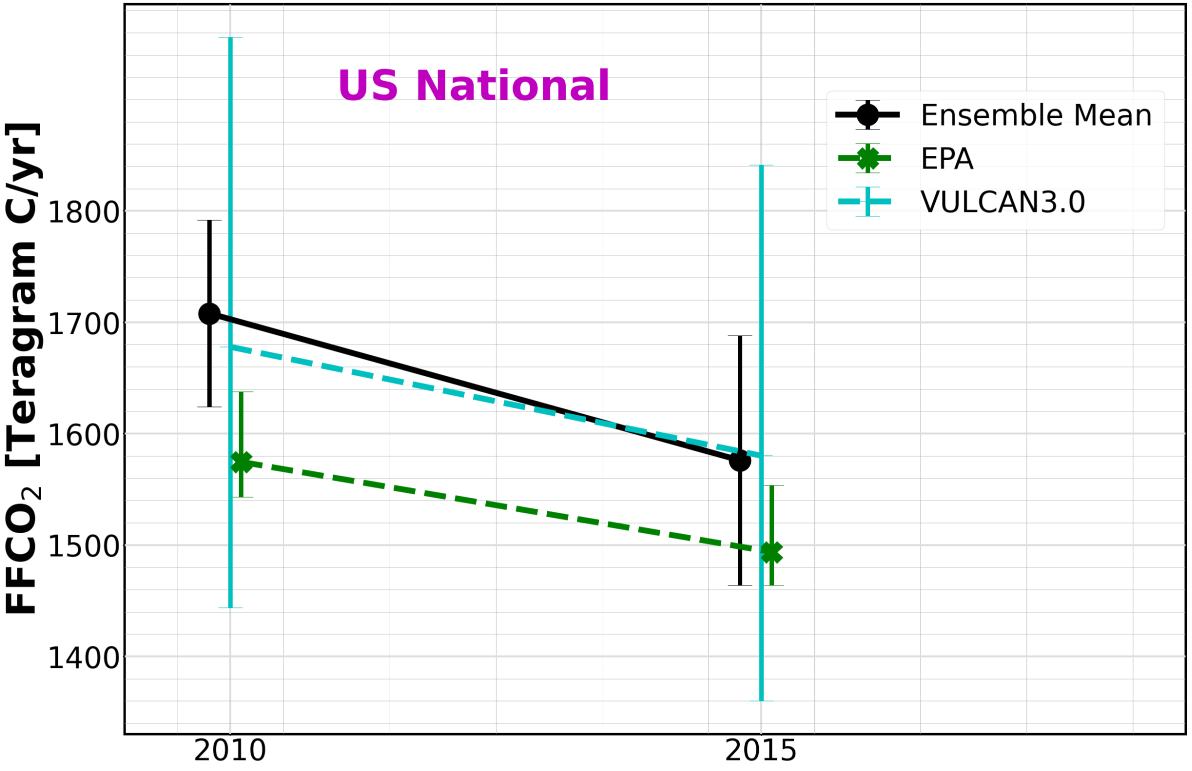
→ Model includes all $\Delta^{14}C$ budget terms: ***Fossil,*** cosmogenic and nuclear reactor production, ***land and ocean disequilibrium***

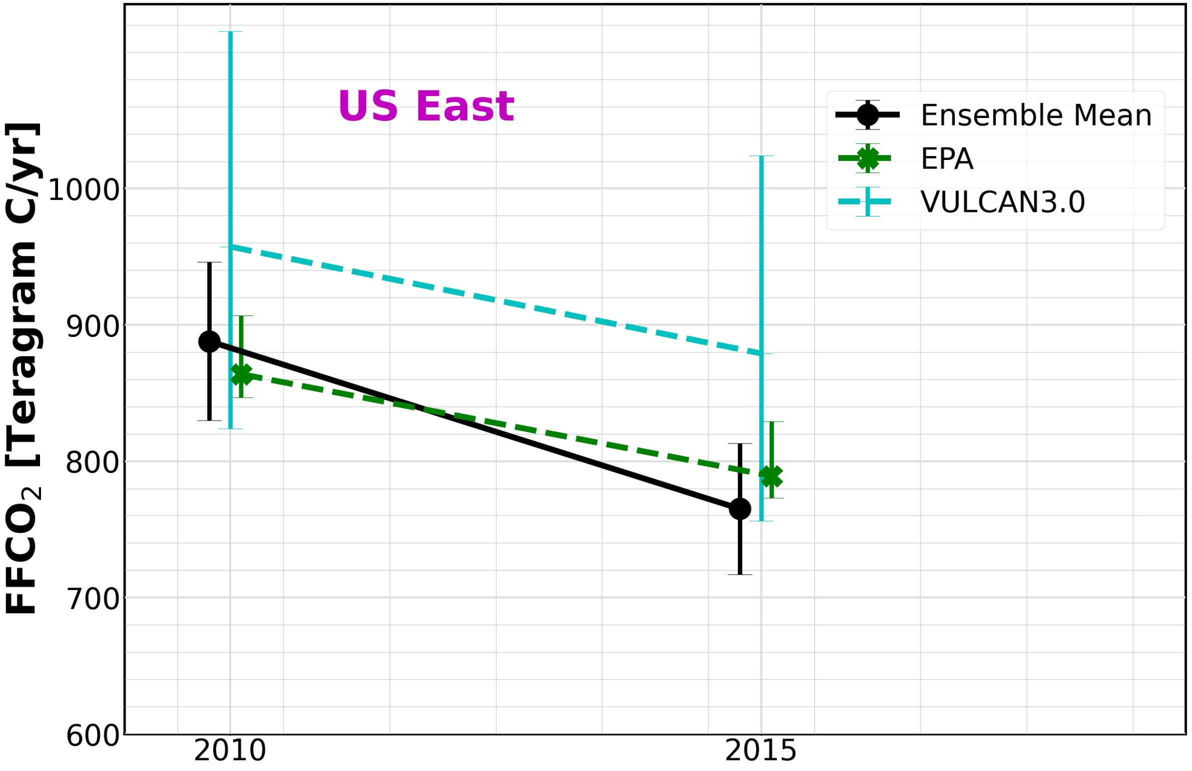
US top-down fossil emissions for 2010 and 2015





Top-down estimates show reductions consistent with US EPA (bottom-up)





Nazrul Islam

LA Megacity ^{14}C sampling

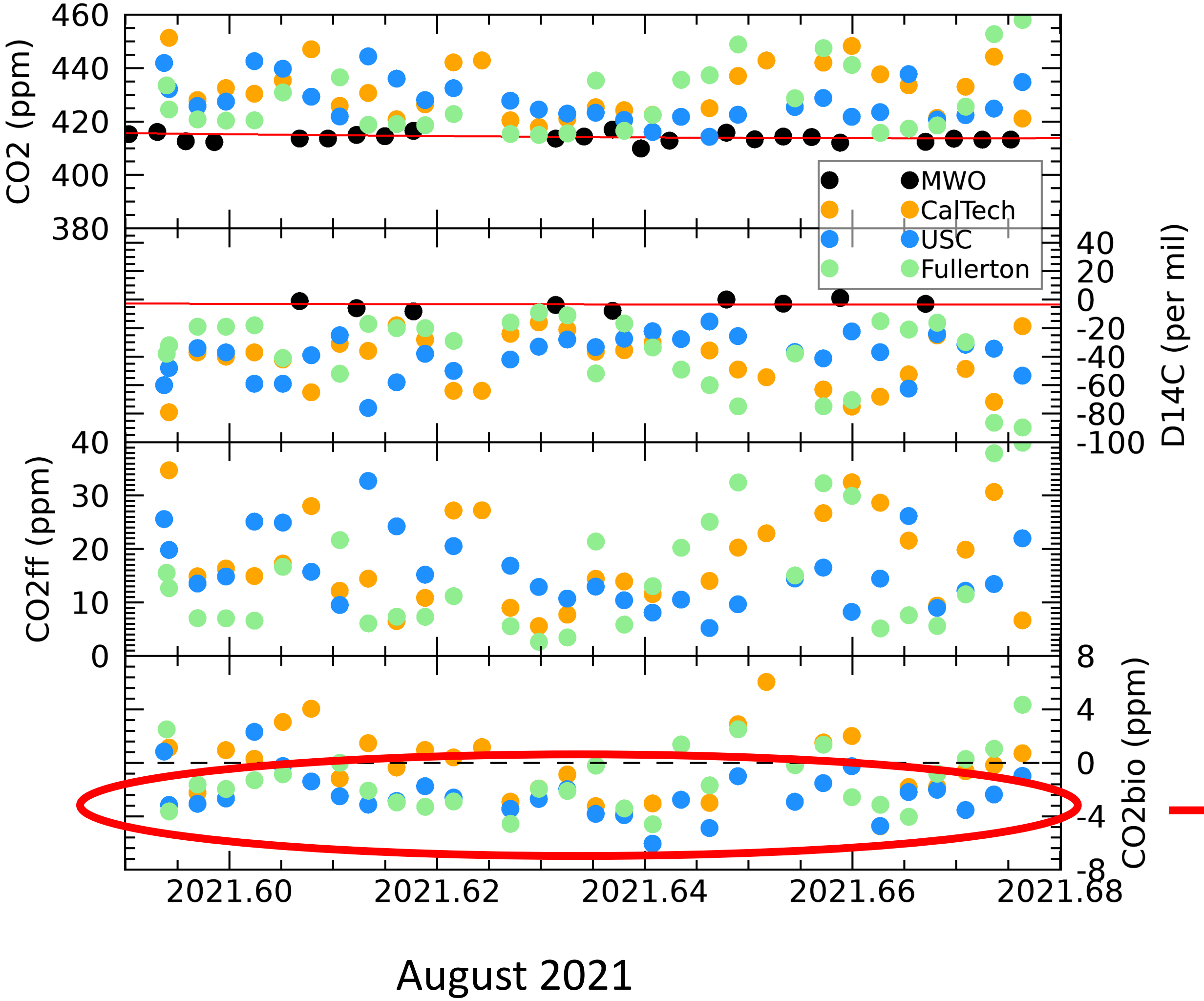
1. Quantify fossil (C_{ff}) and biospheric (C_{bio}) contributions to CO_2 enhancements (C_{xs})

2. 2015 sampling showed that C_{bio} seasonality was correlated with urban water use (PNAS, 2020).

3. Use C_{ff} to evaluate urban bottom-up fossil flux estimates.

LA Megacity GHG Network

Significant C_{bio} during SUNVEX-LA 2021



CalTech ↓ ^{14}C ↓

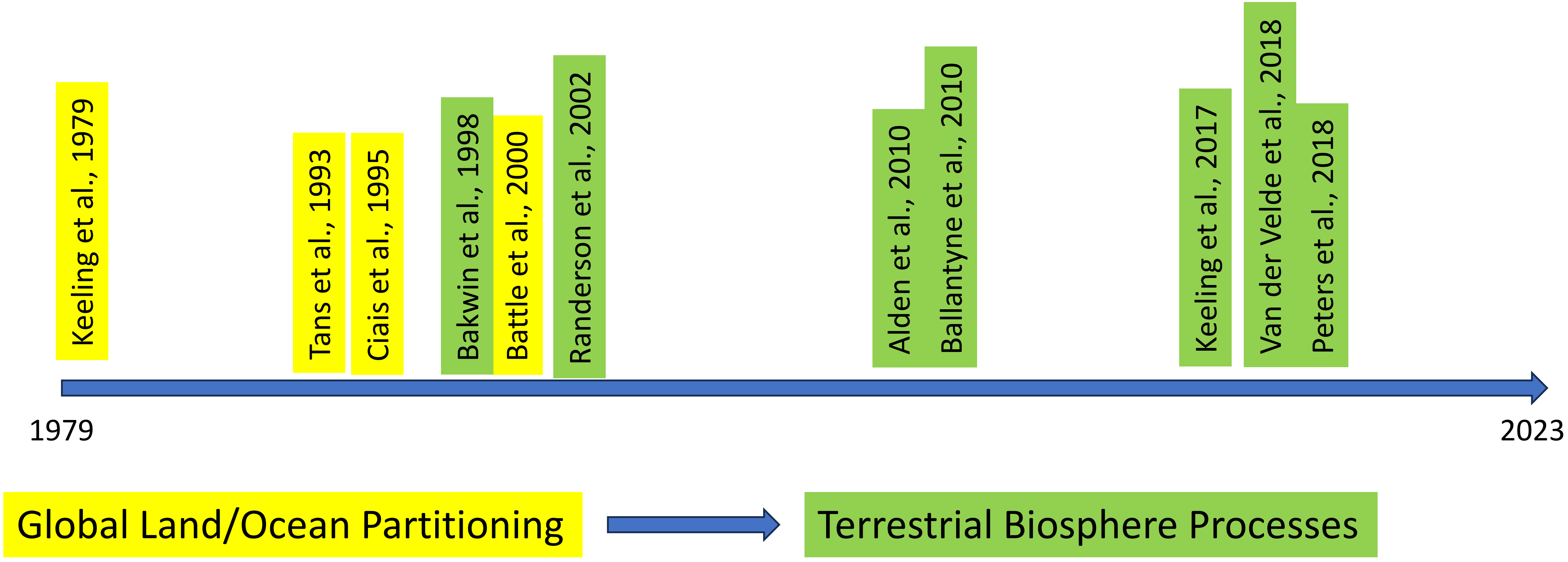
$$C_{obs} = C_{bg} + C_{bio} + C_{ff}$$

↑ MWO

$$C_{xs} = C_{bio} + C_{ff}$$

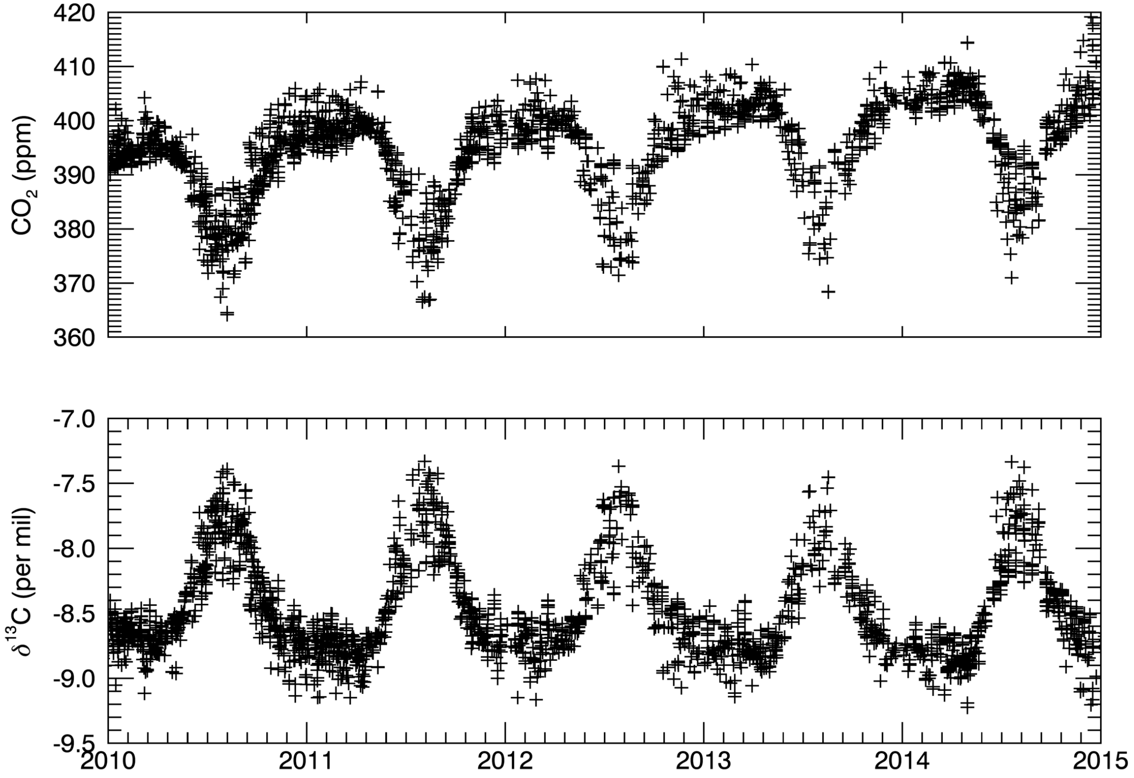
August CO_2 uptake consistent with 2015 results published in Miller et al., 2020 PNAS.

Atmospheric $^{13}CO_2$ in transition…

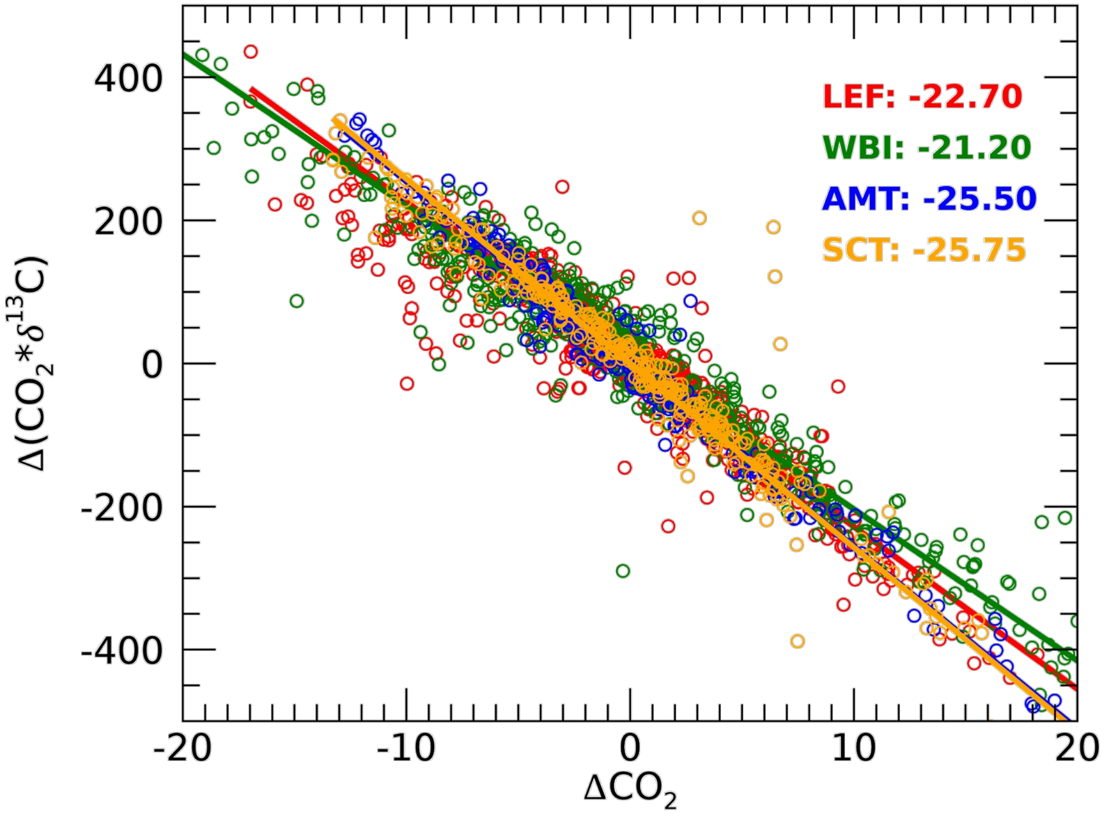


CO_2 and ^{13}C:^{12}C are strongly connected via plant photosynthesis.

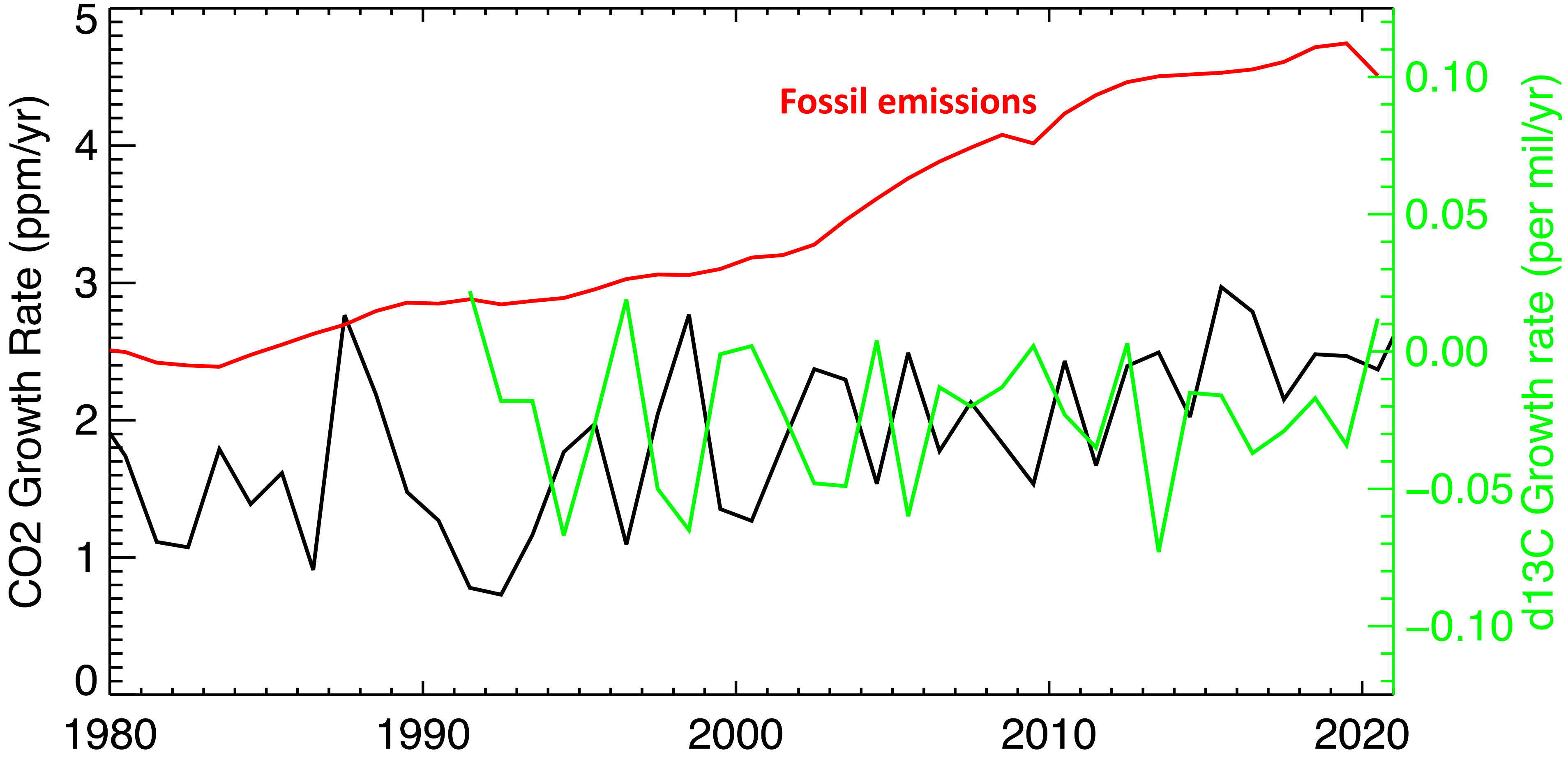
LEF tall tower, northern Wisconsin



Midwest: LEF, WBI influenced by maize (C_4)
East: SCT, AMT influence more by C_3



Global mean $\delta^{13}C$ shows that much of CO_2 variability originates in the terrestrial biosphere.



Why is the δ^{13}C growth rate not trending?

$$C_a \frac{d\delta_a}{dt} = F_f(\delta_f - \delta_a) + F_{netb}\varepsilon_{ab} + F_{neto}\varepsilon_{ao} + F_{ba}(\delta_b - \delta_a) + F_{oa}(\delta_o - \delta_a)$$

Over the last 30 years:

1. Fossil isoflux has decreased from ~ – 120 to – 200 PgC*(per mil)/yr
2. Isotopic disequilibrium has increased over the same period from ~ 80 to 140 PgC*(per mil)/yr
3. What does this mean?

   Diseqflux $\propto$ *GrossFlux*reservoir_residence_time*

→Some combination of gross fluxes (e.g. respiration) and/or residence times in the surface waters or terrestrial biosphere have been changing a lot!
→Our bottom-up calculations explain ~85% of this change (but our bottom-up absolute values are too low.)

$^{13}CO_2$ inversions can improve the drought response of land models.