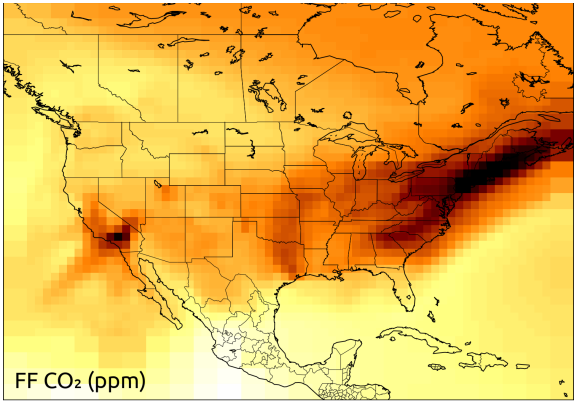
The potential for $^{14}CO_2$ measurements to constrain the North American fossil fuel CO_2 budget

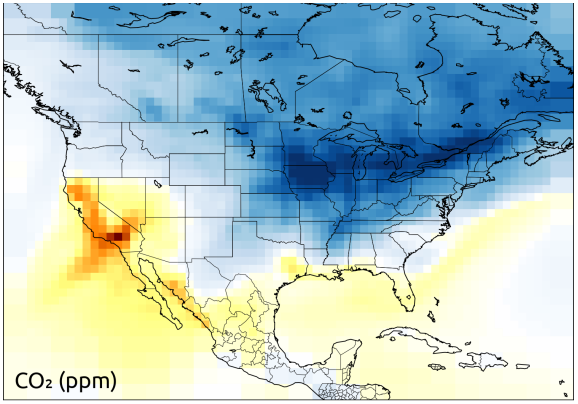
Sourish Basu, John Miller, Scott Lehman

CMS telecon, August 26, 2015

Measurements of total CO_2 are generally ineffective at estimating fossil fuel CO_2 emissions



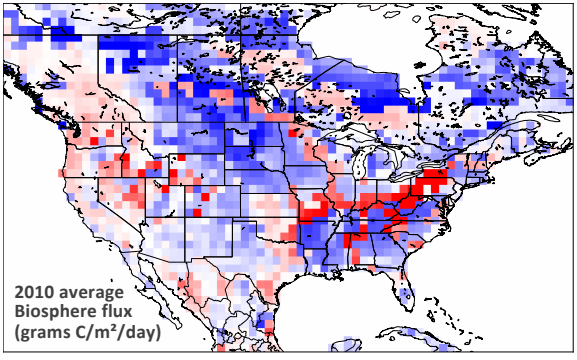
Fossil fuel CO_2

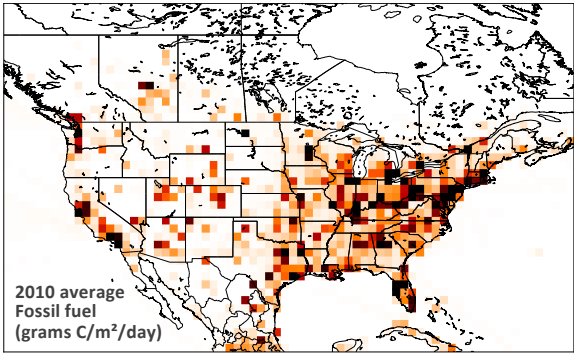


Total CO_2

What is the issue?

NEE estimates $(dC/dt = F_{oce} + F_{bio} + F_{fos})$





- All atmospheric CO_2 inversions assume CO_2(ff) "perfectly" known, solve for natural fluxes
- Global annual FF known to within 10%, not true at small scales
- Usually not up to date, EDGAR 6 yr old, Vulcan 14 yr old

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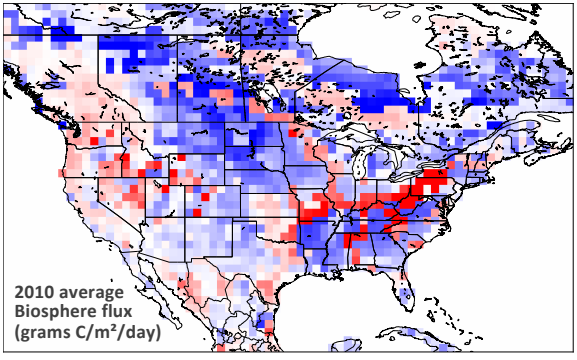

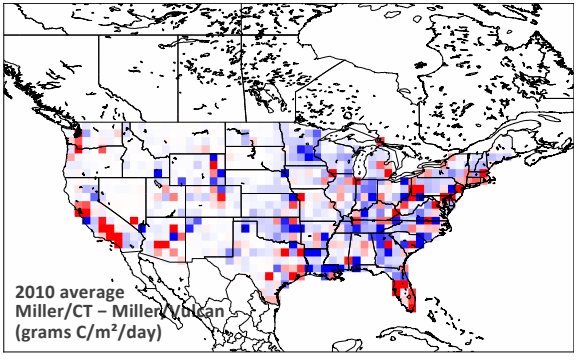

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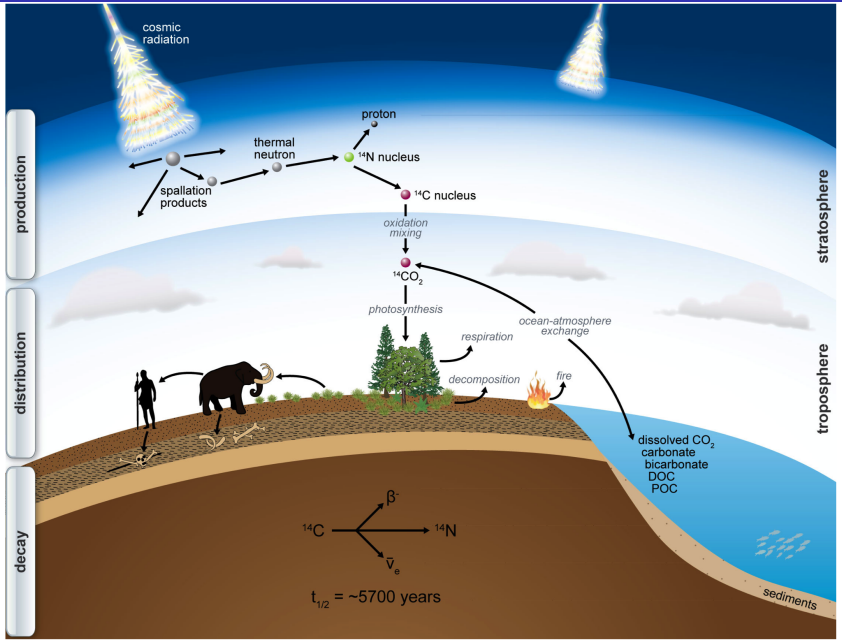
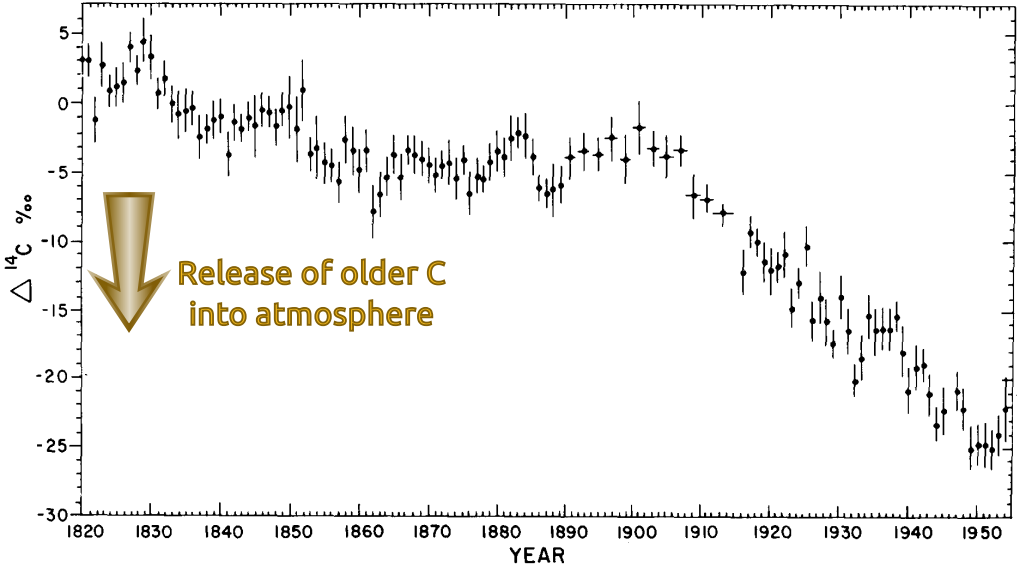
Isotope geochemistry of $^{14}CO_2$



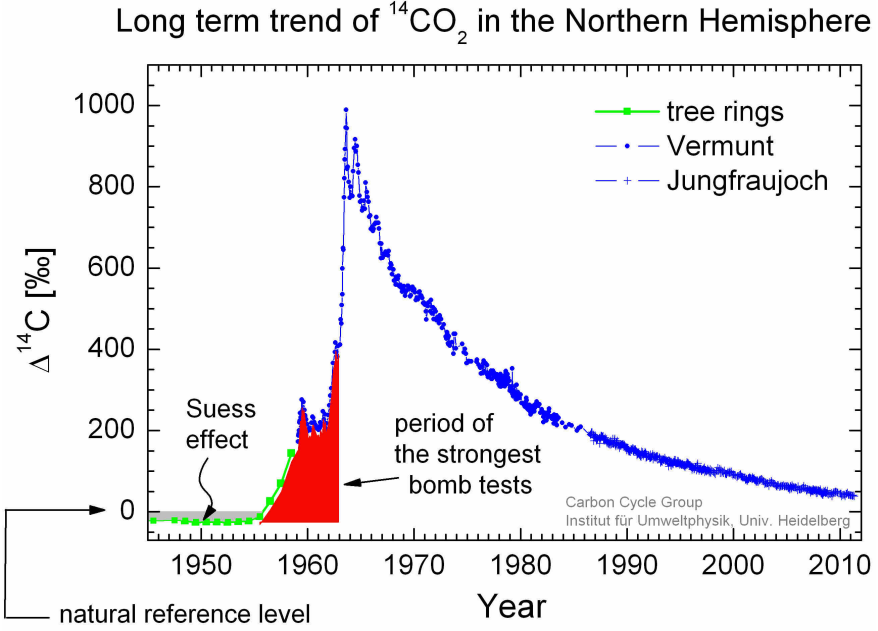
$$\delta^{14}CO_2 = \left[\frac{(^{14}CO_2/CO_2)_{\text{sample}}}{(^{14}CO_2/CO_2)_{\text{reference}}} - 1\right] \times 1000‰$$
$$= \left[\frac{\text{relative abundance in sample}}{\text{“typical” relative abundance}} - 1\right] \times 1000‰$$

- $(^{14}CO_2/CO_2)_{\text{reference}} = 1.176 \times 10^{-12}$
- Basis for radiocarbon dating; older the sample, lower the $\delta^{14}C$
- Emitting fossil fuel CO_2 “ages” the atmosphere

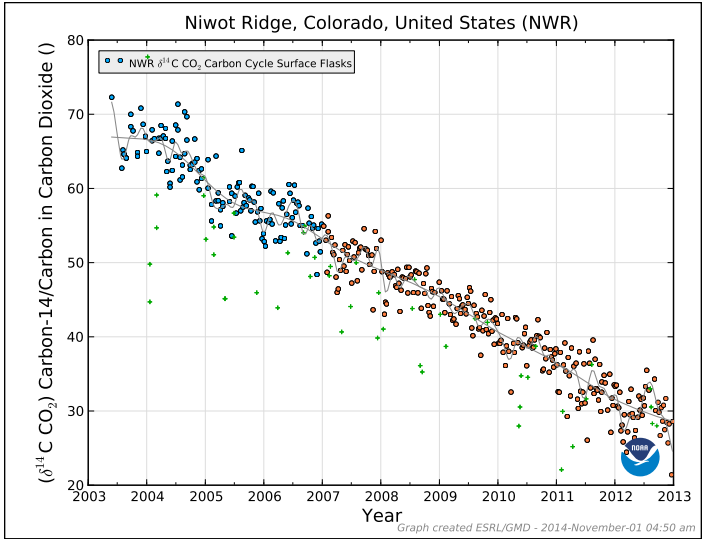
Isotope geochemistry of $^{14}CO_2$



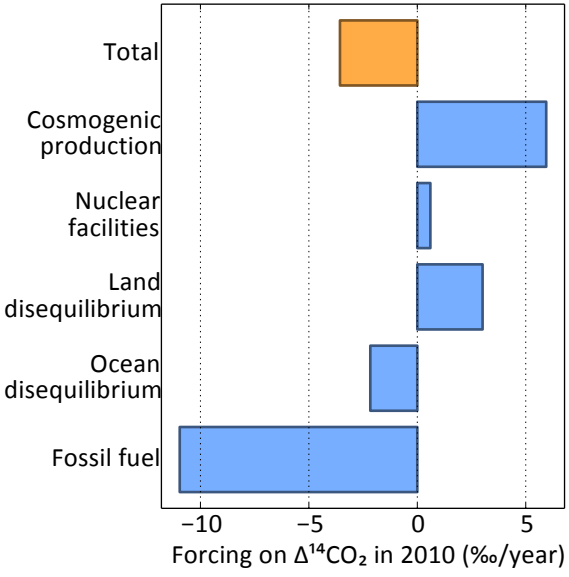
Tree ring $\Delta^{14}C$ by Stuiver & Quay, 1981


Long term trend of $^{14}CO_2$ in the Northern Hemisphere
tree rings
Vermunt
Jungfraujoch
$\Delta^{14}C$ [‰]
1000
800
600
400
200
0
Suess effect
period of the strongest bomb tests
Carbon Cycle Group
Institut für Umweltphysik, Univ. Heidelberg
natural reference level
1950
1960
1970
1980
1990
2000
2010
Year

Isotope geochemistry of $^{14}CO_2$

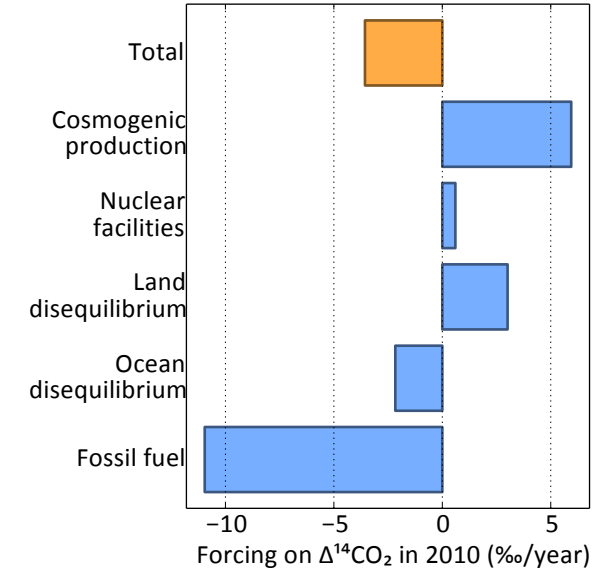


Isotope geochemistry of $^{14}CO_2$

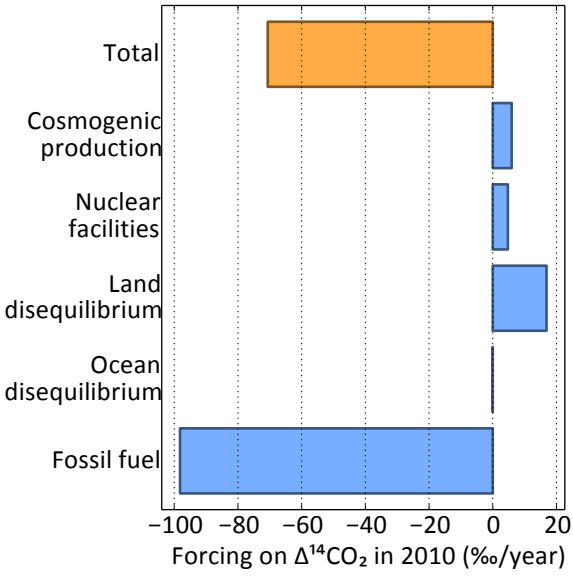


Global budget

Isotope geochemistry of $^{14}CO_2$



Global budget

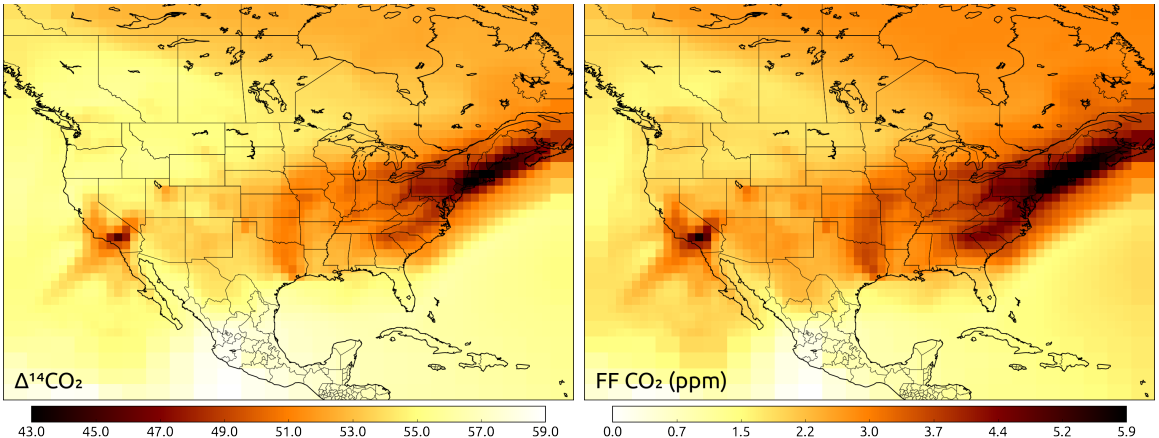


Continental US budget

Over ConUS, $\Delta^{14}CO_2$ signal dominated by fossil fuel

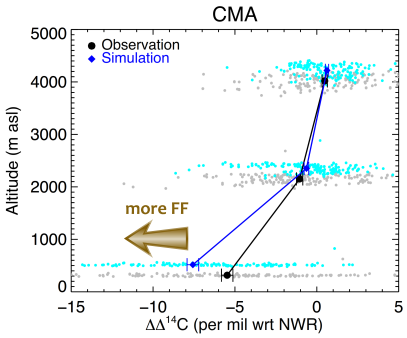
$\Delta^{14}C_{ff}$ = −1000 ‰ (i.e., zero $^{14}CO_2$)

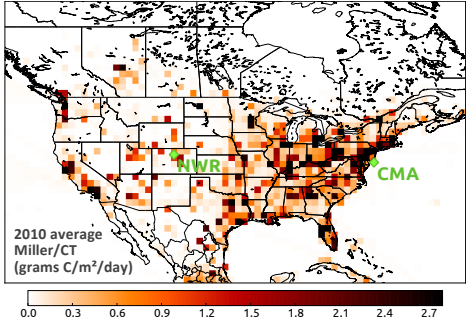
Scaling in 2006 = −2.7 ‰ $\Delta^{14}C$ for 1 ppm CO_2(ff)

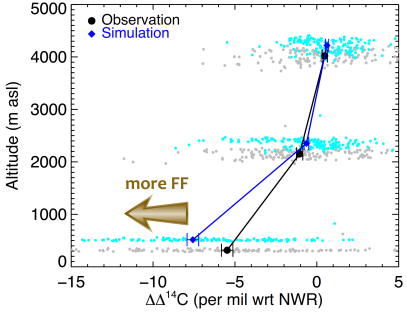


fossil fuel, ocean and land disequilibrium, nuclear and cosmogenic production

fossil fuel only


CMA
Observation
Simulation
Altitude (m asl)
5000
4000
3000
2000
1000
0
more FF
−15
−10
−5
0
5
ΔΔ14C (per mil wrt NWR)


NWR
CMA
2010 average
Miller/CT
(grams C/m²/day)
0.0
0.3
0.6
0.9
1.2
1.5
1.8
2.1
2.4
2.7


CMA
Observation
Simulation
Altitude (m asl)
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4000
3000
2000
1000
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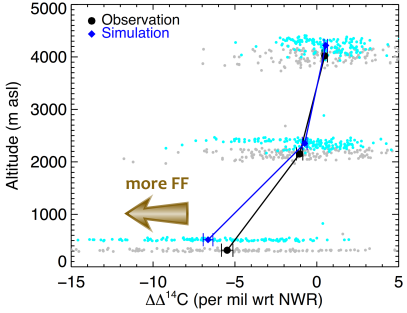
more FF
−15
−10
−5
0
5
ΔΔ14C (per mil wrt NWR)


CMA
Observation
Simulation
Altitude (m asl)
5000
4000
3000
2000
1000
0
more FF
−15
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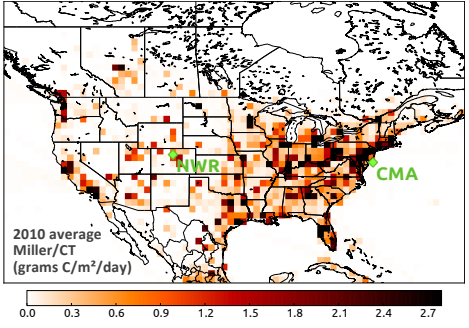
NWR
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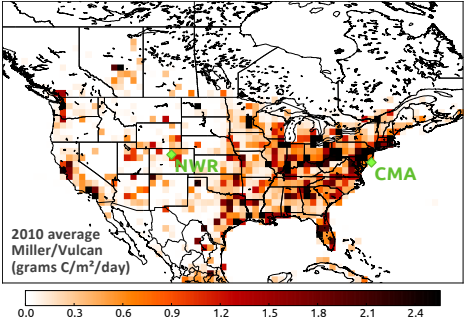
NWR
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0.0
0.3
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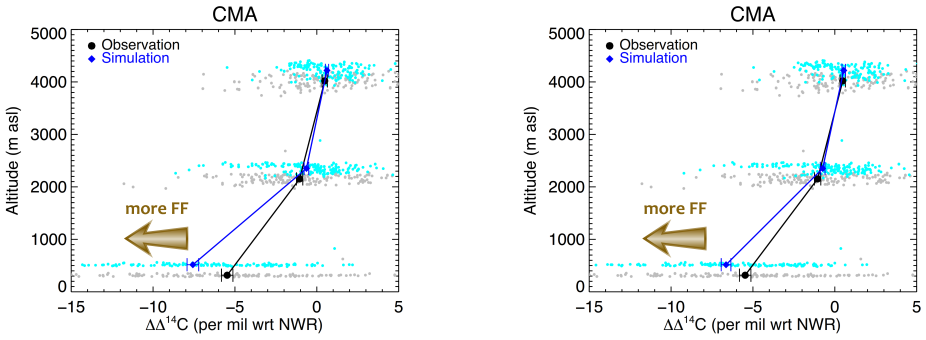
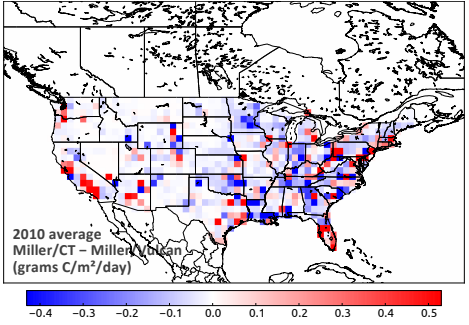

CMA
Observation
Simulation
Altitude (m asl)
5000
4000
3000
2000
1000
0
more FF
−15
−10
−5
0
5
ΔΔ14C (per mil wrt NWR)
CMA
Observation
Simulation
Altitude (m asl)
more FF
ΔΔ14C (per mil wrt NWR)


2010 average
Miller/CT − Miller/Vulcan
(grams C/m²/day)
−0.4
−0.3
−0.2
−0.1
0.0
0.1
0.2
0.3
0.4
0.5

Mass balance

$$\frac{dC}{dt} = F_{oce} + F_{bio} + F_{fos}$$

$$\frac{d}{dt}\left(C \cdot \Delta_{atm}\right) = \Delta_{fos}F_{fos} + \Delta_{atm}\left(F_{oce} + F_{bio}\right) + \Delta_{oce}F_{oce\rightarrow atm} + \Delta_{bio}F_{bio\rightarrow atm} + \alpha\left(F_{nuc} + F_{cosmo}\right)$$

tracers transported
fluxes estimated

Our OSSE setup

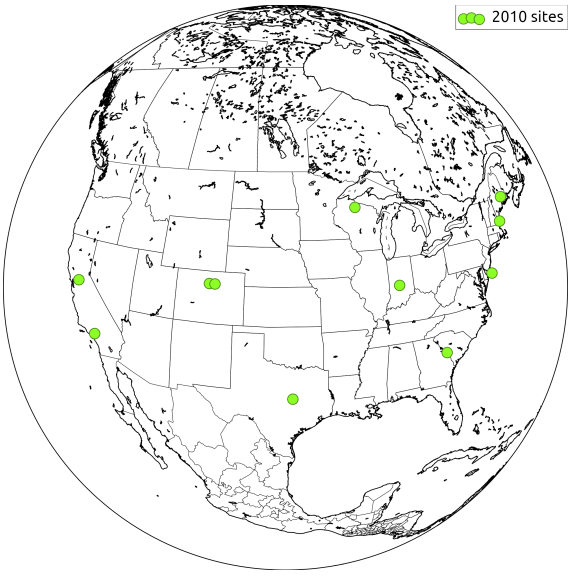
- Simulate pseudo-obs of CO_2 and $\Delta^{14}CO_2$ with "true" fluxes and an atmospheric transport model
- Assimilate those pseudo-obs in an atmospheric inversion
- Prior fossil fuel, oceanic and biospheric fluxes are different from and biased w.r.t. "true" fluxes (disequilibrium and pure isofluxes are same)
- Check performance of OSSE by
  - How well posterior fluxes match "true" fluxes
  - Posterior correlation between natural and fossil fuel CO_2 fluxes

Observation System Simulation Experiment (OSSE)

OSSE to gauge potential of $^{14}CO_2$ measurements

How accurately can a $CO_2 + {}^{14}CO_2$ inversion estimate fossil fuel fluxes

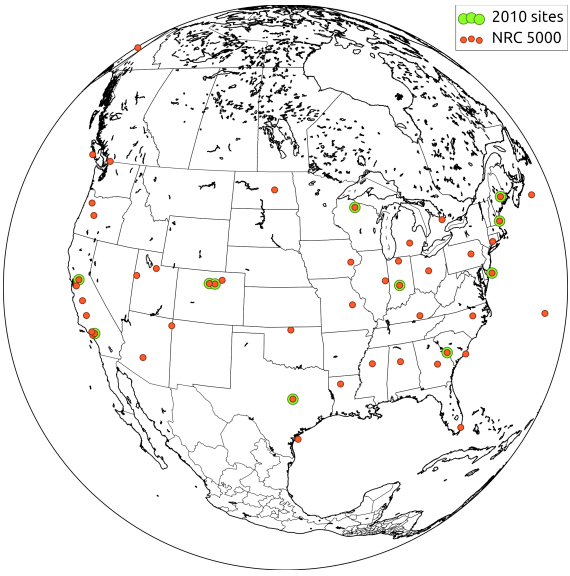
- with $^{14}CO_2$ measurements at the level of 2010 coverage?



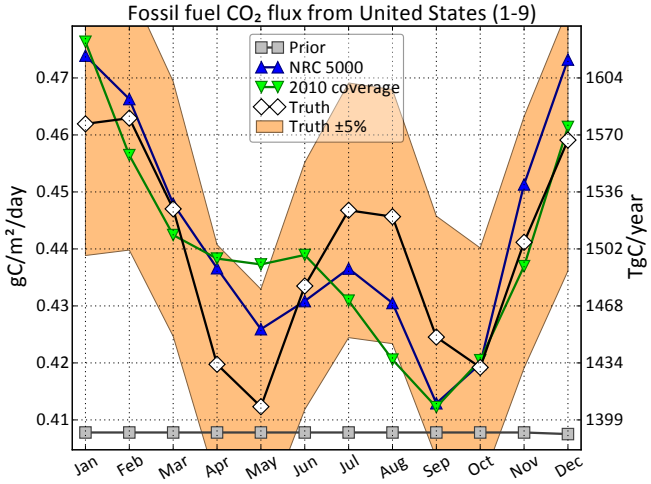
OSSE to gauge potential of $^{14}CO_2$ measurements

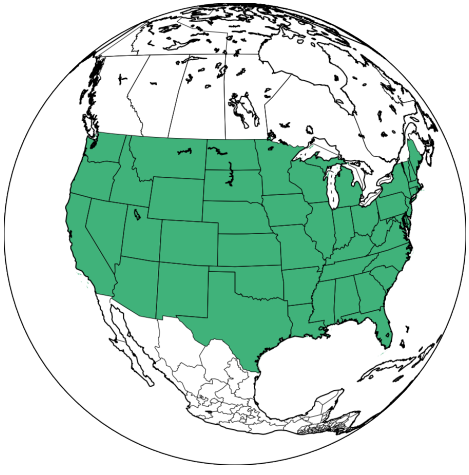
How accurately can a $CO_2 + {}^{14}CO_2$ inversion estimate fossil fuel fluxes

- with $^{14}CO_2$ measurements at the level of 2010 coverage?
- with $\sim$ 5000 $^{14}CO_2$ measurements/year?



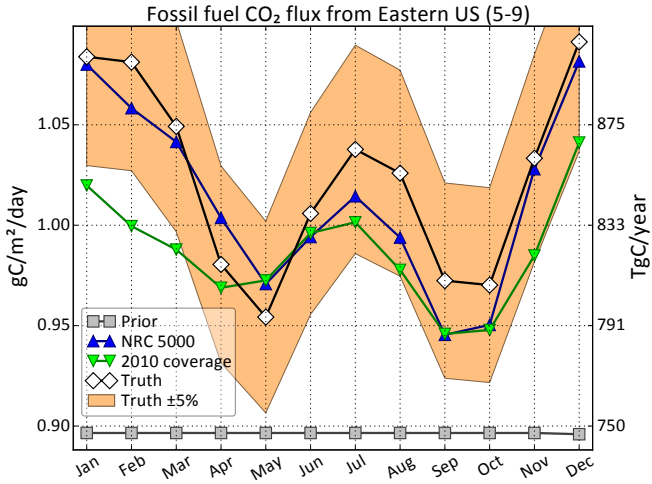
OSSE results 1: fluxes





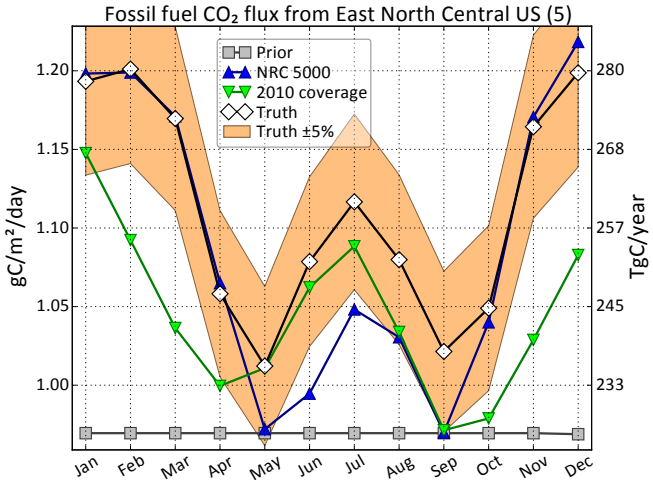
Monthly fluxes ± 5% recovered for the continental US ...

OSSE results 1: fluxes



... for large subregions ...

OSSE results 1: fluxes



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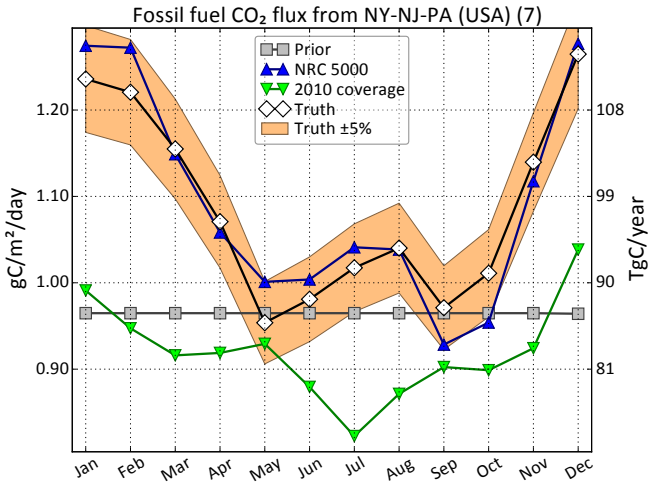
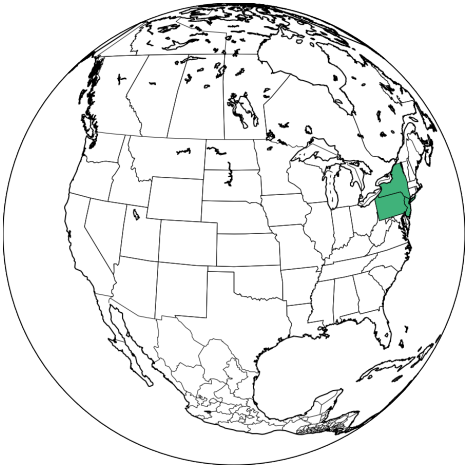
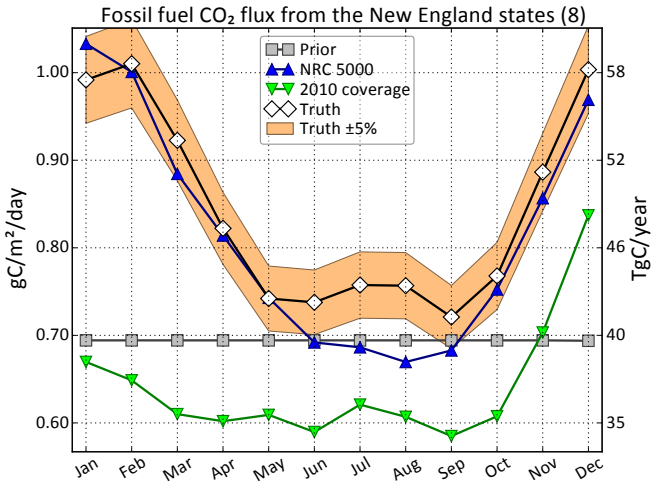
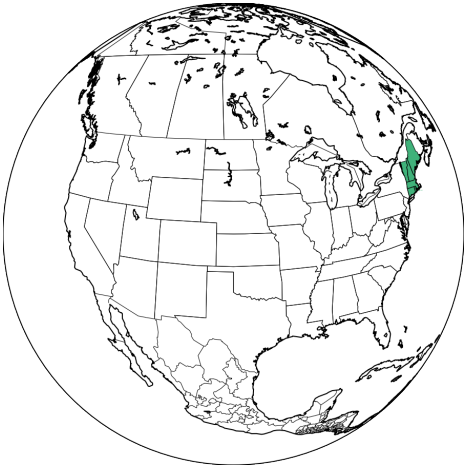




... and even for fairly small regions.

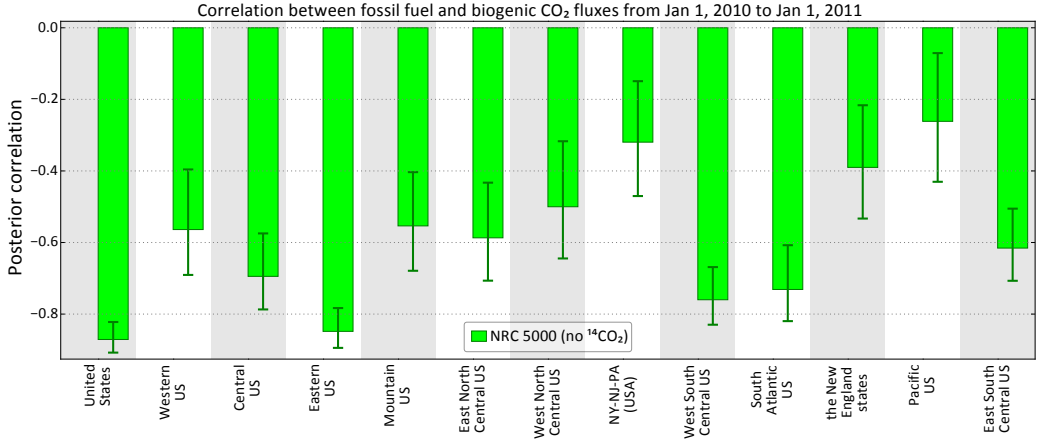
OSSE results 1: fluxes





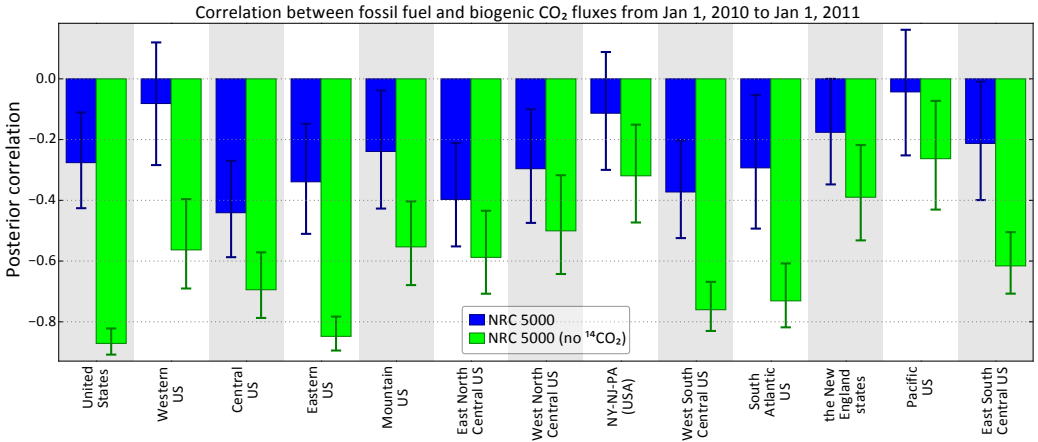
... and even for fairly small regions.

OSSE results 2: correlations



$$\frac{dC}{dt} = F_{\text{natural}} + F_{\text{fos}}$$

OSSE results 2: correlations



$$\frac{dC}{dt} = F_{\text{natural}} + F_{\text{fos}}$$

$$C\frac{d}{dt}\Delta_{\text{atm}} = (\Delta_{\text{fos}} - \Delta_{\text{atm}})F_{\text{fos}} + \cdots$$

Take home messages

- $^{14}CO_2$ measurements provide a top-down constraint on fossil fuel CO_2 emission estimates
- All CO_2 inversions assume a "known" fossil fuel flux, which can be relaxed using measurements of $^{14}CO_2$
- With 5000 $^{14}CO_2$ obs/year, we could recover the monthly national total FF CO_2 to 5%, and also monthly regional FF CO_2 from high-emitting regions
- Even with 2010 coverage, we could recover the monthly national total FF CO_2 to 5% for most months