Joint CO-CO_2 inversion system – a first OSSE

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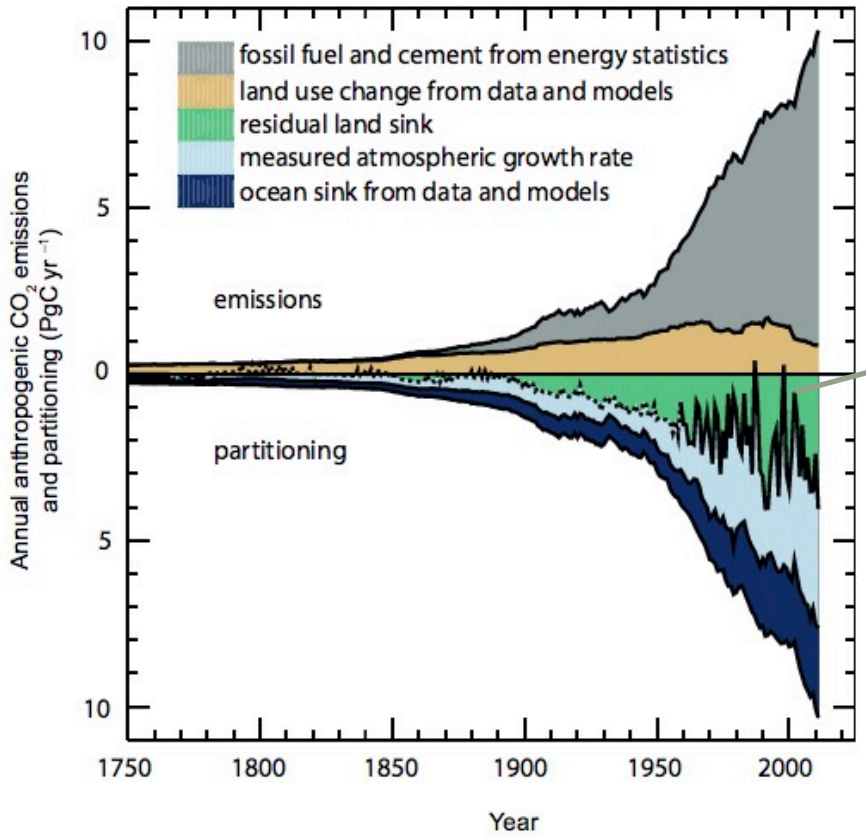
Joint CO-CO2: Motivation



Land CO2 fluxes

- 122.0 Pg C/yr Photosynthesis
115.8 Pg C/yr Respiration
2.0 Pg C/yr Biomass burning
- 4.3 Pg C/yr Net

The inverse modelling system TM5-4DVAR

$$J(x) = \underbrace{\tfrac{1}{2}(x - x_a)^T B^{-1}(x - x_a)}_{\text{A priori emissions and error covariance matrix}} + \underbrace{\tfrac{1}{2}(y - Hx)^T R^{-1}(y - Hx)}_{\text{Observations and observation covariance matrix}}$$

x = fluxes
y = observations
H = model operator, converting emissions into observations

The inverse modelling system TM5-4DVAR

$$J(x) = \tfrac{1}{2}(x - x_a)^T B^{-1}(x - x_a) + \tfrac{1}{2}(y - Hx)^T R^{-1}(y - Hx)$$

A priori emissions and error covariance matrix

Observations and observation covariance matrix

x = CO biomass burning emissions,
CO_2 biosphere, ocean fluxes,
CO/CO_2 biomass burning emission factors

y = CO and CO_2 observations

H = model operator, converting emissions into observations

The inverse modelling system TM5-4DVAR

Change of variables:

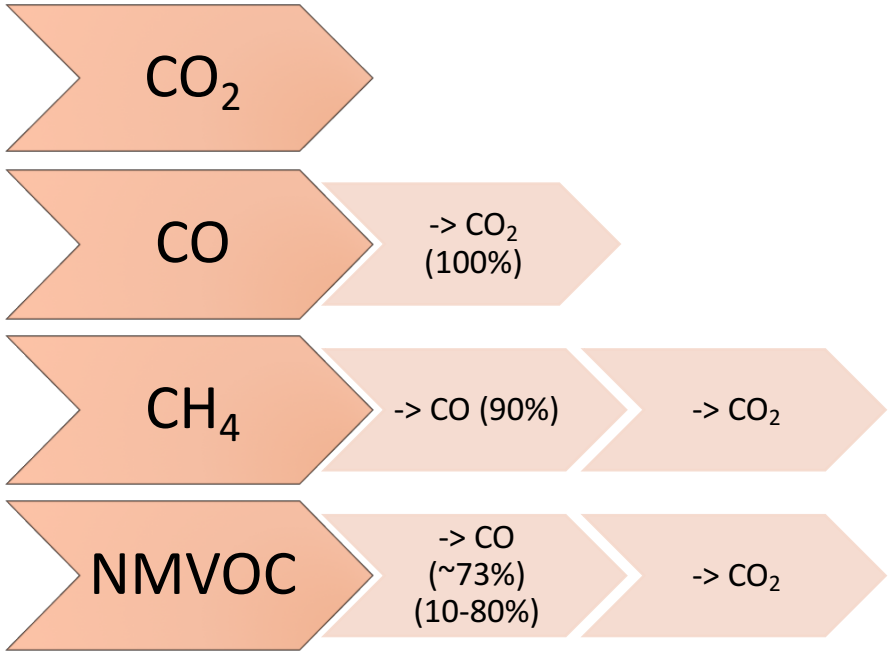
$$J(E_{CObb}, E_{CO2bb}, etc) \leftrightarrow J(E_{CObb}, EFbb, etc)$$
$$EFbb = E_{CO2bb}/E_{CObb}$$

Optimizing J uses $\frac{\partial J}{\partial x}$

$$\frac{\partial J}{\partial EF} = \frac{\partial J}{\partial E_{CO2}} \times \frac{\partial E_{CO2}}{\partial EF} + \frac{\partial J}{\partial E_{CO}} \times \frac{\partial E_{CO}}{\partial EF}$$

$$\frac{\partial J}{\partial EF} = \frac{\partial J}{\partial E_{CO2}} \times E_{CO} - \frac{\partial J}{\partial E_{CO}} \times \frac{E_{CO}^2}{E_{CO2}}$$

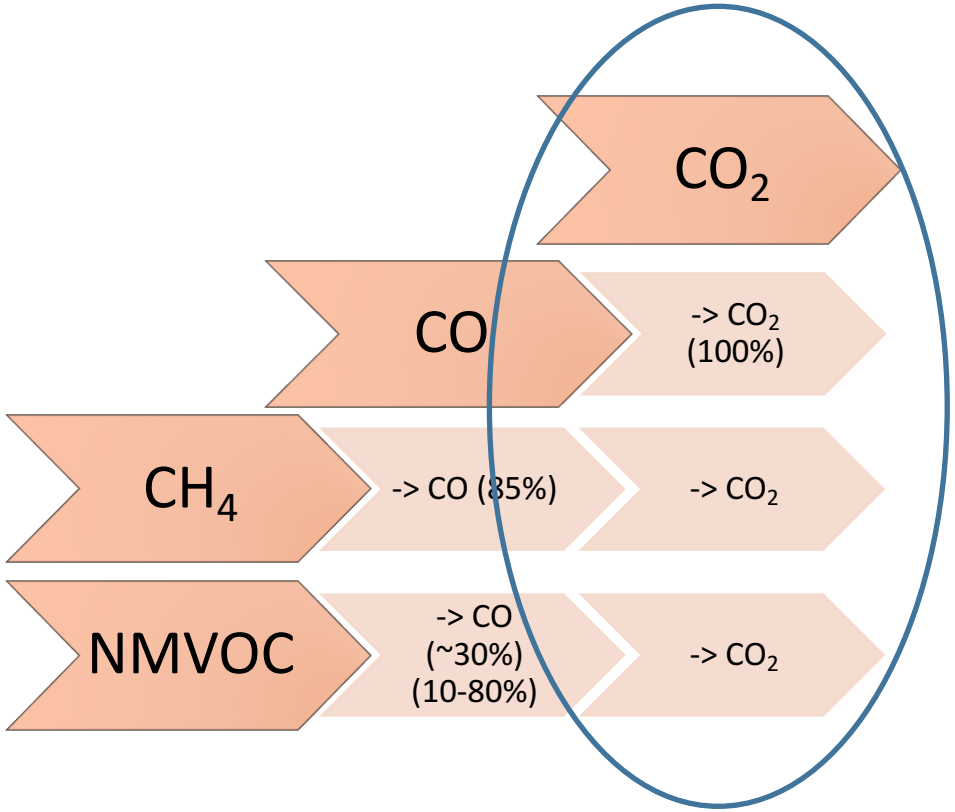
C emissions ending up as CO2



CO+OH-> CO_2 (~1 PG C)

Yields such that CO chemistry production in TM5 matches EDGAR+LPJ+MACC 2008 emission

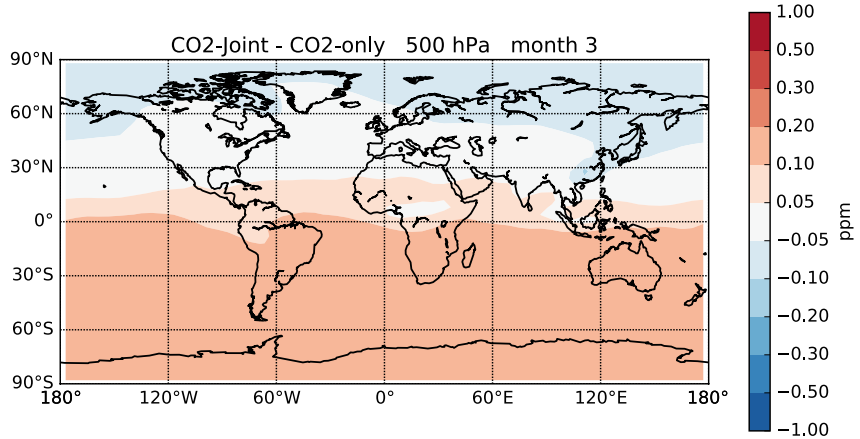
What inventories give

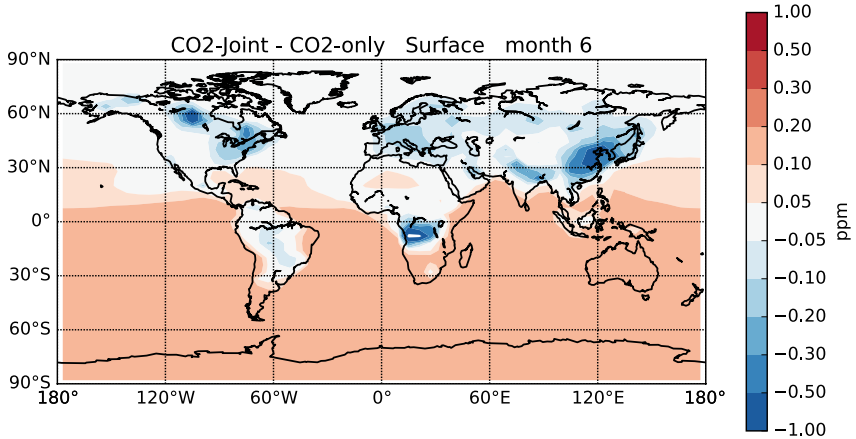


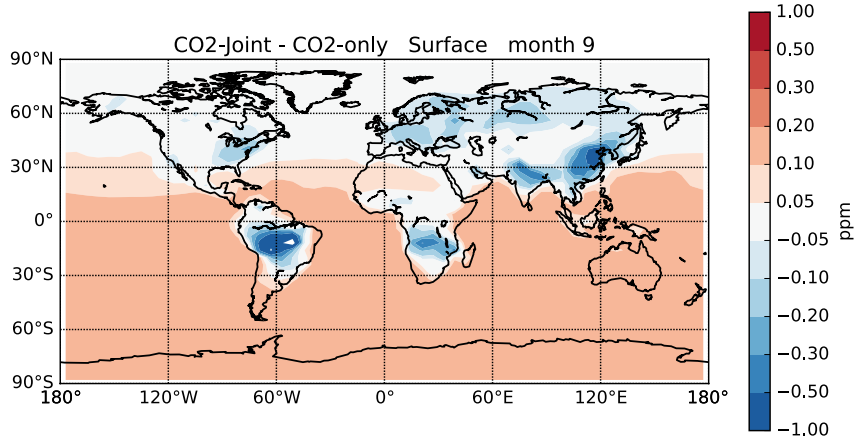
EDGAR, CDIAC, SiBCASA - 'Total Carbon'
→ CO_2 only emissions by subtracting CO, CH_4, NMVOC emissions, take into account yields

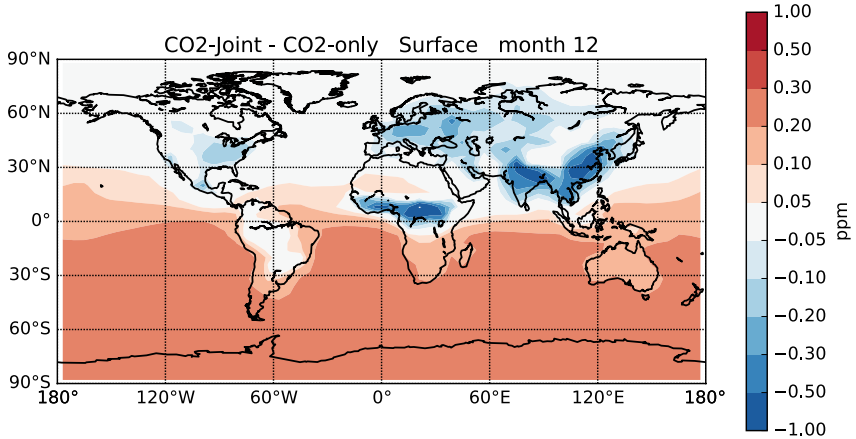
GFED4 – CO_2 only emissions

Forward runs – Impact of CO_2 chem production







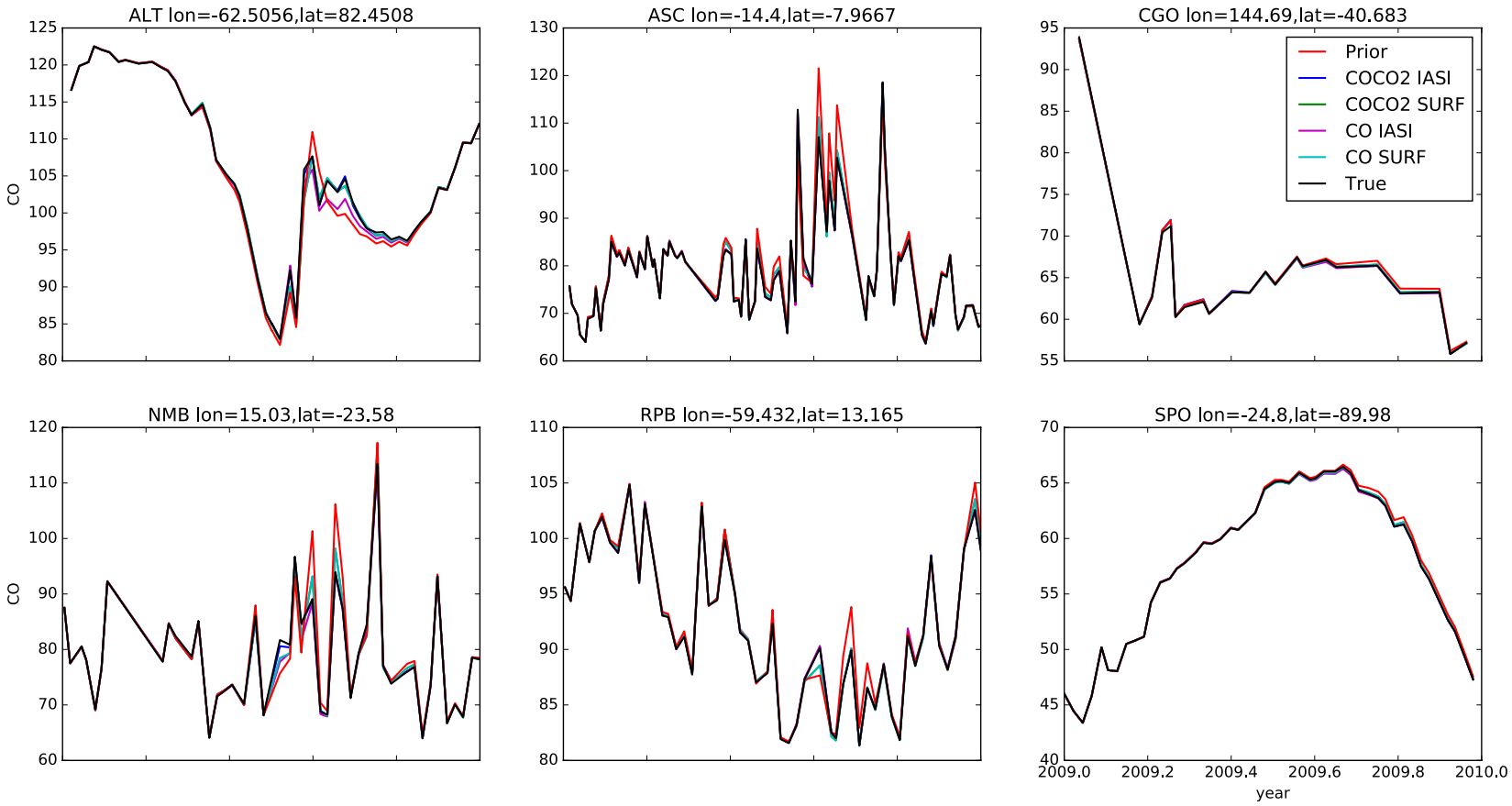


One OSSE

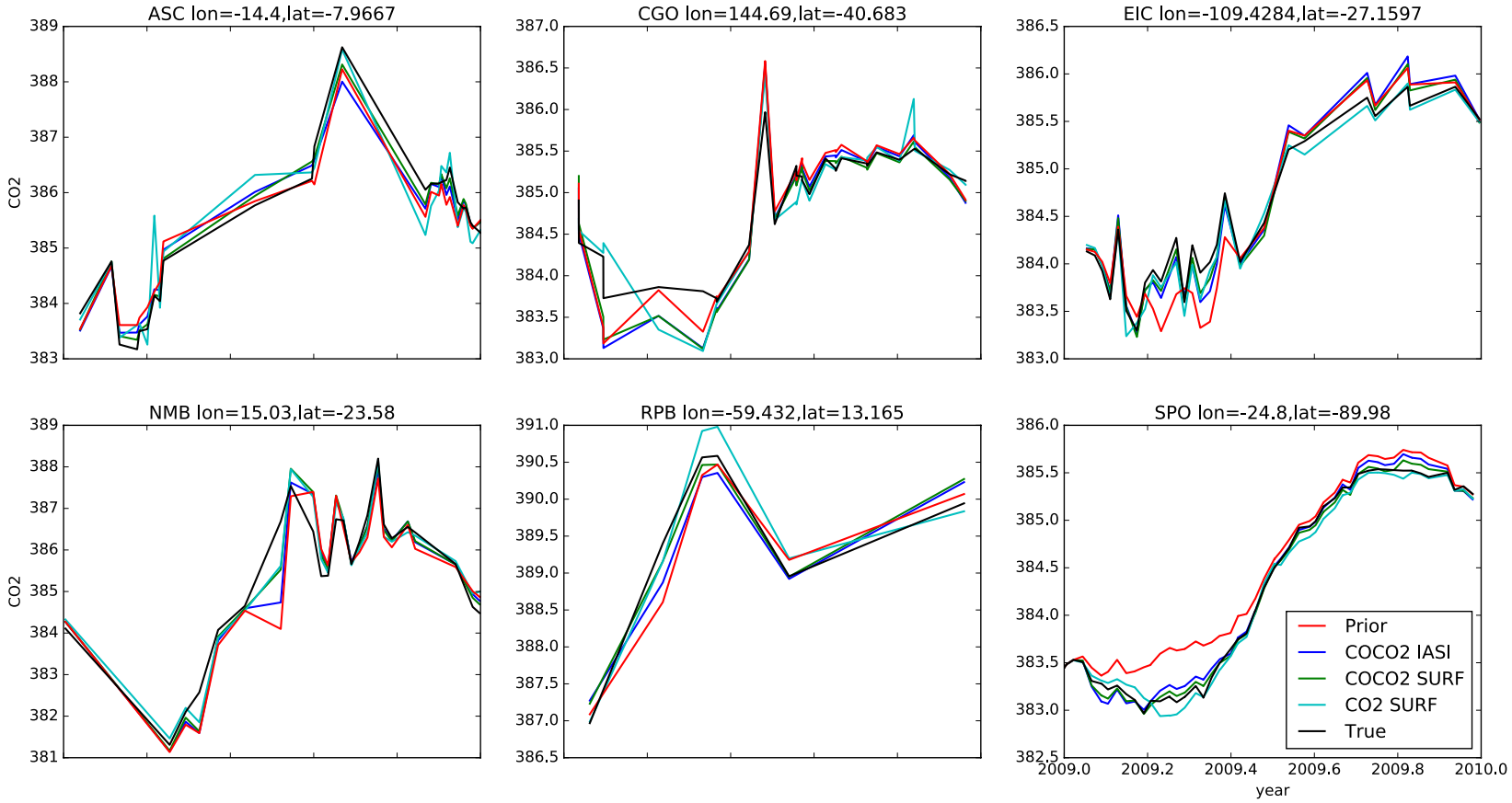
From inventories (GFED4, SiBCASA, EDGAR) -> **'True' emissions**
True emissions + perturbations -> **Prior emissions** (only one set of perturbations applied)
Run forward CO-CO2 model with True emissions -> **Synthetic observations** (sample for station data and IASI CO)
Runs on global 6x4, monthly resolution

Run	N iterations	Observations	Optimized fluxes
CO-CO2 SURF	25	CO, CO_2 surface	CO biomass burning (-> CO2 biomass burning) CO_2 biosphere, CO_2 ocean
CO-CO2 IASI	75	CO, CO_2 surface CO IASI data	CO biomass burning (-> CO2 biomass burning) CO_2 biosphere, CO_2 ocean
CO SURF	25	CO surface	CO biomass burning
CO IASI	25	CO surface, CO IASI	CO biomass burning
CO2 SURF	25	CO_2 surface	C terrestrial, C ocean (total carbon!)
CO2 SURFC	25	CO_2 surface from CO_2 model run with true emissions	C terrestrial, C ocean (total carbon!)

Comparison to CO stations



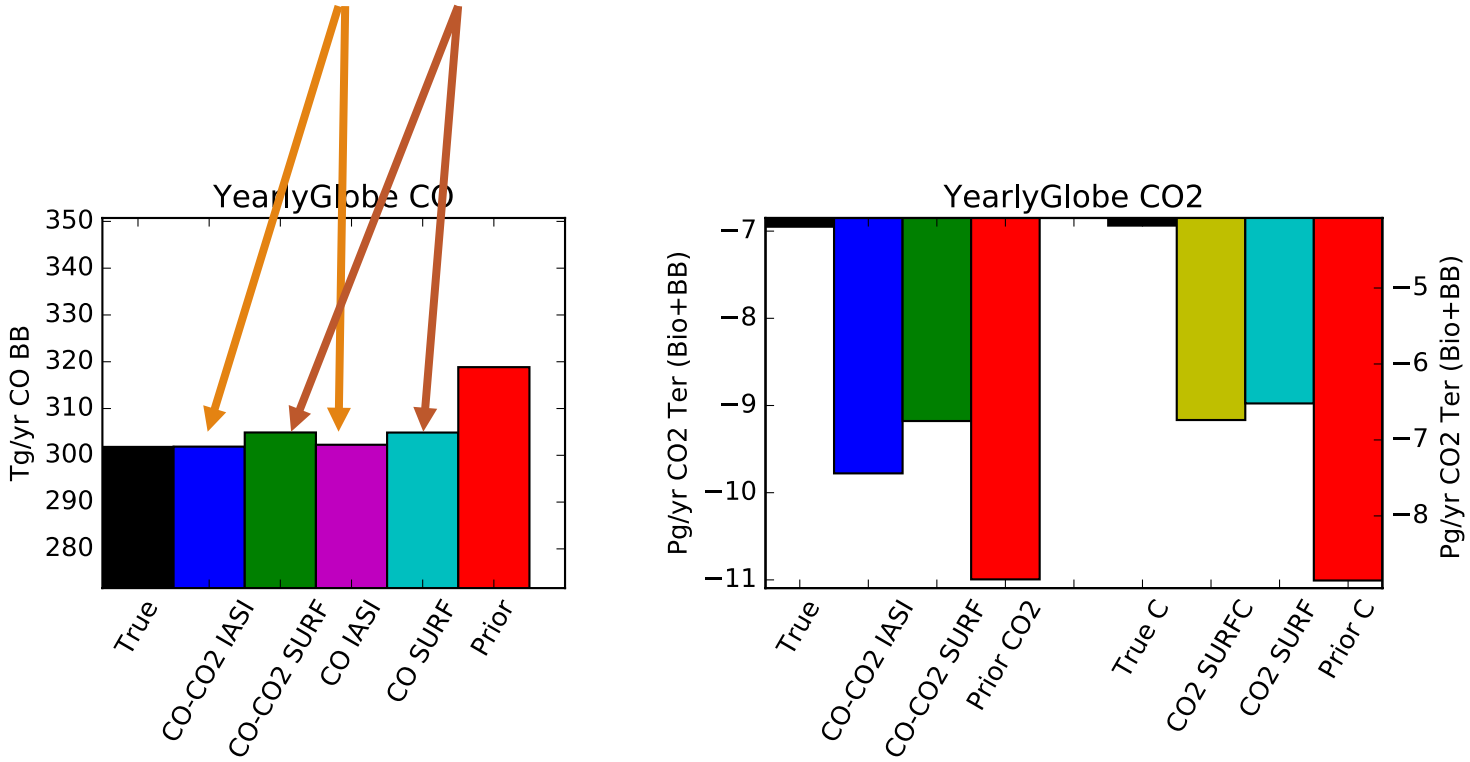
Comparison to CO_2 stations



Emissions

CO? OK

Similar CO posterior emissions in CO and CO-CO2 inversions

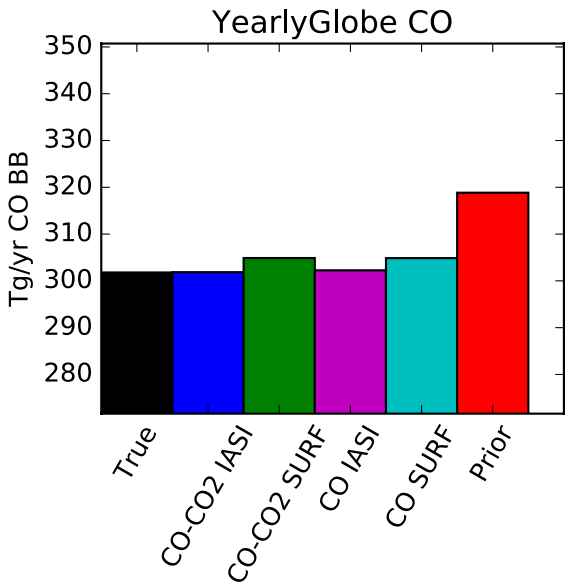


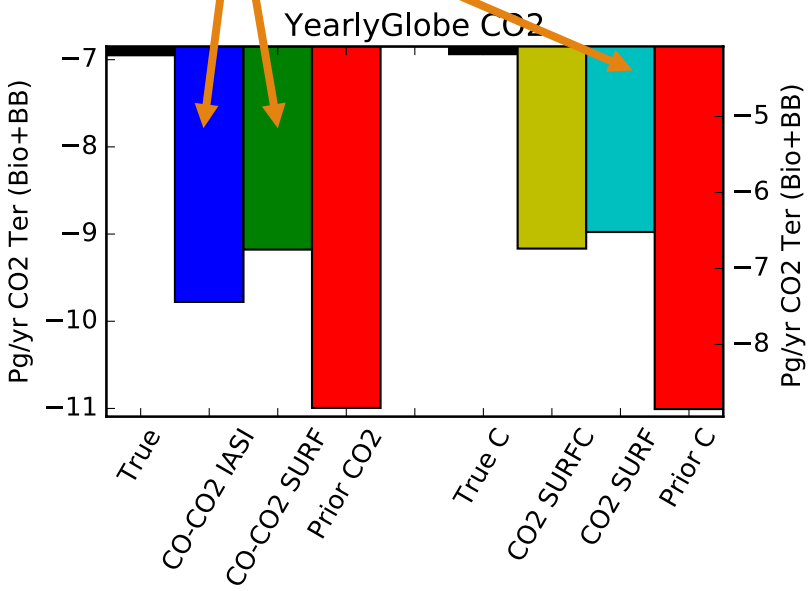
Emissions

CO2?

CO_2 emissions are better retrieved in the CO_2-only inversion

For CO-CO2 IASI not much improvement between iteration 25 and 75 (not shown)





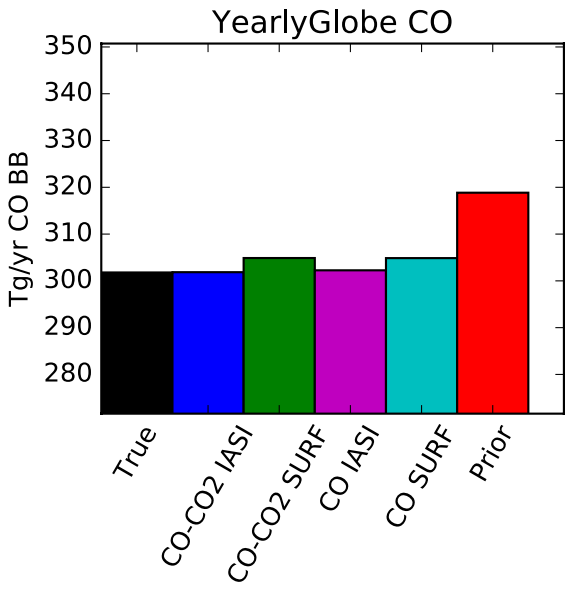
Emissions

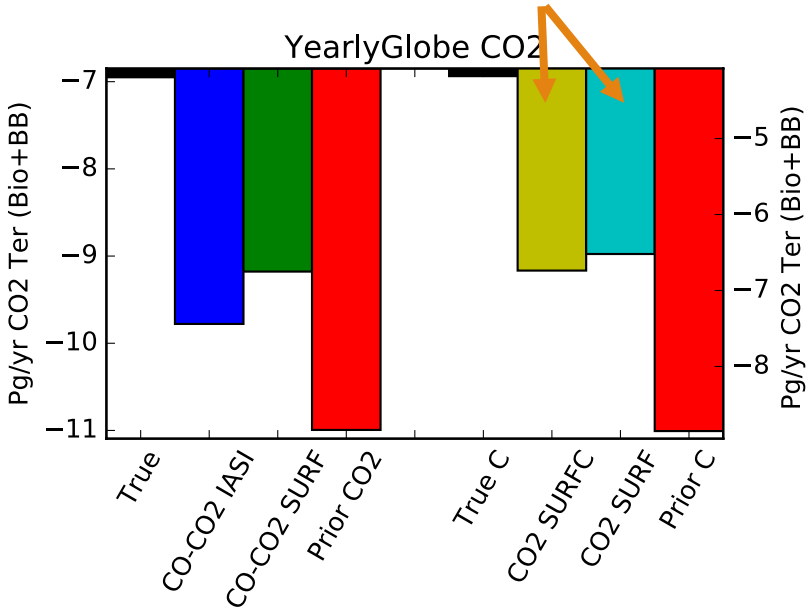
CO2?

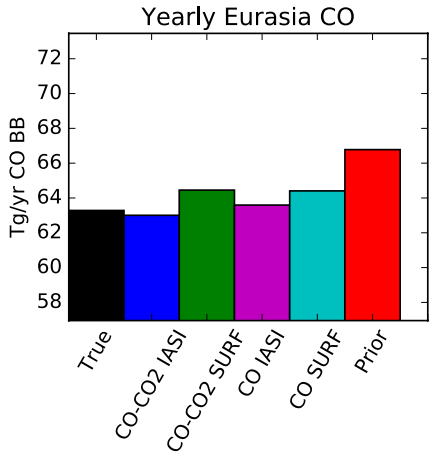
The effect of chemistry:

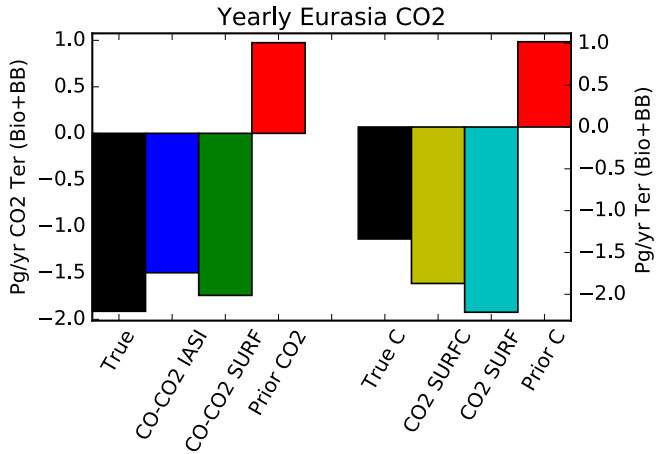
CO SURF uses obs from the CO-CO2 forward run (inconsistent with the CO2-only inversion)

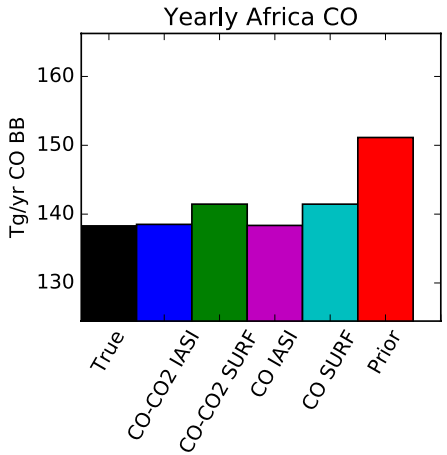
CO SURFC uses obs from a CO2-only forward run

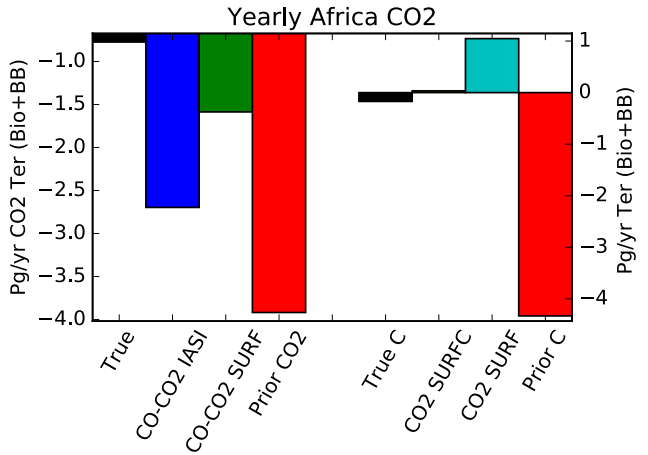


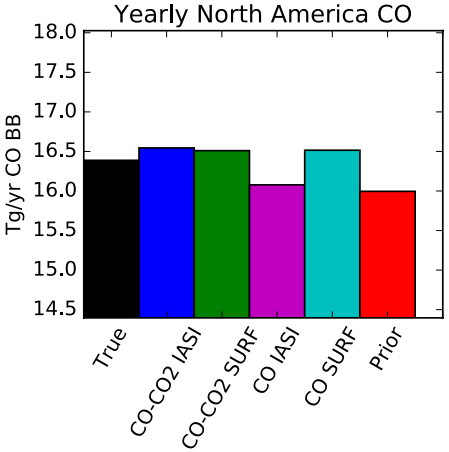


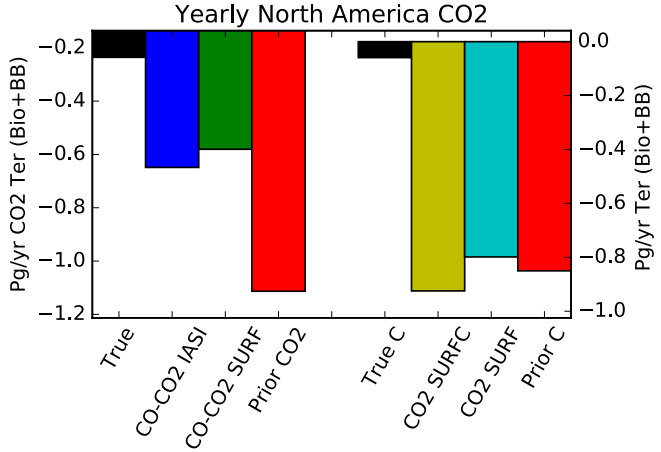

Yearly Eurasia CO
Tg/yr CO BB
72
70
68
66
64
62
60
58
True
CO-CO2 IASI
CO-CO2 SURF
CO IASI
CO SURF
Prior

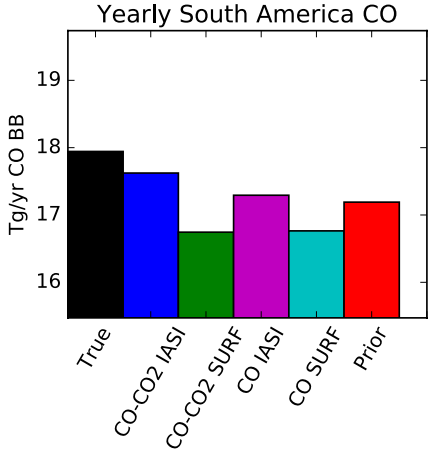

Yearly Eurasia CO2
Pg/yr CO2 Ter (Bio+BB)
Pg/yr Ter (Bio+BB)
1.0
0.5
0.0
−0.5
−1.0
−1.5
−2.0
True
CO-CO2 IASI
CO-CO2 SURF
Prior CO2
True C
CO2 SURFC
CO2 SURF
Prior C

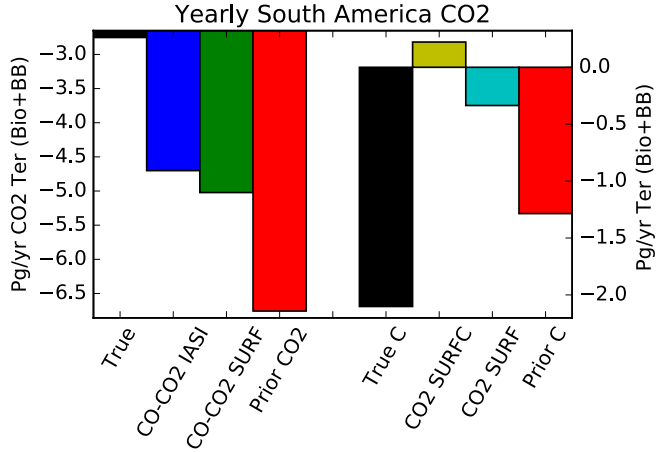

Yearly Africa CO
Tg/yr CO BB
160
150
140
130
True
CO-CO2 IASI
CO-CO2 SURF
CO IASI
CO SURF
Prior


Yearly Africa CO2
Pg/yr CO2 Ter (Bio+BB)
Pg/yr Ter (Bio+BB)
−1.0
−1.5
−2.0
−2.5
−3.0
−3.5
−4.0
0
−1
−2
−3
−4
True
CO-CO2 IASI
CO-CO2 SURF
Prior CO2
True C
CO2 SURFC
CO2 SURF
Prior C

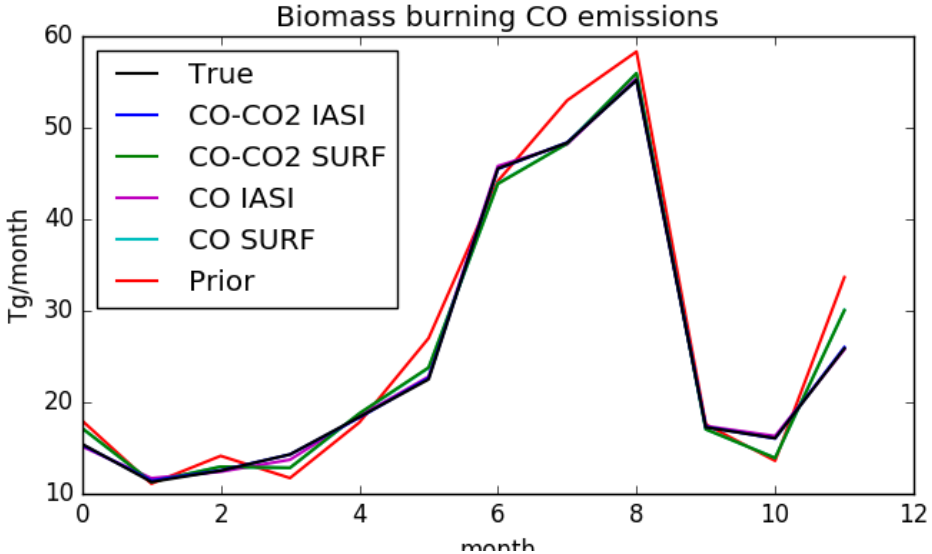

Yearly North America CO
Tg/yr CO BB
18.0
17.5
17.0
16.5
16.0
15.5
15.0
14.5
True
CO-CO2 IASI
CO-CO2 SURF
CO IASI
CO SURF
Prior

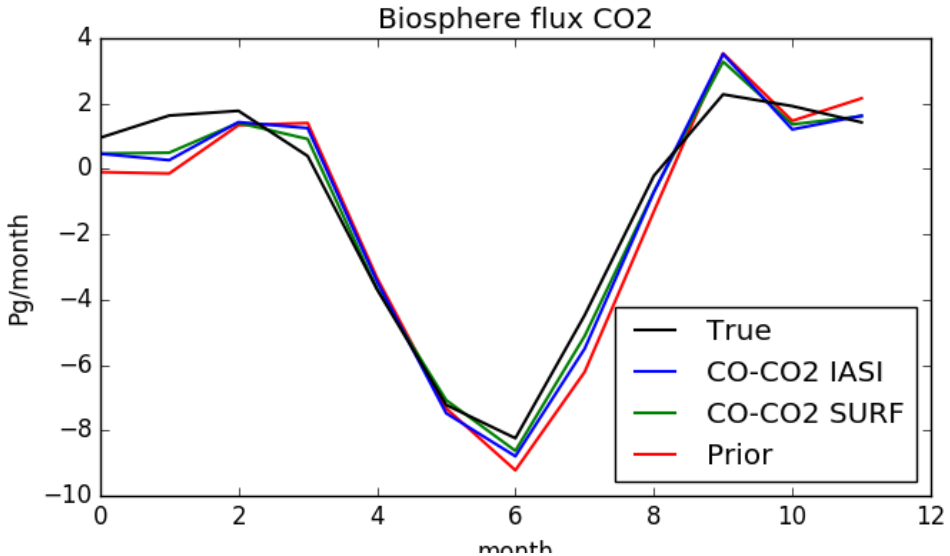

Yearly North America CO2
Pg/yr CO2 Ter (Bio+BB)
Pg/yr Ter (Bio+BB)
−0.2
−0.4
−0.6
−0.8
−1.0
−1.2
0.0
−0.2
−0.4
−0.6
−0.8
−1.0
True
CO-CO2 IASI
CO-CO2 SURF
Prior CO2
True C
CO2 SURFC
CO2 SURF
Prior C

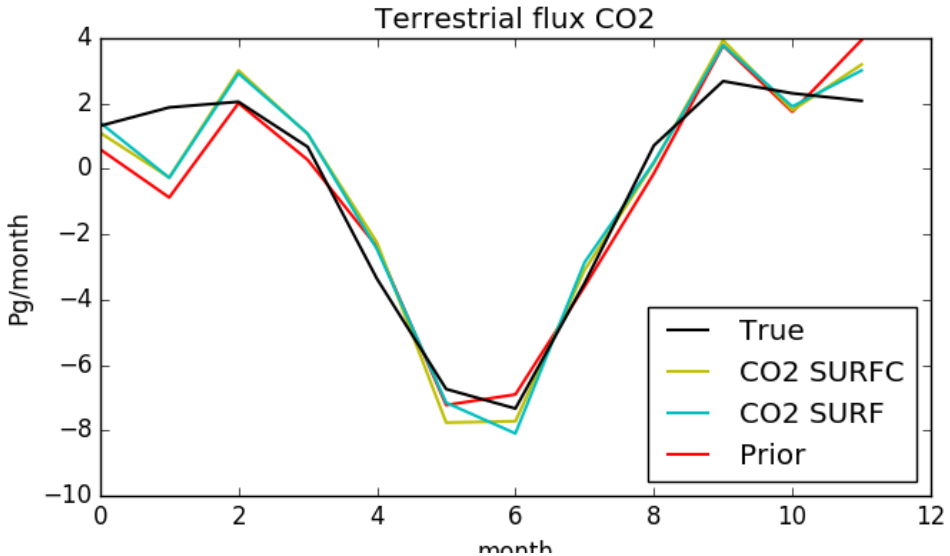

Yearly South America CO
Tg/yr CO BB
19
18
17
16
True
CO-CO2 IASI
CO-CO2 SURF
CO IASI
CO SURF
Prior


Yearly South America CO2
Pg/yr CO2 Ter (Bio+BB)
Pg/yr Ter (Bio+BB)
−3.0
−3.5
−4.0
−4.5
−5.0
−5.5
−6.0
−6.5
0.0
−0.5
−1.0
−1.5
−2.0
True
CO-CO2 IASI
CO-CO2 SURF
Prior CO2
True C
CO2 SURFC
CO2 SURF
Prior C

Emissions


Biomass burning CO emissions
True
CO-CO2 IASI
CO-CO2 SURF
CO IASI
CO SURF
Prior
Tg/month
month


Biosphere flux CO2
True
CO-CO2 IASI
CO-CO2 SURF
Prior
Pg/month
month


Terrestrial flux CO2
True
CO2 SURFC
CO2 SURF
Prior
Pg/month
month

One OSSE

Run	N iterations	Observations	J reduction factor	J gradient reduction factor
CO-CO2 SURF	25	CO, CO_2 surface	4.6	145
CO-CO2 IASI	75 (25)	CO, CO_2 surface CO IASI data	53 (22)	374 (20)
CO SURF	25	CO surface	3.7	2800
CO IASI	25	CO surface, CO IASI	25	38
CO2 SURF	25	CO_2 surface	4.4	385
CO2 SURFC	25	CO_2 surface from CO_2 model run with true emissions	14	500

Conclusions & Plans

We have a working CO-CO_2 inversion system.

More tests needed to ensure the coupled system performs well

First test show that:

- CO-CO2 inversions and CO-only inversions have a similar performance capturing CO
- CO_2 is more tricky, none of the simulations perform very well. Issue? Not enough constraints? No iterations?
- CO-CO2 inversion performs in some regions better than CO2-only due to the extra constraint on CO

Future plans:

- Setup a set of Monte-Carlo OSSE inversions, with focus on one region (zoom)
  - Use CO_2 satellite obs?
  - Look at the ability to capture interannual variability
- Optimize EF either per biome, or use Thijs parameterizations