Setting up a coupled Carbonyl Sulfide (COS) – CO_2 4DVAR inversion system

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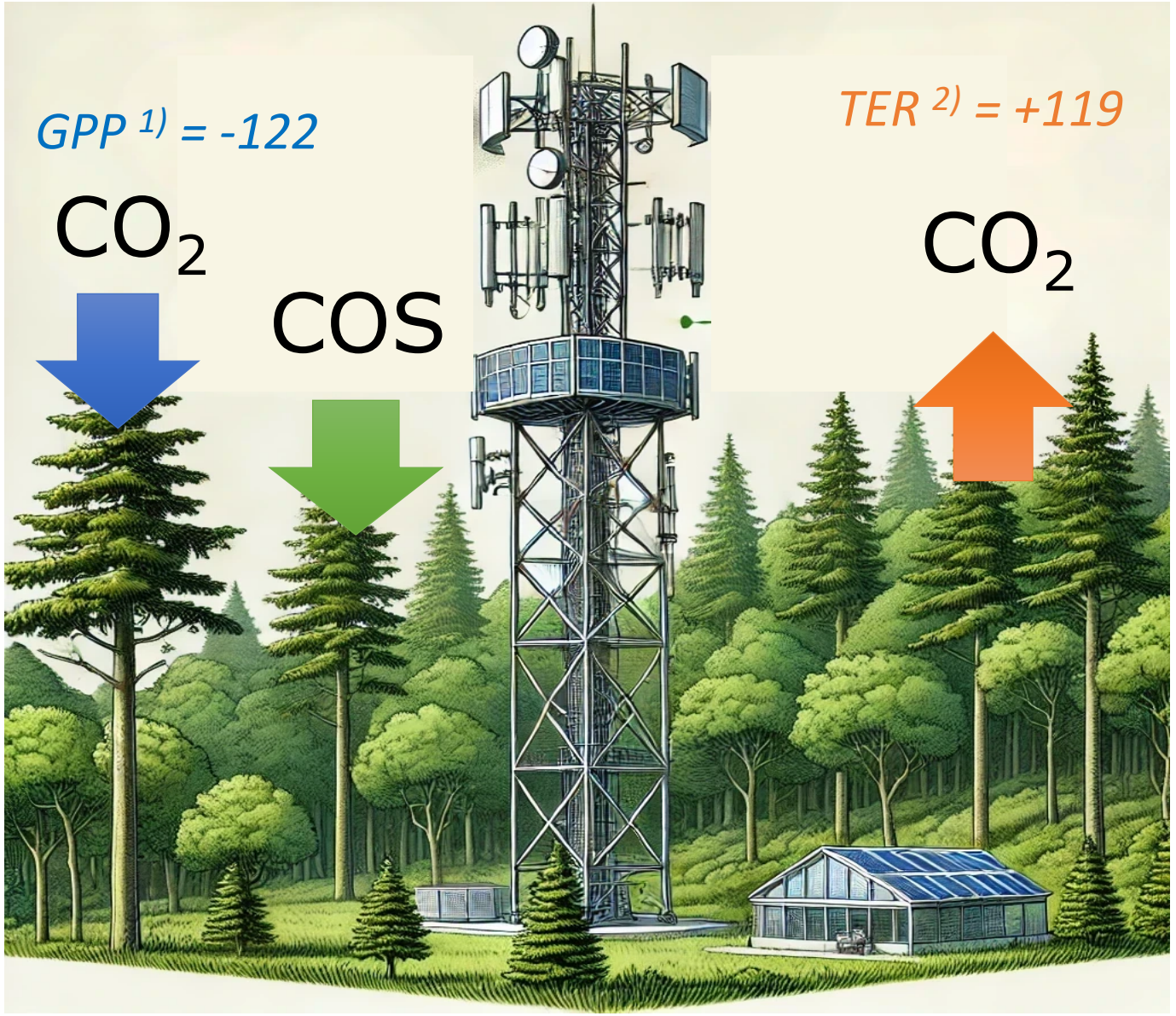
Introduction

Unit: Pg C yr^{-1}



CO_2 Net ecosystem exchange (NEE)

= 119 – 122 = **- 3 Pg C yr $^{-1}$**

change!

Significant changes in CO_2 budget

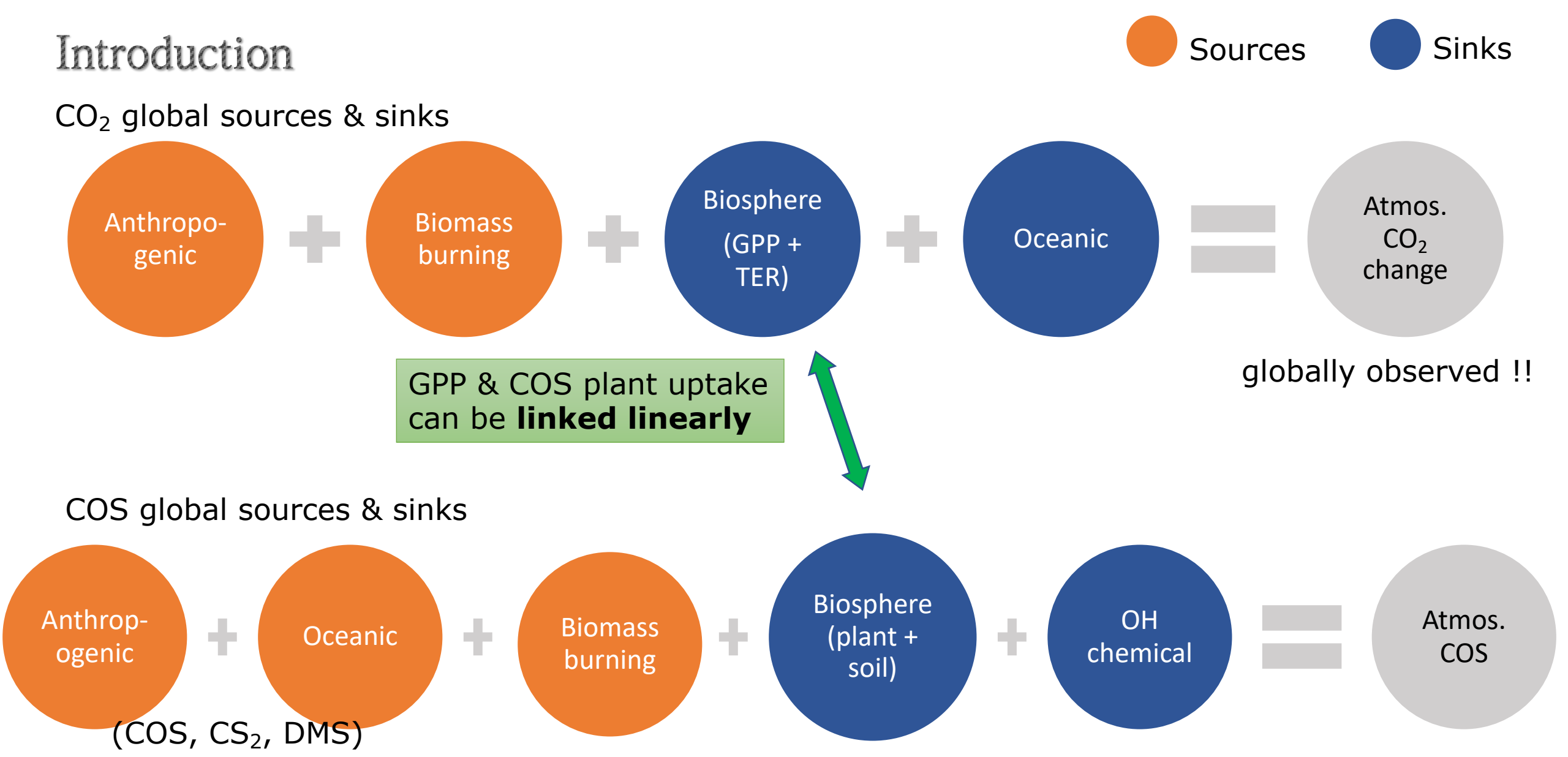
➔ Important to calculate GPP accurately

COS shares the leaf uptake pathway with CO_2,
but is not released!

➔ COS is a promising tracer for estimating GPP

1) GPP = Gross Primary Production
2) TER = Terrestrial Ecosystem Respiration

Introduction



Questions

1. Can we achieve a balanced budget for CO_2 and COS by performing an inversion of the coupled system?

2. Can we identify the unknown sources of COS in tropical and high-latitude regions of the Northern Hemisphere using CO_2 data?

3. Can COS provide new insights into the global CO_2 budget?

Goal

➔ Develop a coupling system using TM5 4D-Var.

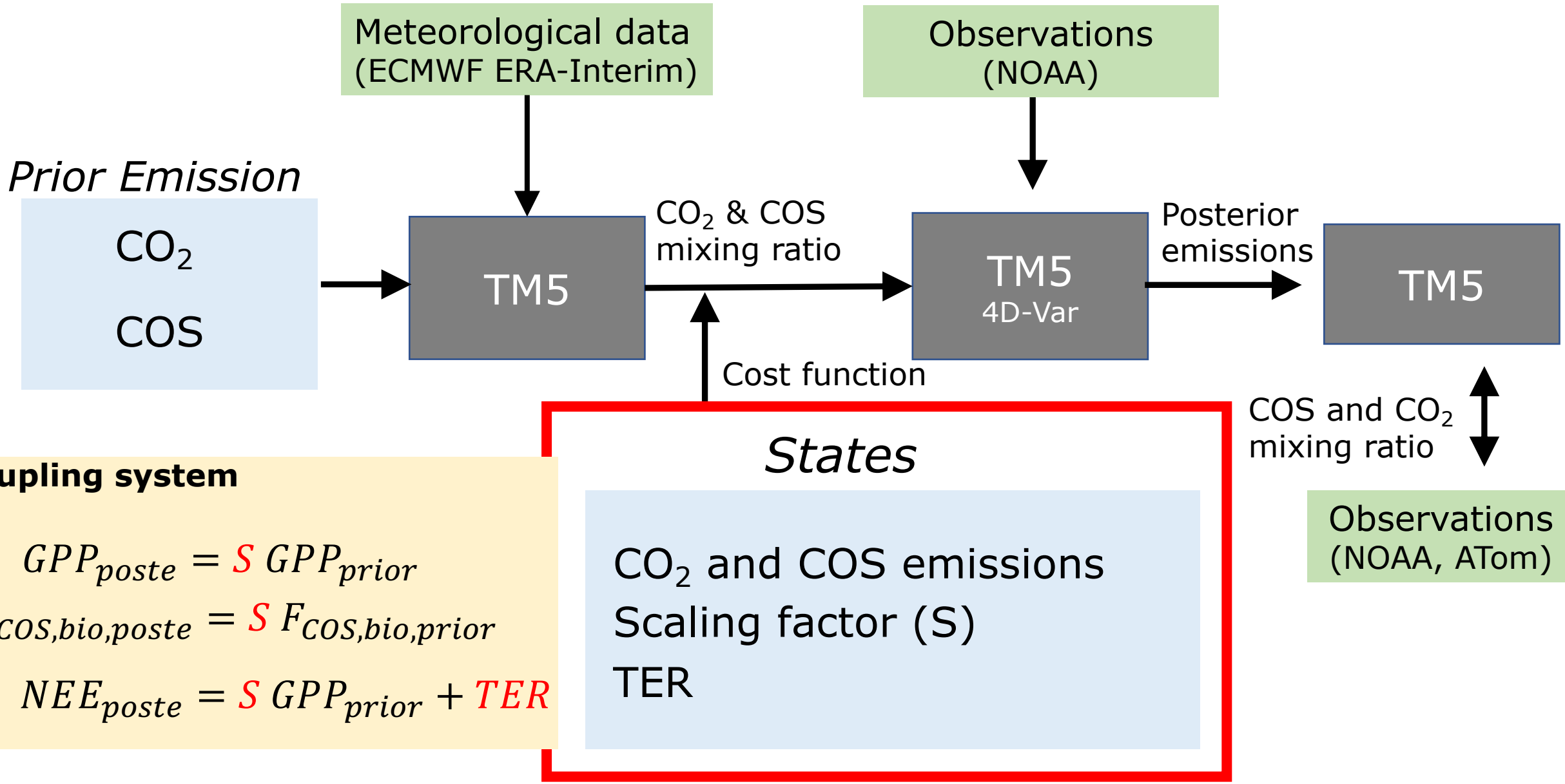
➔ Evaluate scenarios with different settings of COS emissions

- Optimize all / Only oceanic & biosphere / with larger prior biosphere flux

➔ Compare results with single optimized results (CarbonTracker, Ma et al., 2021)

Methods

Coupled 4DVAR inversion system



Coupling system

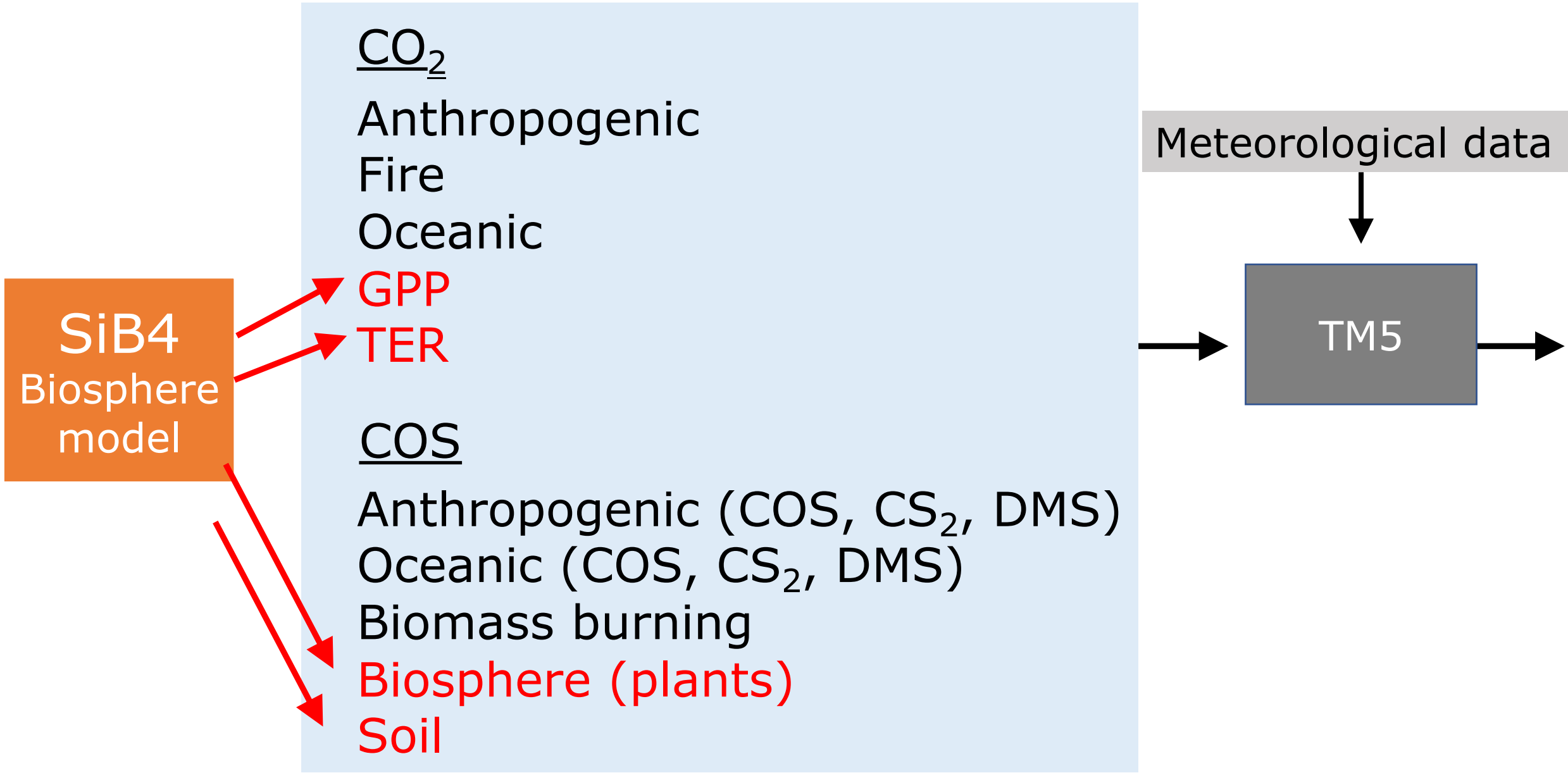
$$GPP_{poste} = S\, GPP_{prior}$$

$$F_{COS,bio,poste} = S\, F_{COS,bio,prior}$$

$$NEE_{poste} = S\, GPP_{prior} + TER$$

Methods

Prior Emission



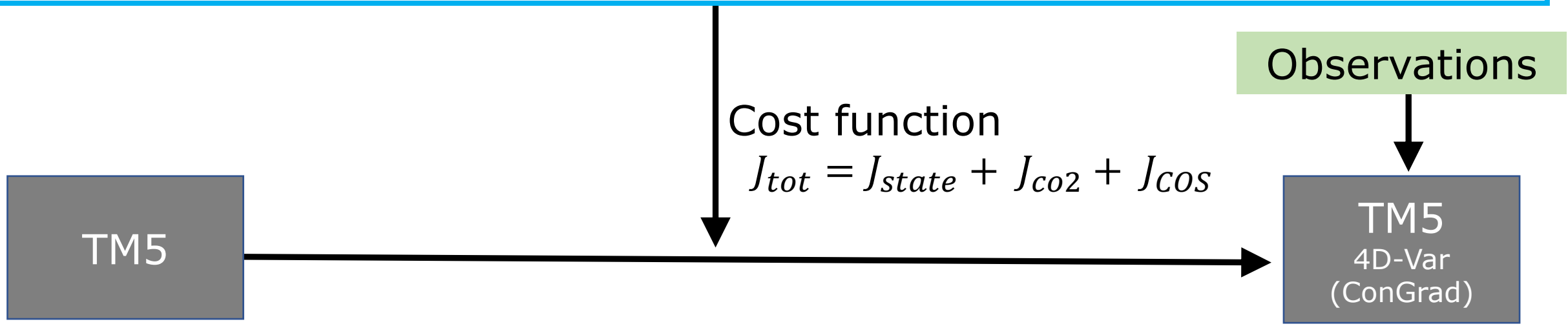
Methods

State variables

Scaling factor (S), TER, COS and CO_2 emissions

CO_2 anthropogenic and fire, COS Soil, and DMS were fixed

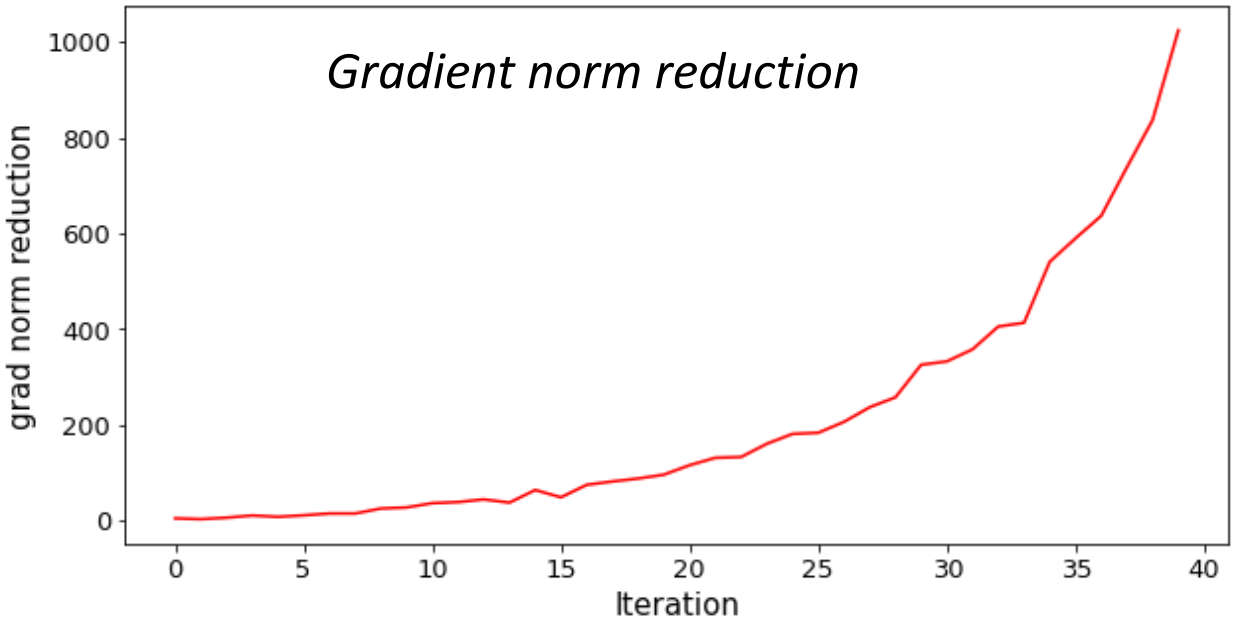
Error : S = 10 %, TER = 5 %, other emissions = 100 %

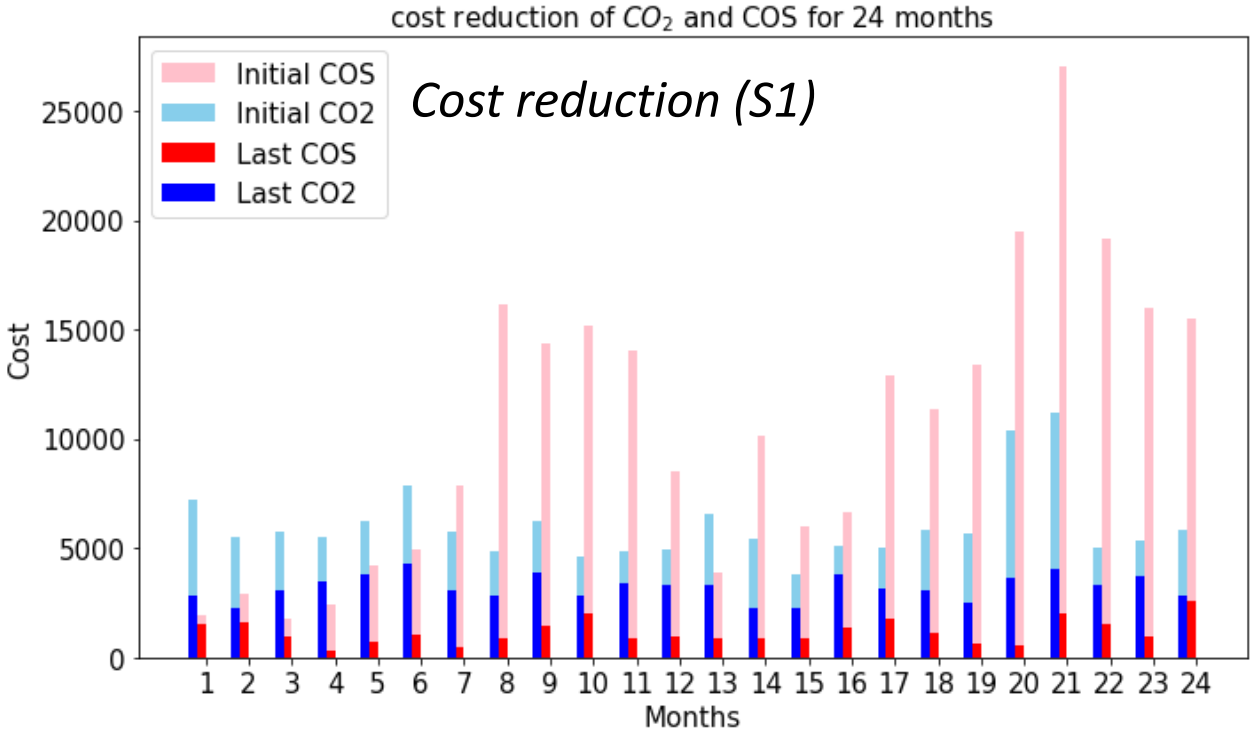


Results 1.1. Convergence

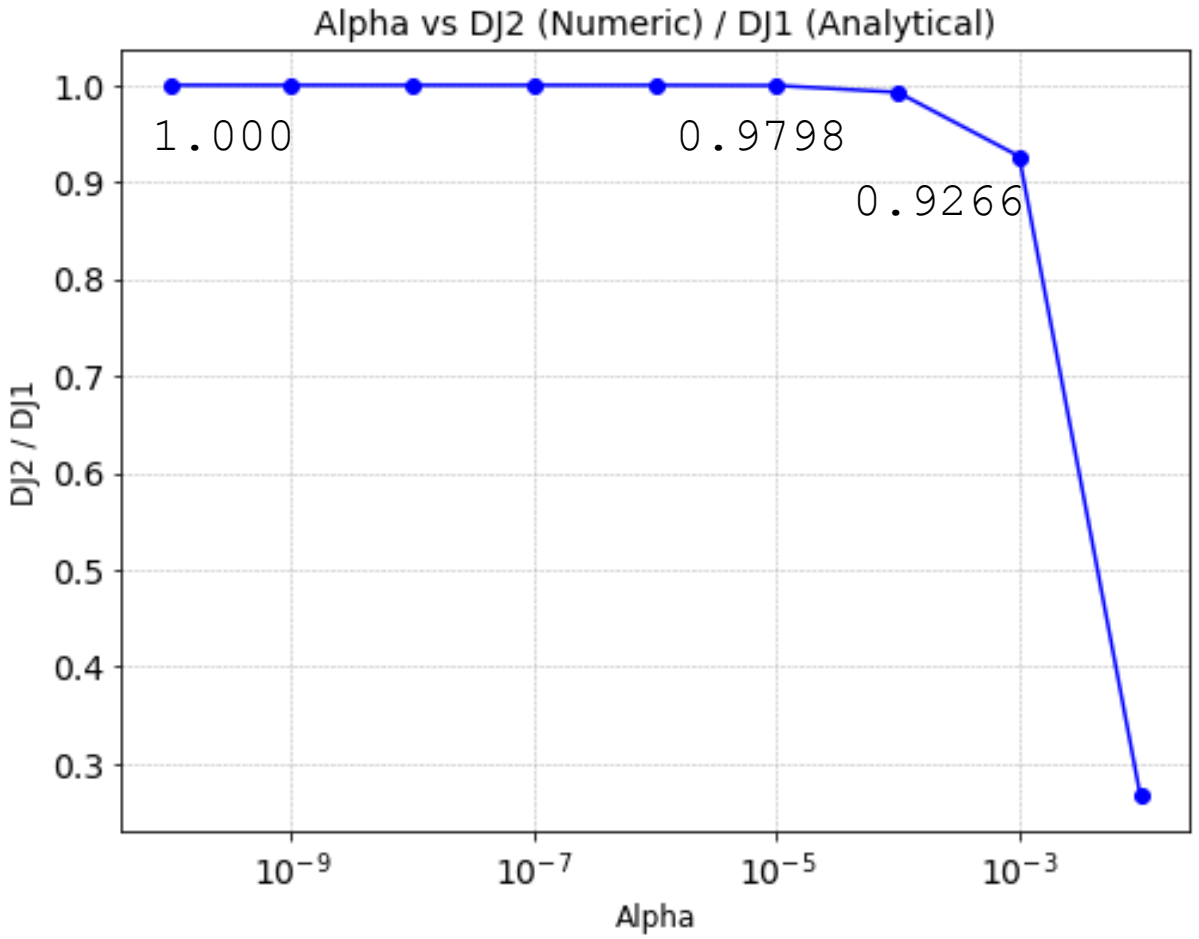
Simulation period: Jan, 2016 – Dec, 2017

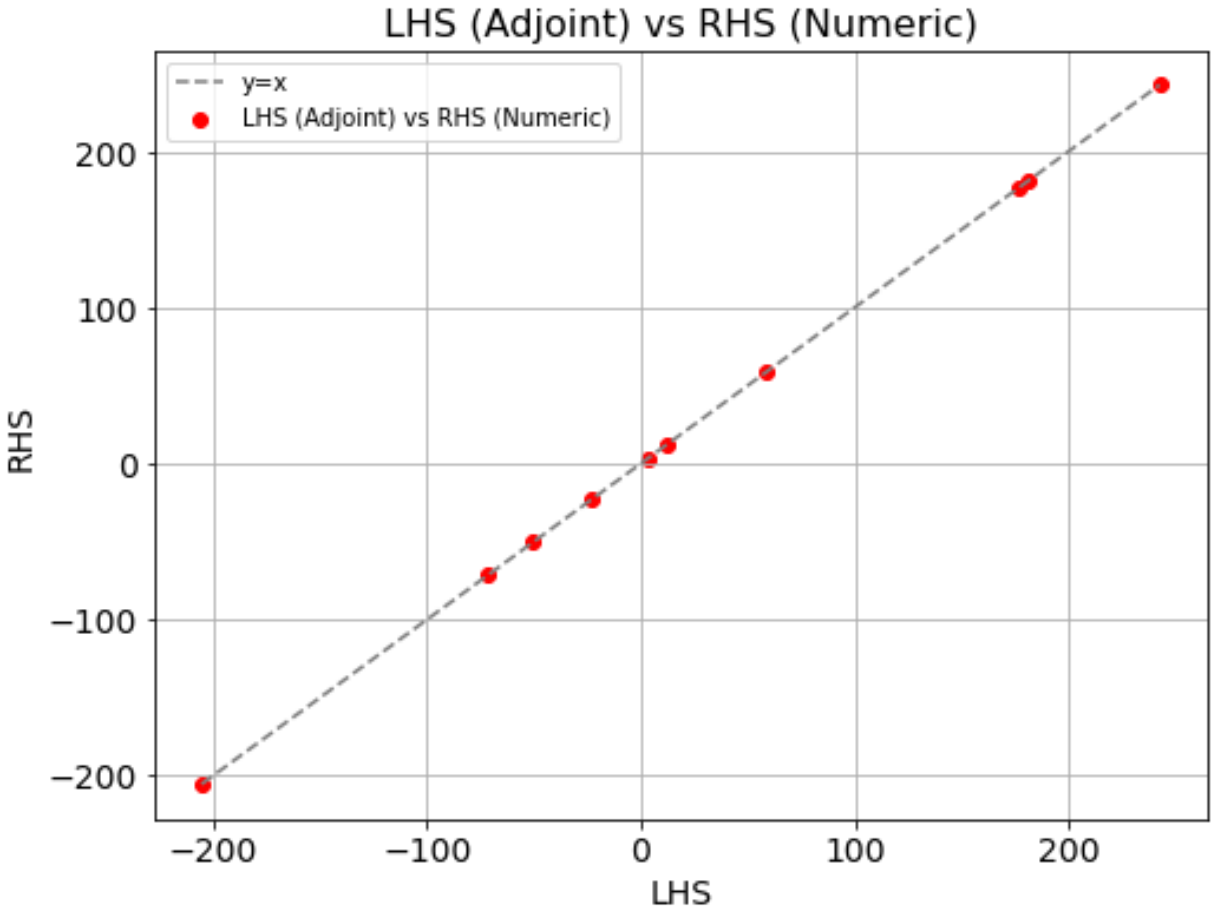
Analysis period : Jul, 2016 – Jun, 2017



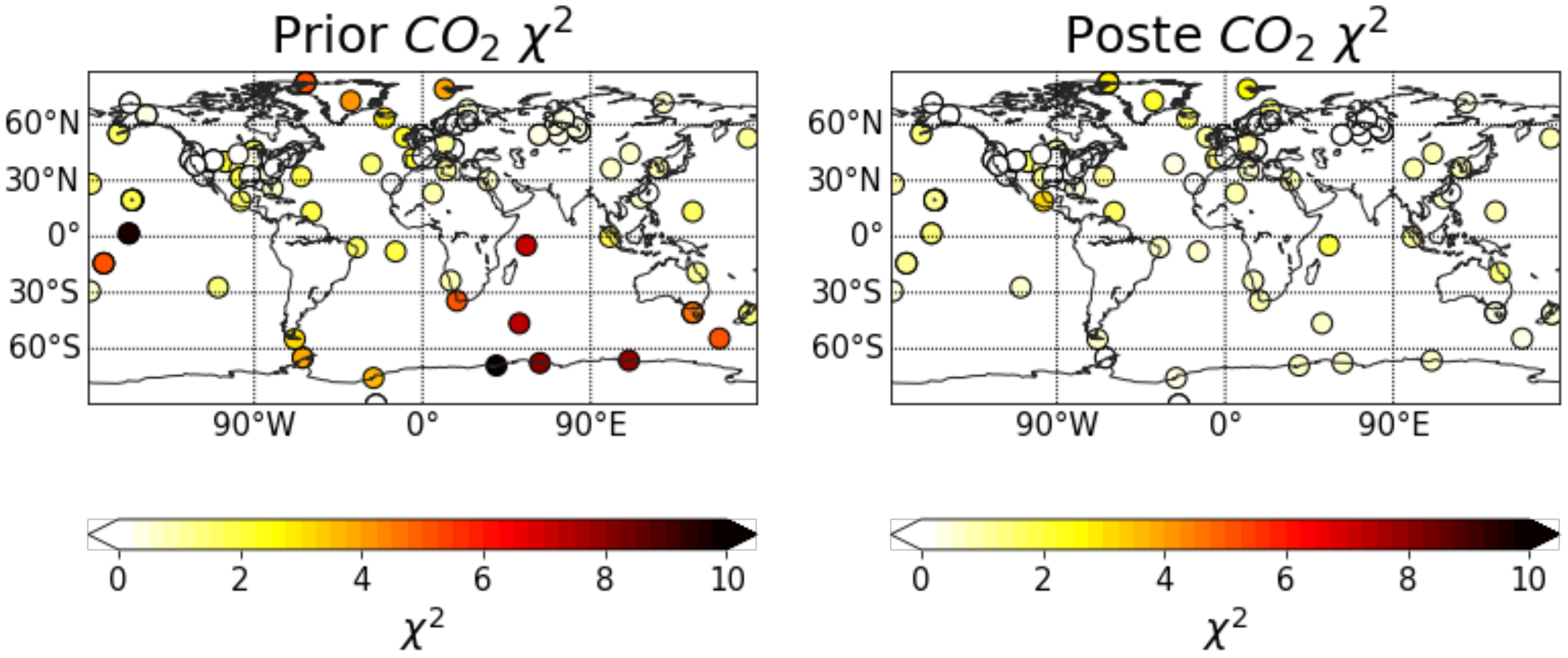


1.2. Gradient test and Adjoint test (Simulation for a month)



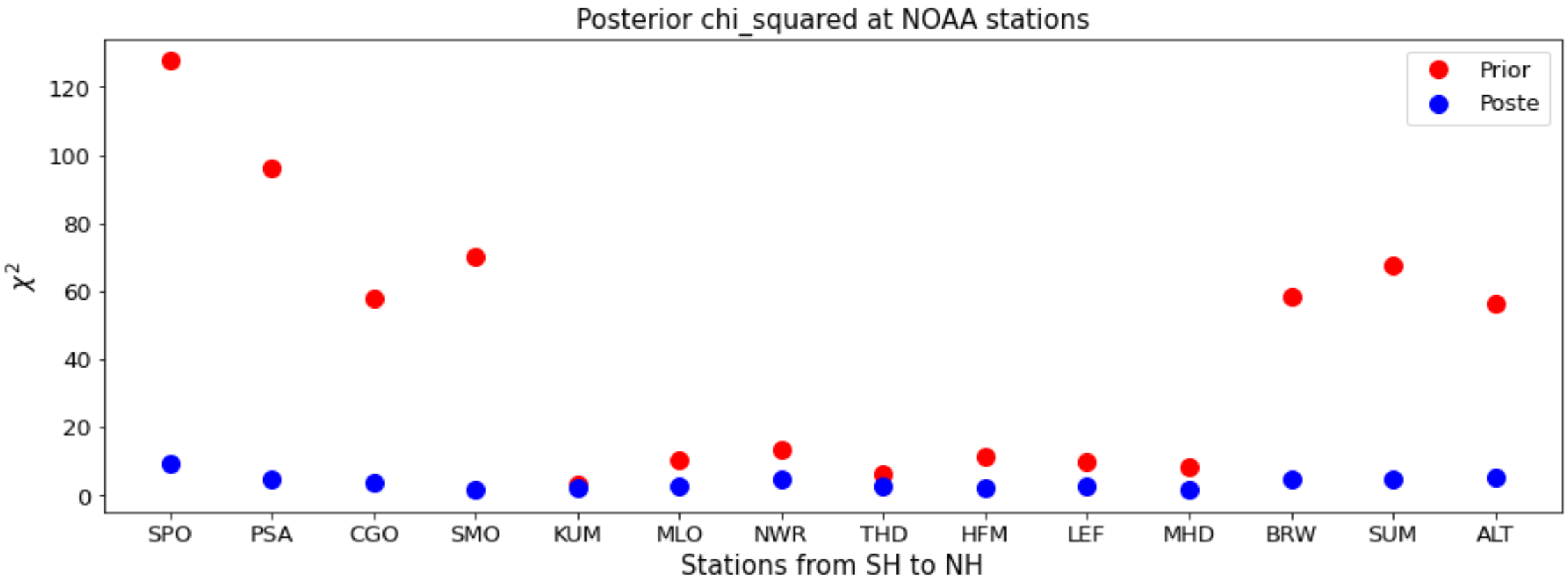


Results 2. Chi-squared values; CO_2



Results 2. Chi-squared values; COS

COS χ^2
Prior = 36.2 (S1)
Poster = 3.6 (S1), 5.2 (S2), 4.5 (S3)

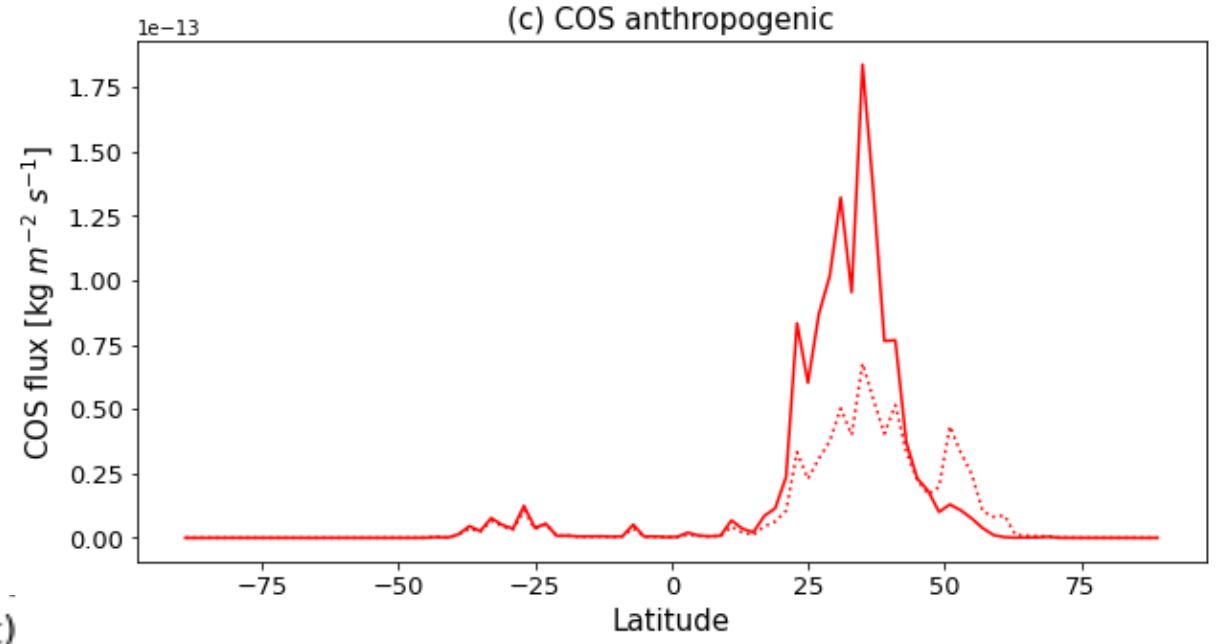


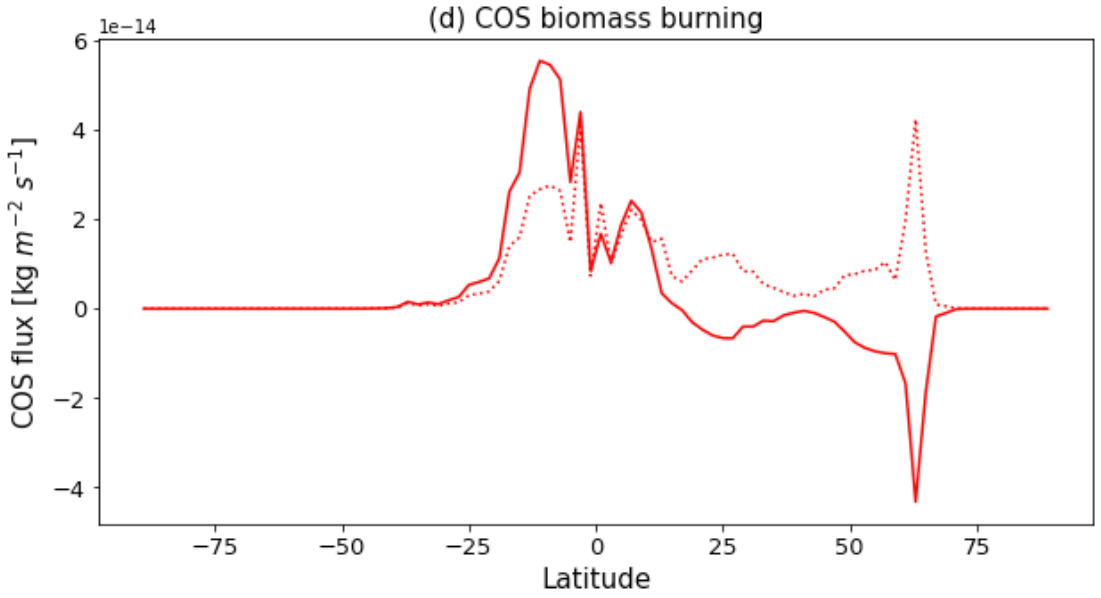
Results 3. COS flux

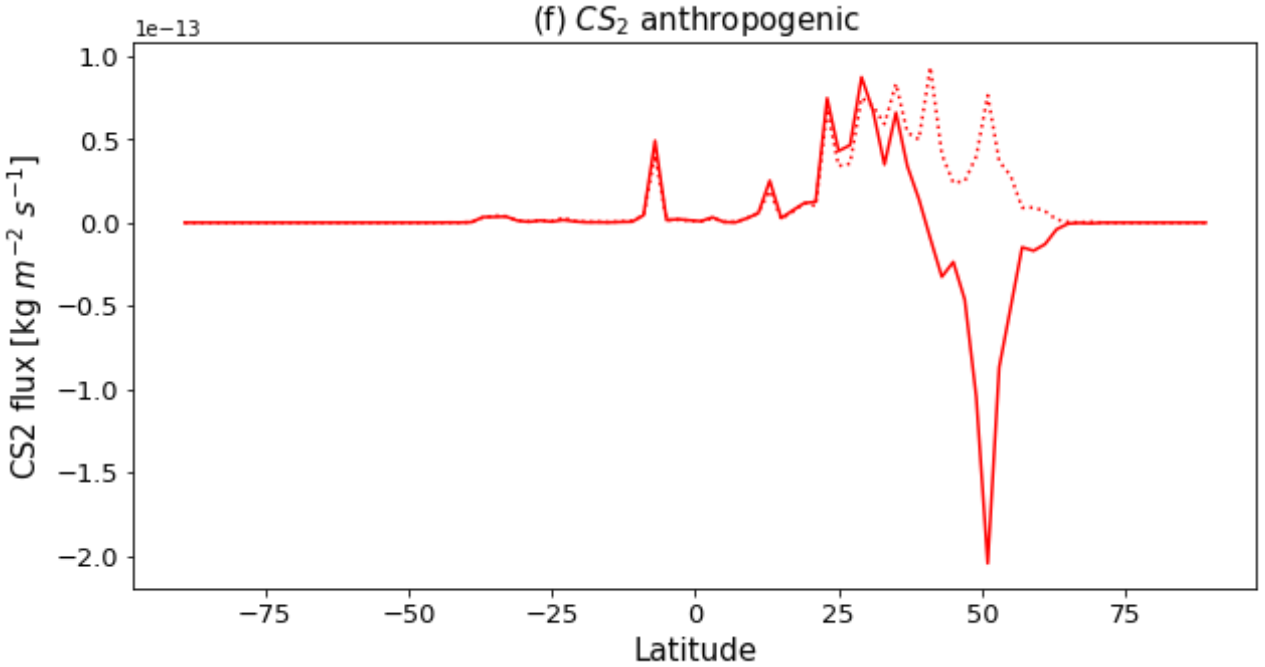
Biomass burning: S1 shows negative values in the NH.

Anthropogenic emission: More than doubled in mid latitudes.

CS_2 anthropogenic: S1 shows negative values in the NH.







Conclusion

We assumed CO_2 and COS are absorbed via a similar uptake pathway in plants, leading to a linear relationship.

The coupled system effectively reduced CO_2 and COS costs, showing better alignment with observed data compared to previous models.

While it increases the oceanic CS_2 flux in the low latitudes, it does not resolve the lack of COS sinks in the high-latitude northern hemisphere.
This may be due to
underestimated biosphere flux,
a non-linear uptake relationship, or **other unknown COS sinks**.

More work (e.g. applying weights in the COS cost) is needed to study the joint exchange of CO_2 and COS with the biosphere.

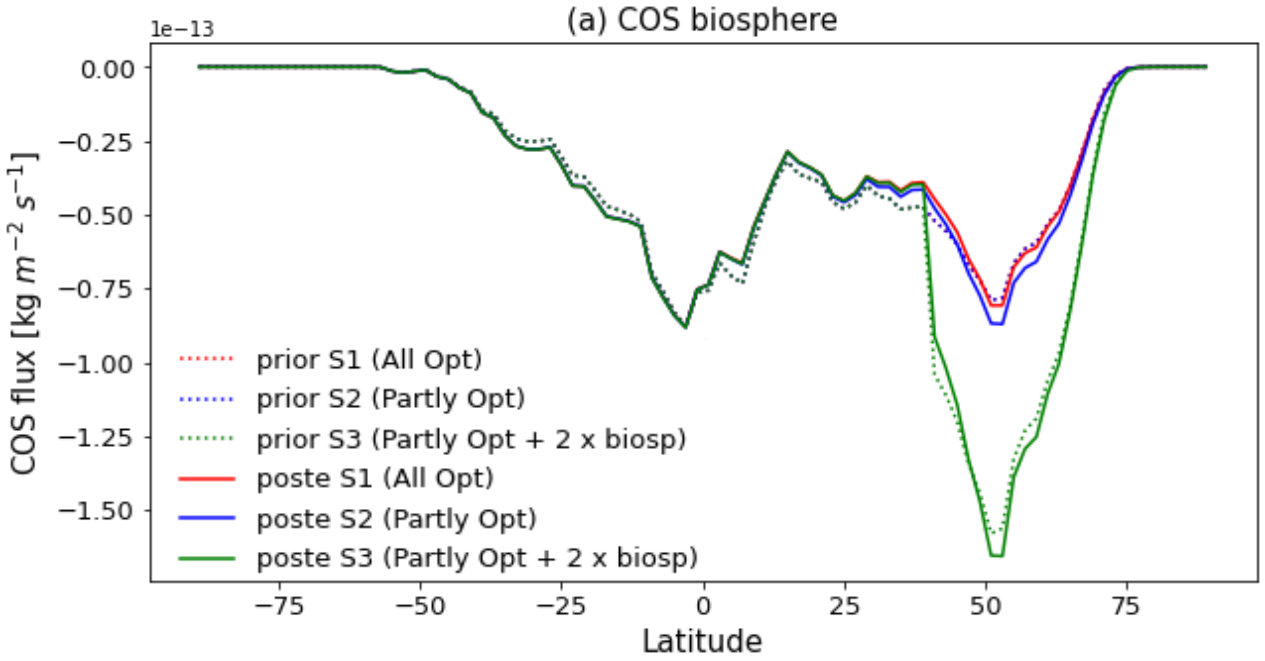
Thank you! ara.cho@wur.nl

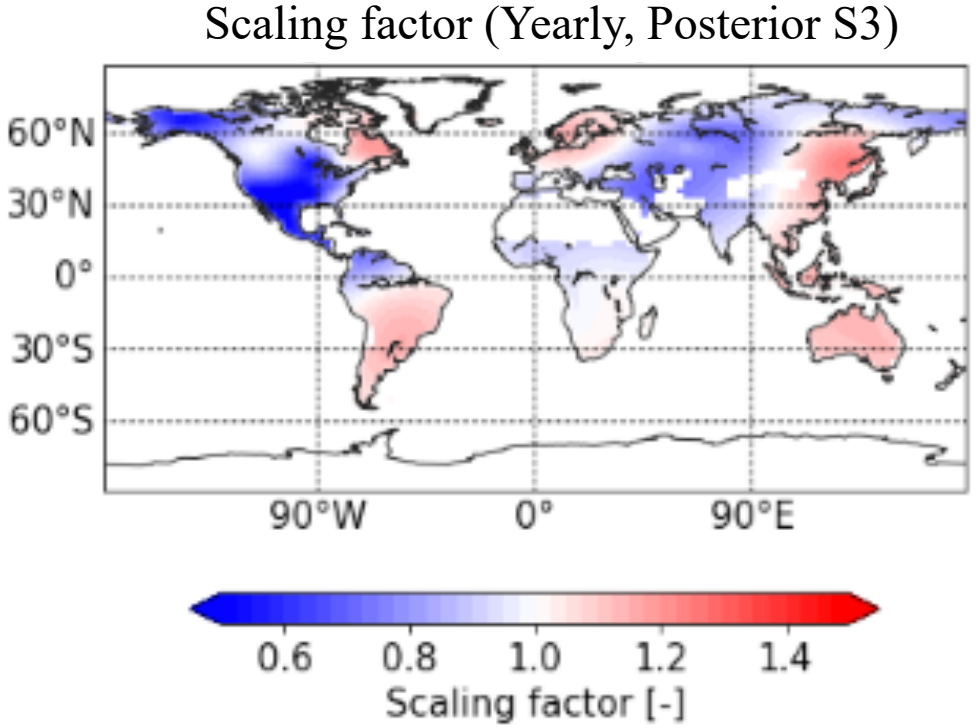
Appendix

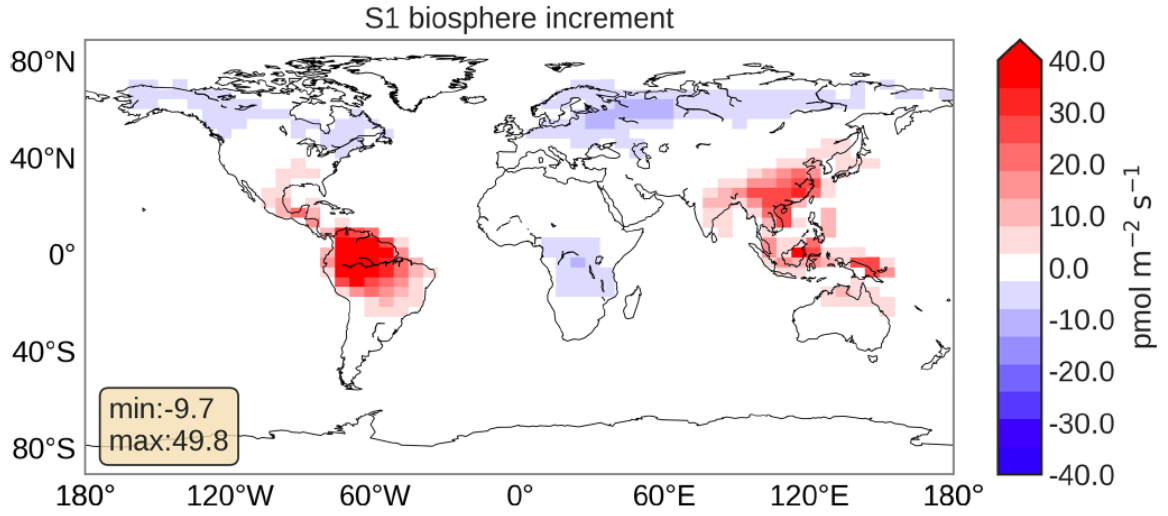
Results 3. COS flux

Biosphere flux: small changes vs. prior.

Different spatial distribution of biosphere increments compared to uncoupled optimization. → CO_2 effect





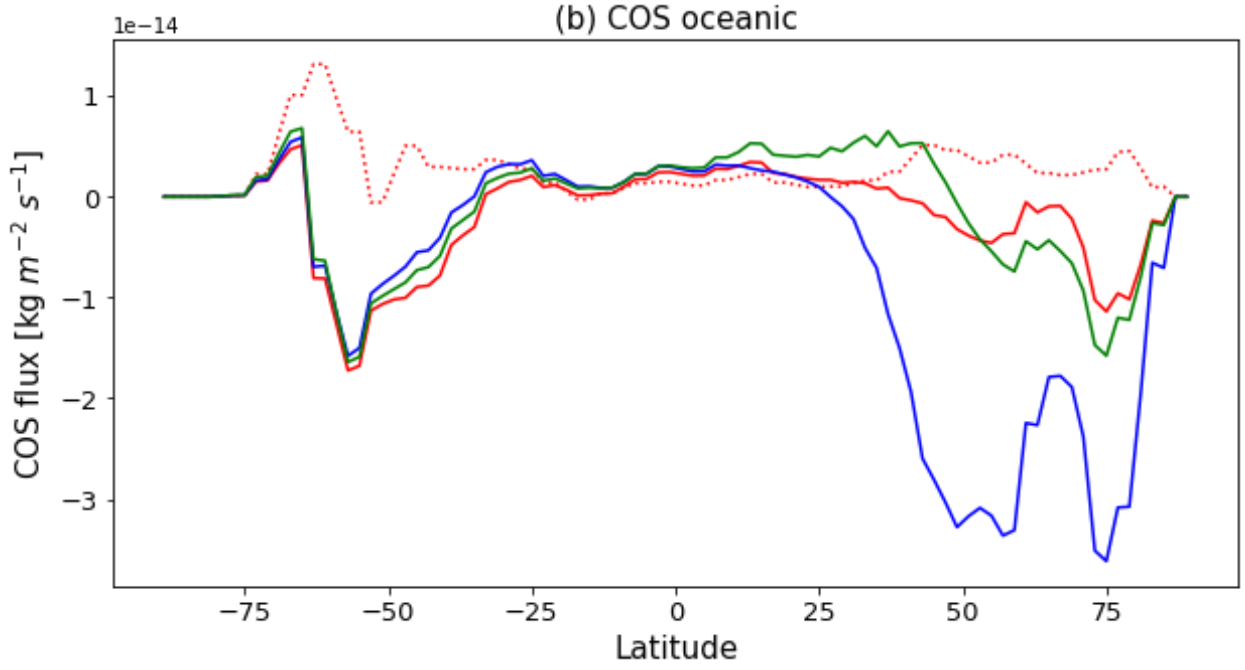


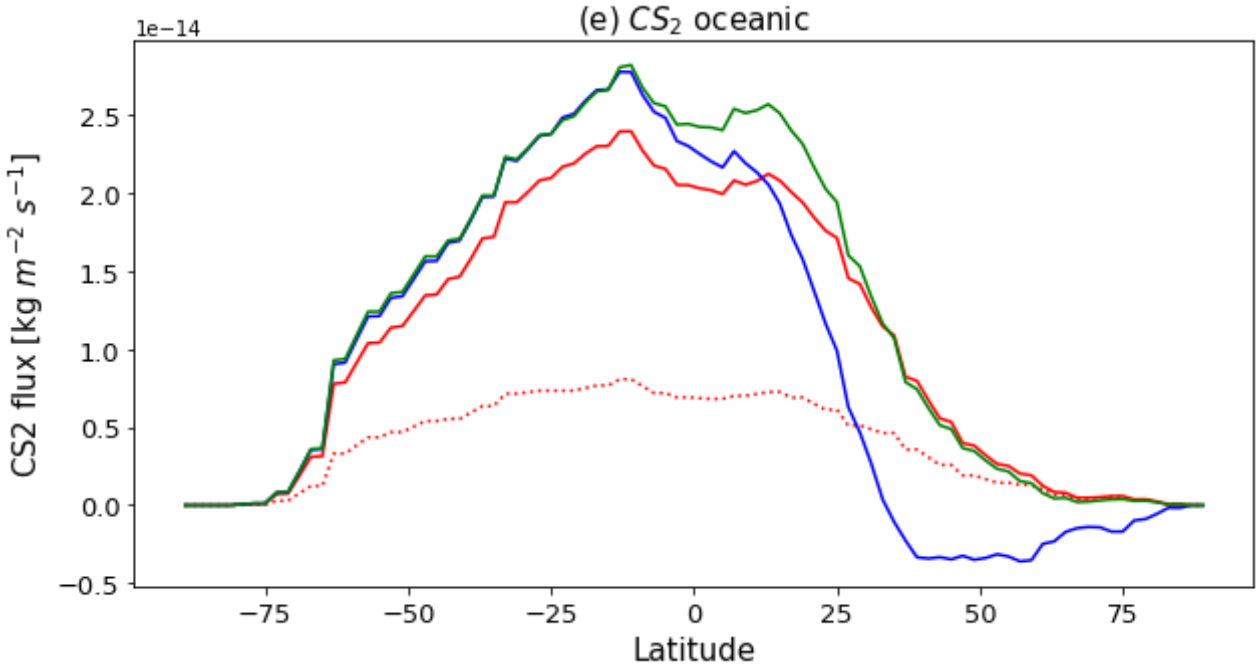
Ma et al. (2021)

Results 3. COS flux

Oceanic flux: S2 shows large sink in NH high latitudes.

CS_2 oceanic: More than doubled vs. prior, S2 shows negative values.

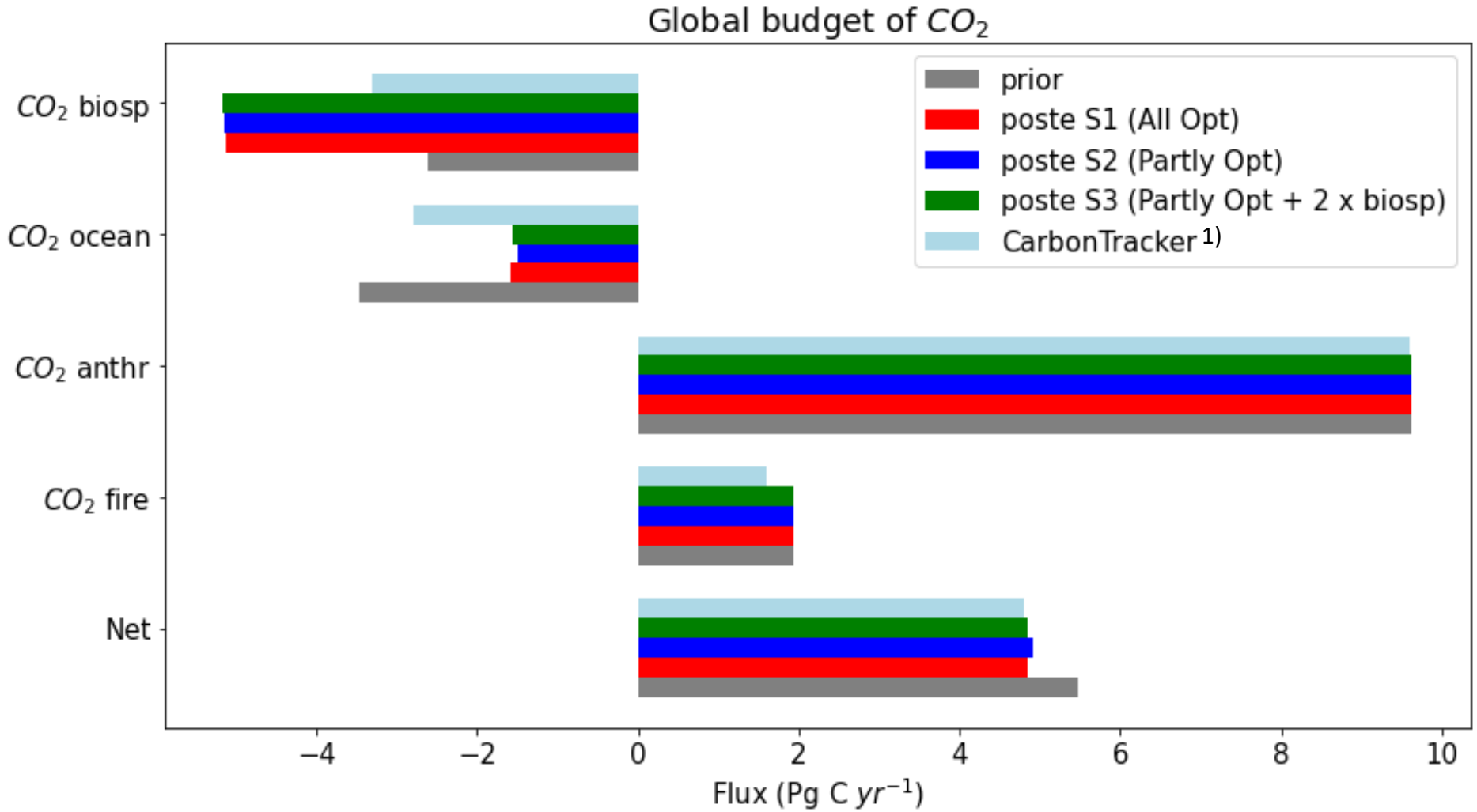




prior S1 (All Opt)
prior S2 (Partly Opt)
prior S3 (Partly Opt + 2 x biosp)
poste S1 (All Opt)
poste S2 (Partly Opt)
poste S3 (Partly Opt + 2 x biosp)

Results 4. CO_2 flux; global budget

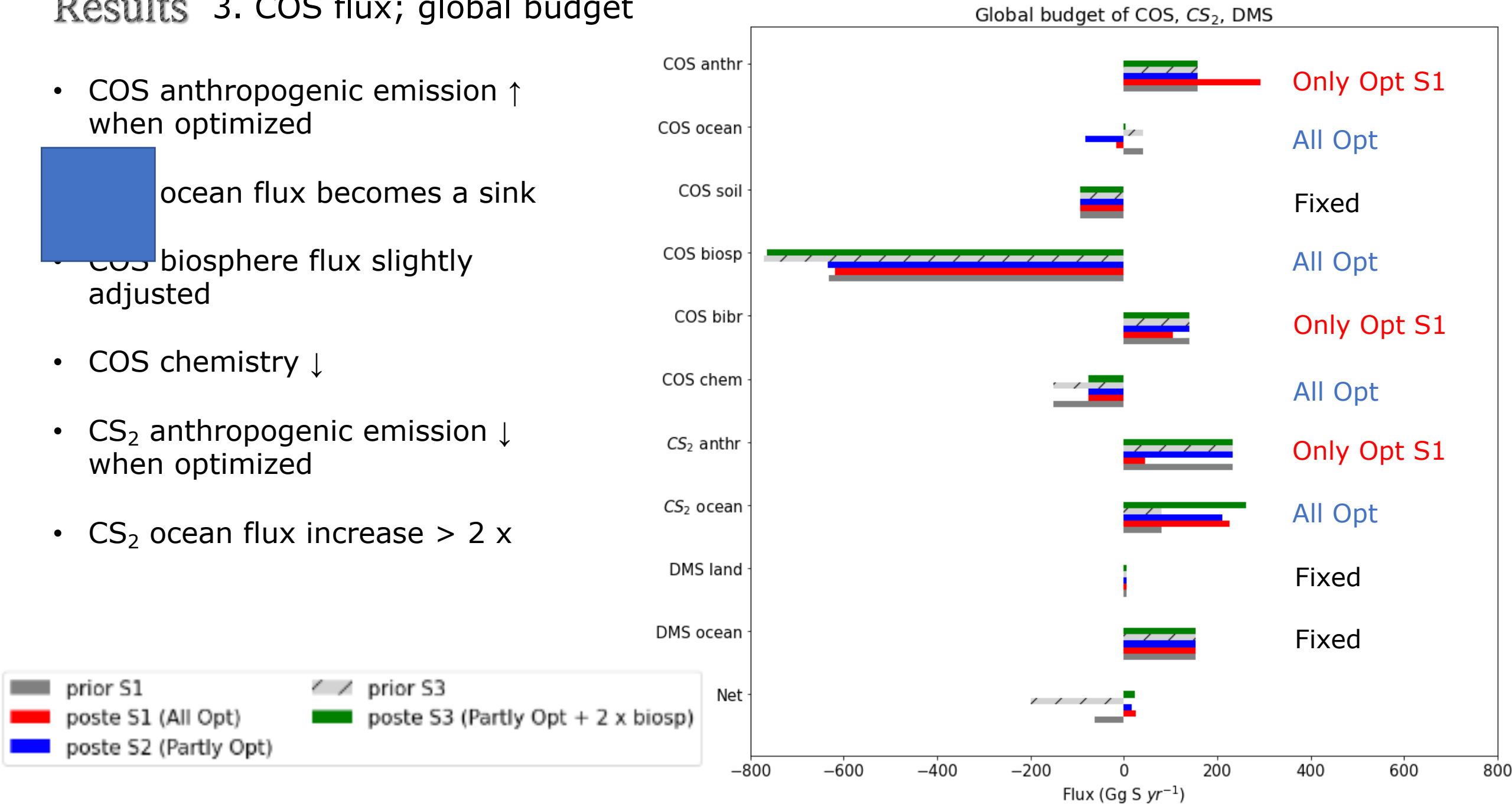
- Posterior models optimized biosphere flux larger and oceanic flux smaller than Carbon Tracker [1].



1) Friedlingstein et al., 2023

Results 3. COS flux; global budget

- COS anthropogenic emission ↑ when optimized
- ocean flux becomes a sink
- COS biosphere flux slightly adjusted
- COS chemistry ↓
- CS_2 anthropogenic emission ↓ when optimized
- CS_2 ocean flux increase > 2 x



Results 3. COS flux at 50 ~ 90 N

- S1 optimized negative CS_2 & reduced COS anthropogenic values show seasonal variation.
- A sink is needed year-round, especially larger in August and September.