Constraining the large spread future ocean carbon sinks in ESMs

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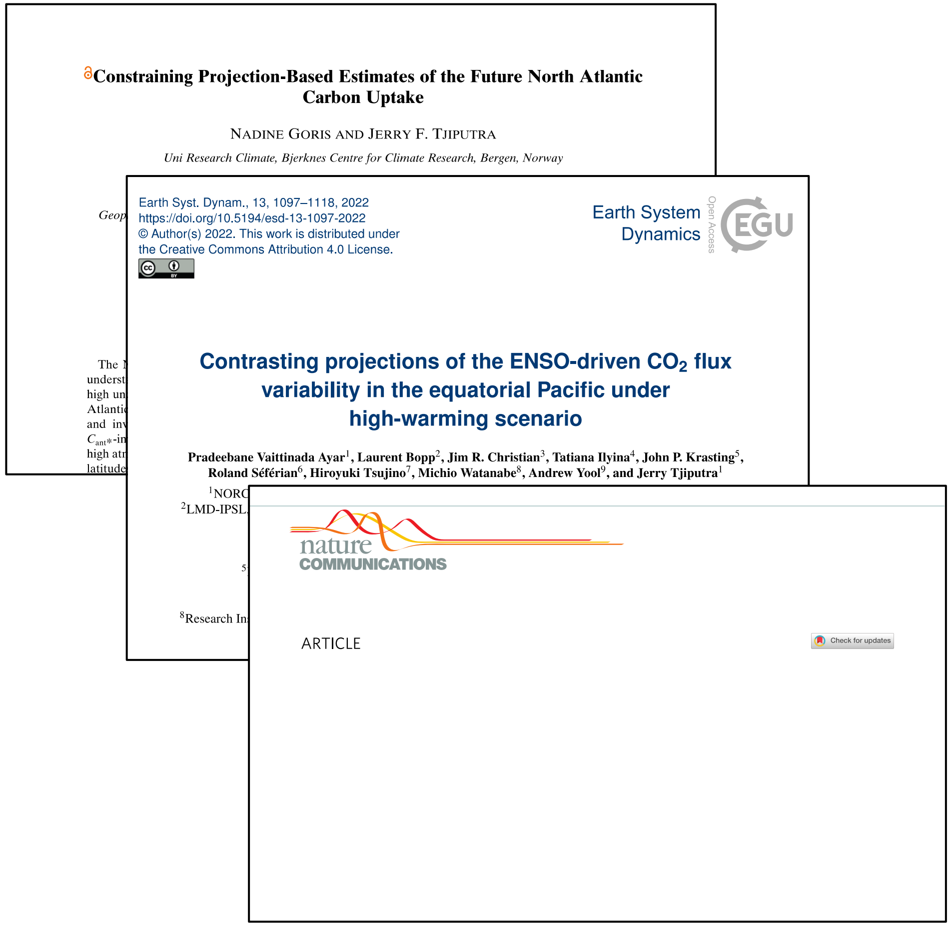
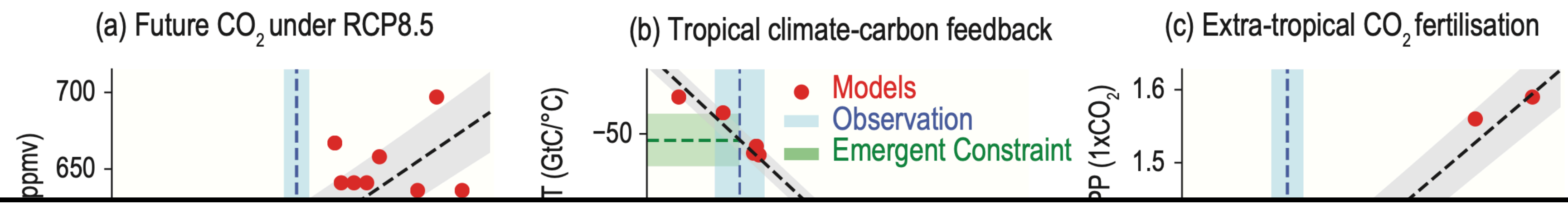


ECMWF 6th WGNE workshop on systematic errors in weather and climate models, Reading, UK

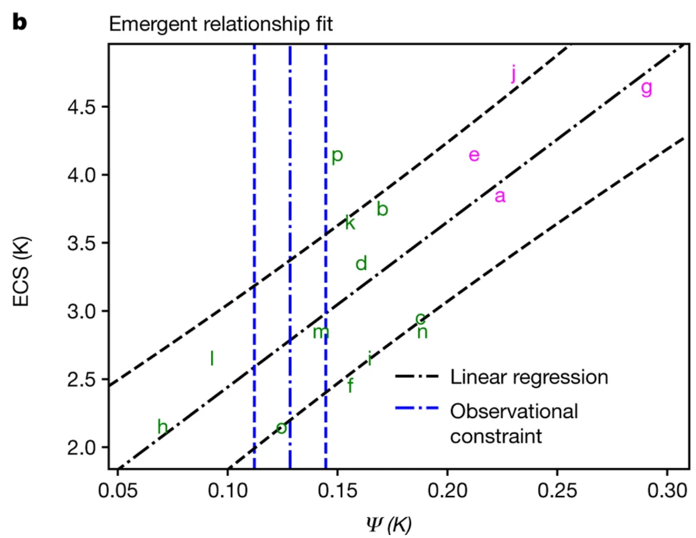
Emergent Constraint

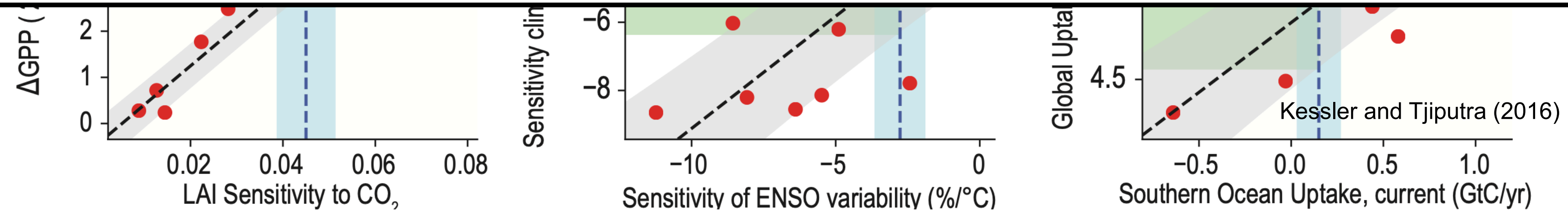


Rational:

- There often exist <u>systematic biases</u> in models
- That are <u>quasi-linearly</u> linked to observable metrics
- Together they provide insights to root of <u>projection uncertainties</u>
- Guidance for future <u>model developments</u>
- Feed back the <u>observing community</u> (process understanding)

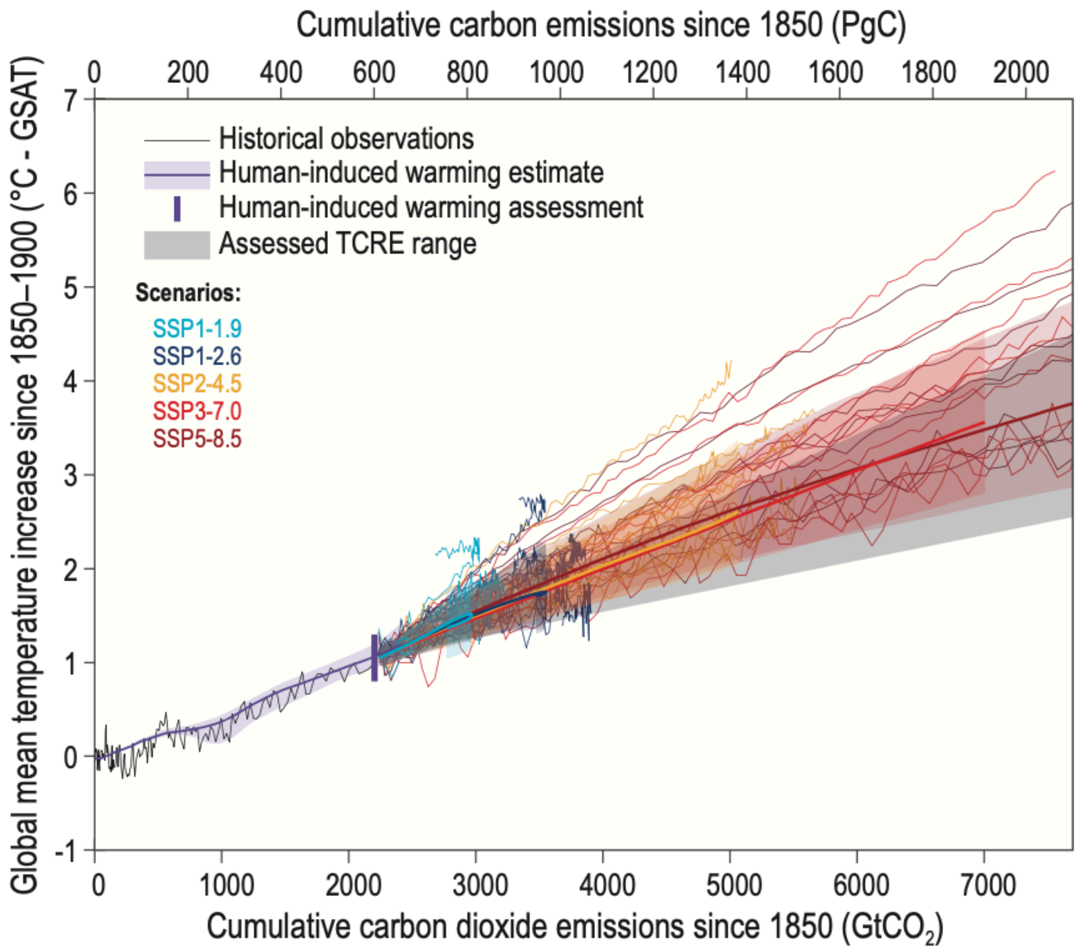
Cox et al. (2018)

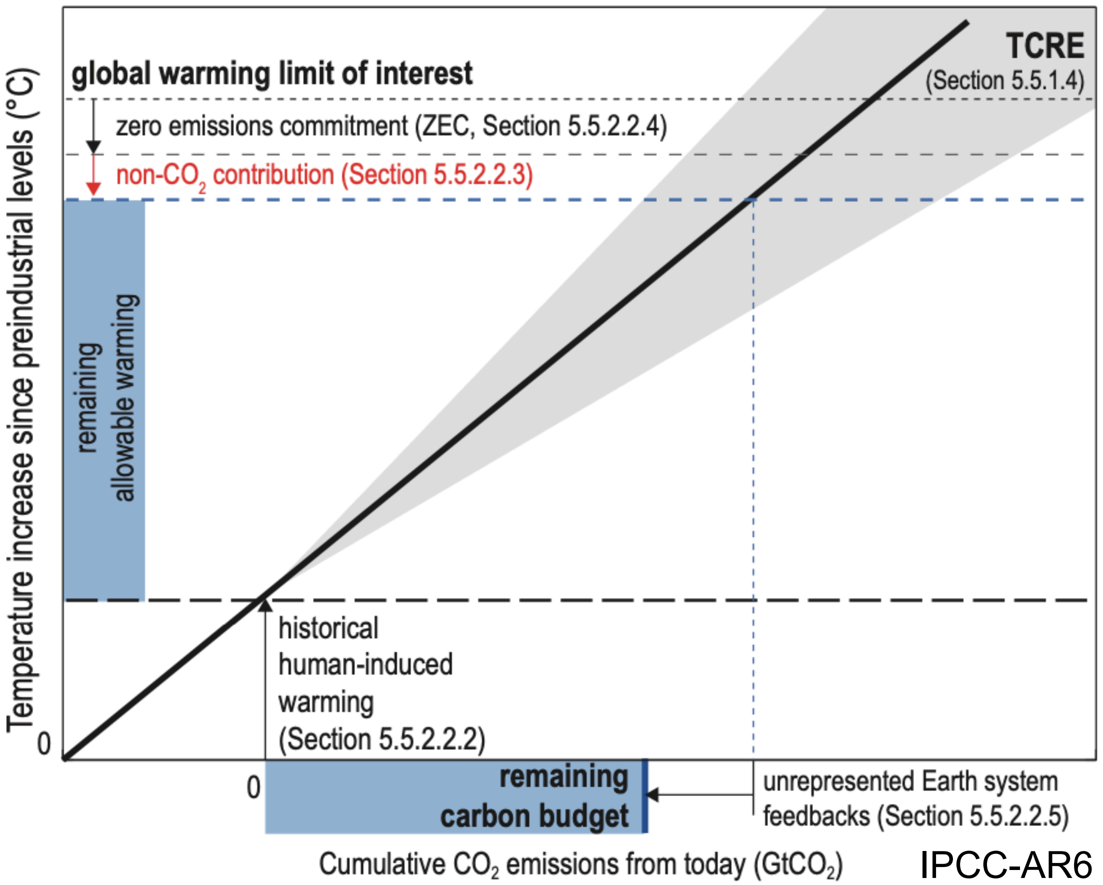




IPCC-AR6

› Understanding and limiting the spread of ocean carbon sink projections are crucial to
- effectively guide the development of climate mitigation policies,
- determine an accurate future carbon budget,
- constrain CO_2 and climate change projections.





IPCC-AR6

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GLOBAL CARBON project

Fate of anthropogenic CO_2 emissions (2011–2020)

Sources = Sinks

34.8 $GtCO_2$/yr

89%

11%

4.1 $GtCO_2$/yr

18.6 $GtCO_2$/yr

48%

29%

11.2 $GtCO_2$/yr

26%

10.2 $GtCO_2$/yr

Budget Imbalance:
(the difference between estimated sources & sinks)

3%
-1.0 $GtCO_2$/yr

Source: Friedlingstein et al 2021; Global Carbon Project 2021

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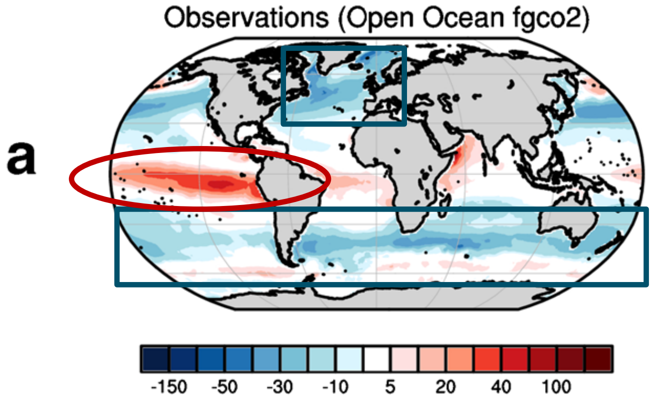
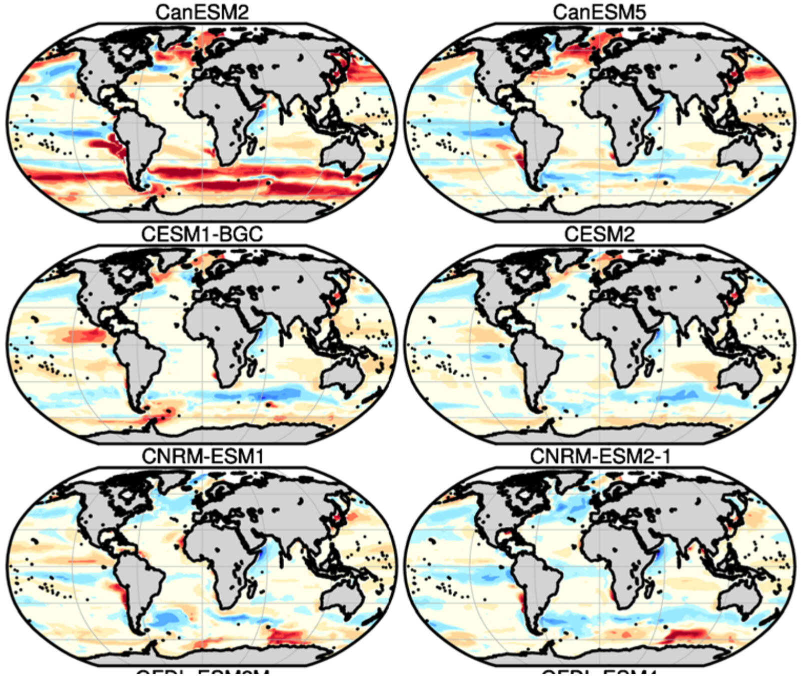
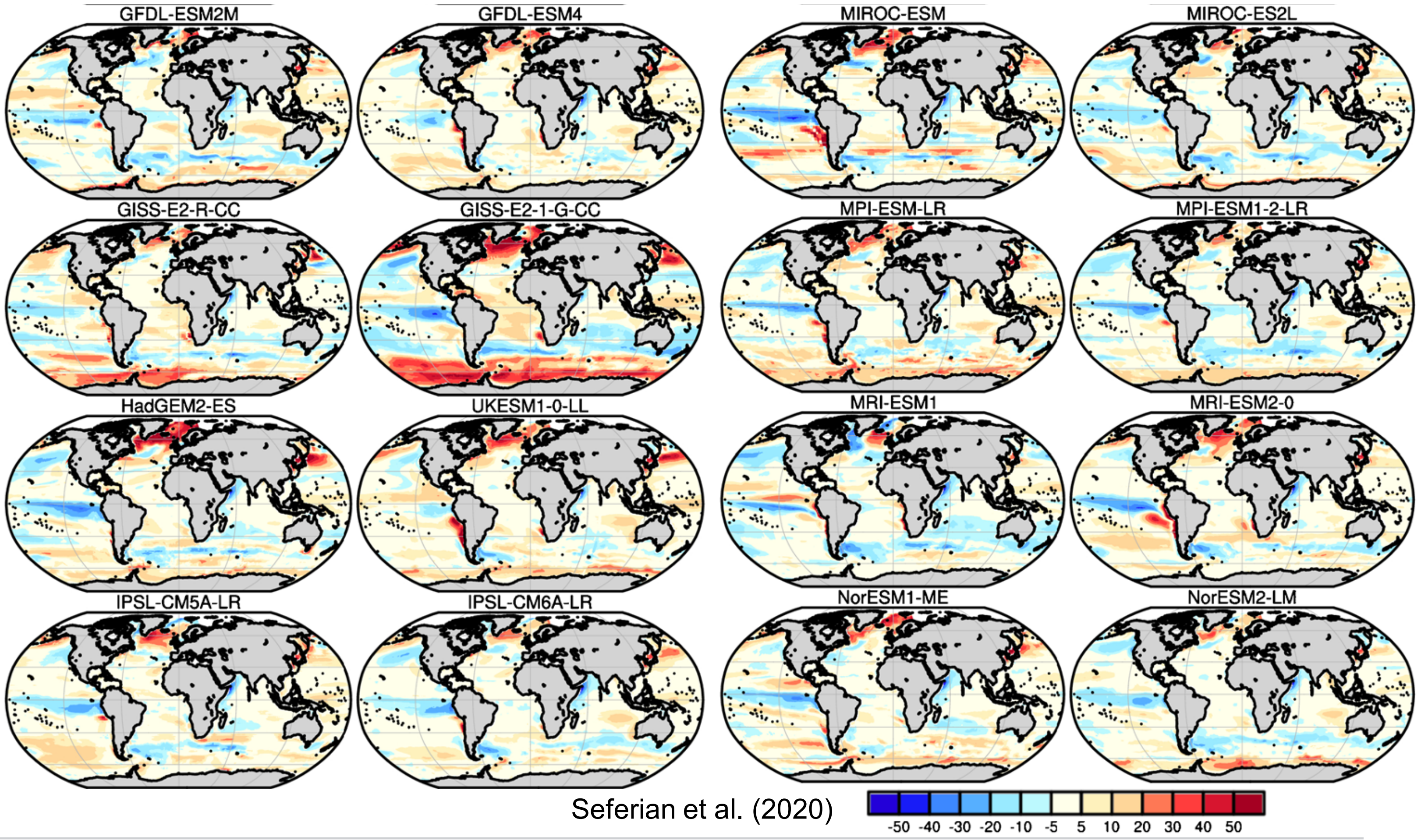
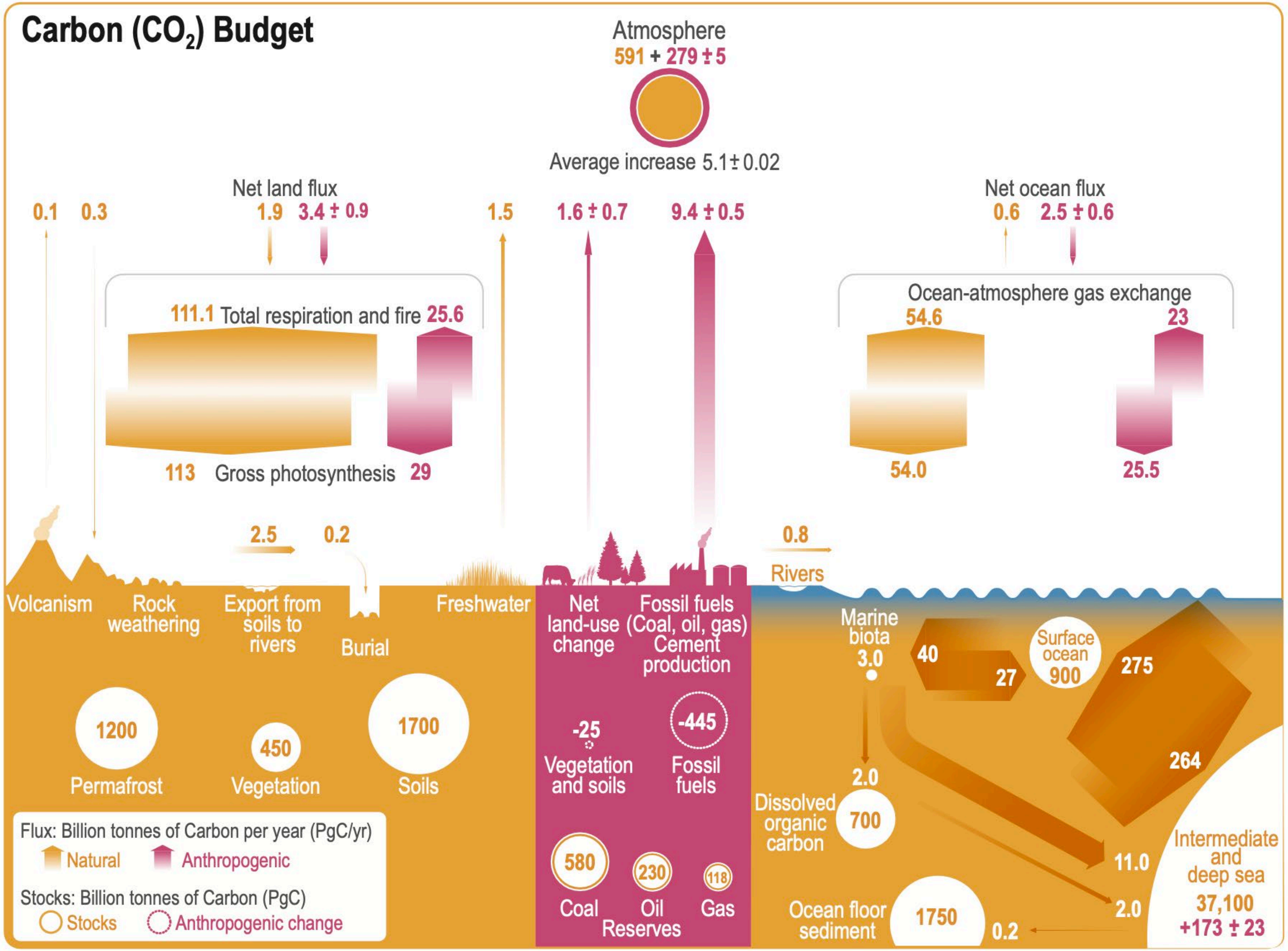
CMIP5/6 Simulated climatology sea-air CO_2 fluxes





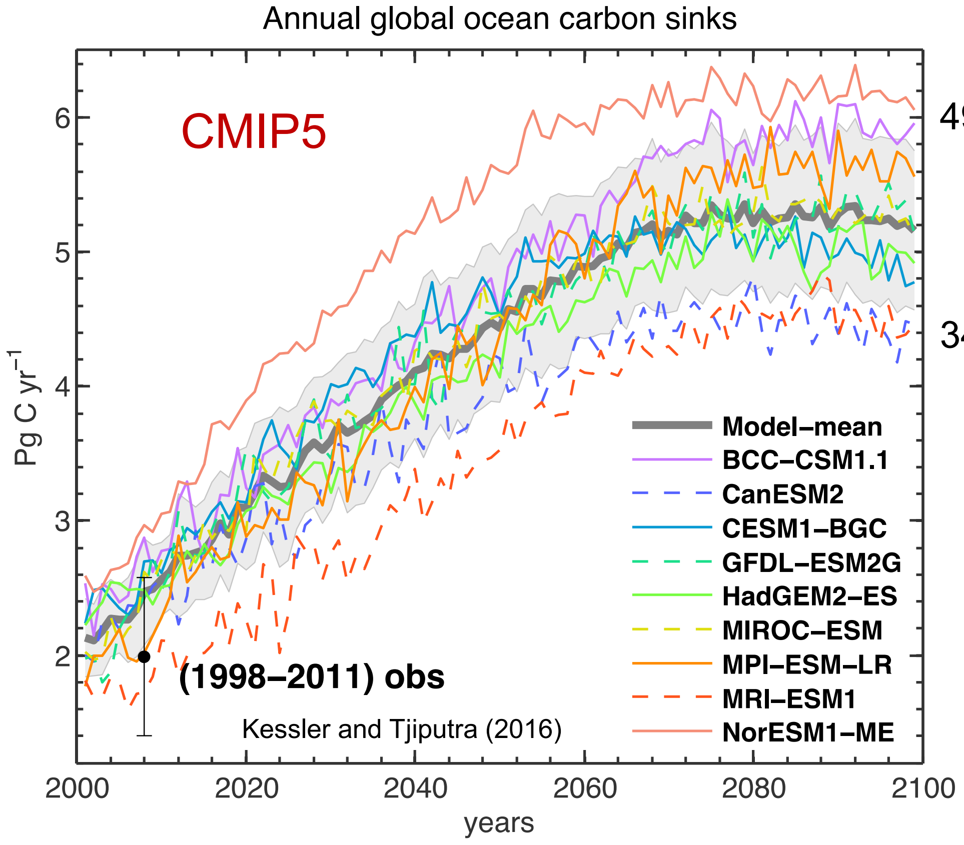


Seferian et al. (2020)

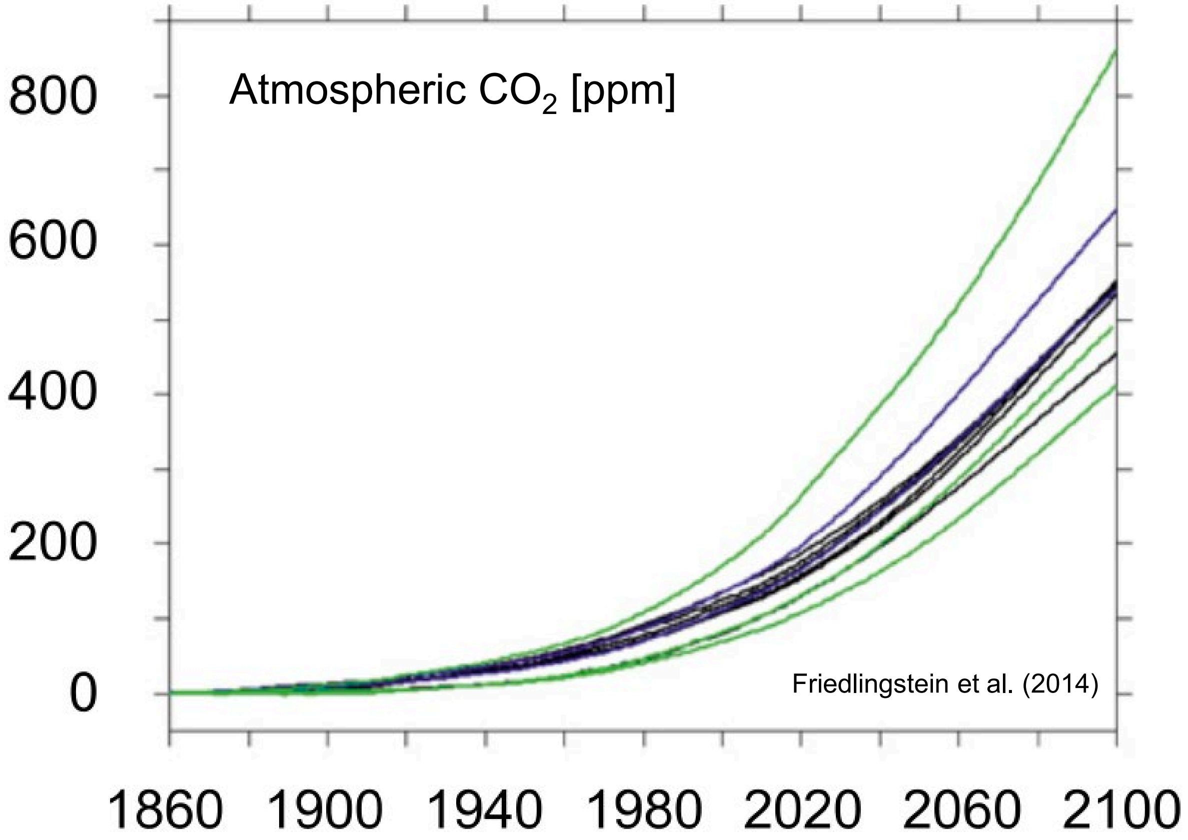

Carbon (CO_2) Budget
Atmosphere
591 + 279 ± 5
Average increase 5.1 ± 0.02
Net land flux
0.1
0.3
1.9
3.4 ± 0.9
1.5
1.6 ± 0.7
9.4 ± 0.5
Net ocean flux
0.6
2.5 ± 0.6
111.1 Total respiration and fire 25.6
113 Gross photosynthesis 29
Ocean-atmosphere gas exchange
54.6
23
54.0
25.5
2.5
0.2
0.8
Rivers
Volcanism
Rock weathering
Export from soils to rivers
Burial
Freshwater
Net land-use change
Fossil fuels (Coal, oil, gas) Cement production
Marine biota
3.0
40
27
Surface ocean
900
275
264
1200
Permafrost
450
Vegetation
1700
Soils
-25
Vegetation and soils
-445
Fossil fuels
2.0
Dissolved organic carbon
700
11.0
2.0
Intermediate and deep sea
37,100
+173 ± 23
Flux: Billion tonnes of Carbon per year (PgC/yr)
Natural
Anthropogenic
Stocks: Billion tonnes of Carbon (PgC)
Stocks
Anthropogenic change
580
Coal
230
Oil
118
Gas
Reserves
Ocean floor sediment
1750
0.2

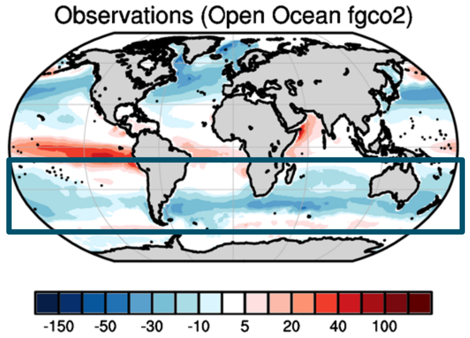
IPCC-AR6

Projection uncertainty

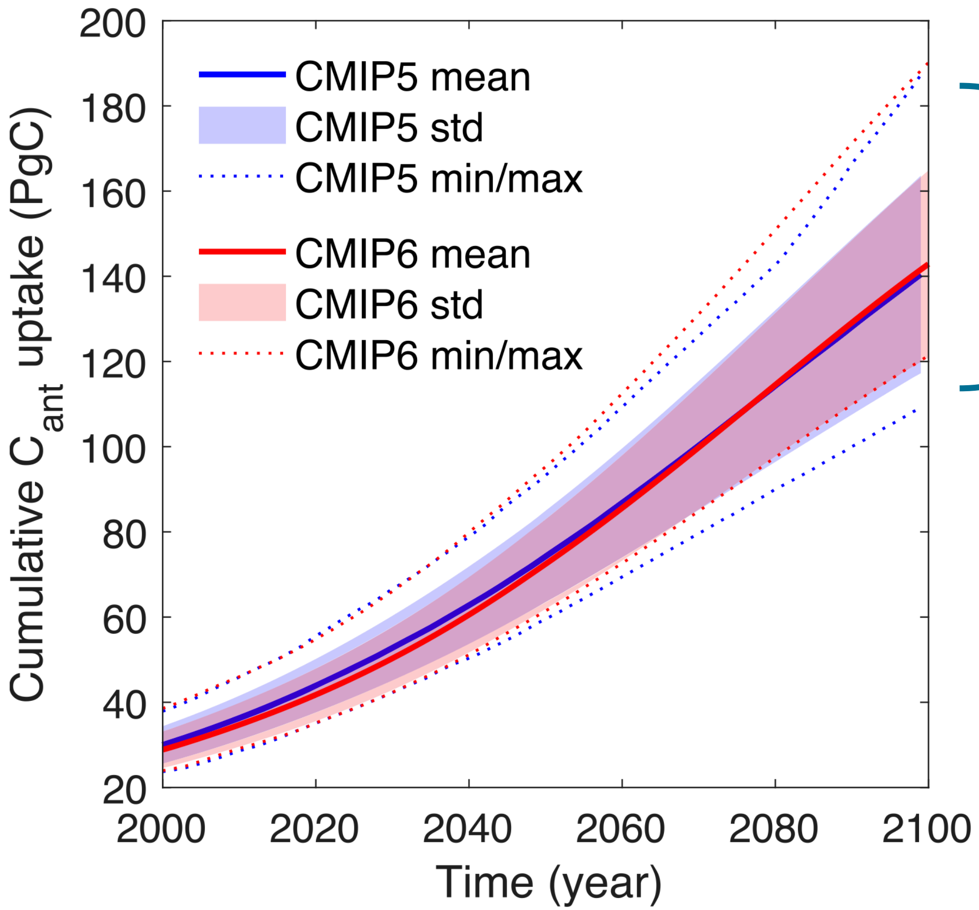


70 ppm





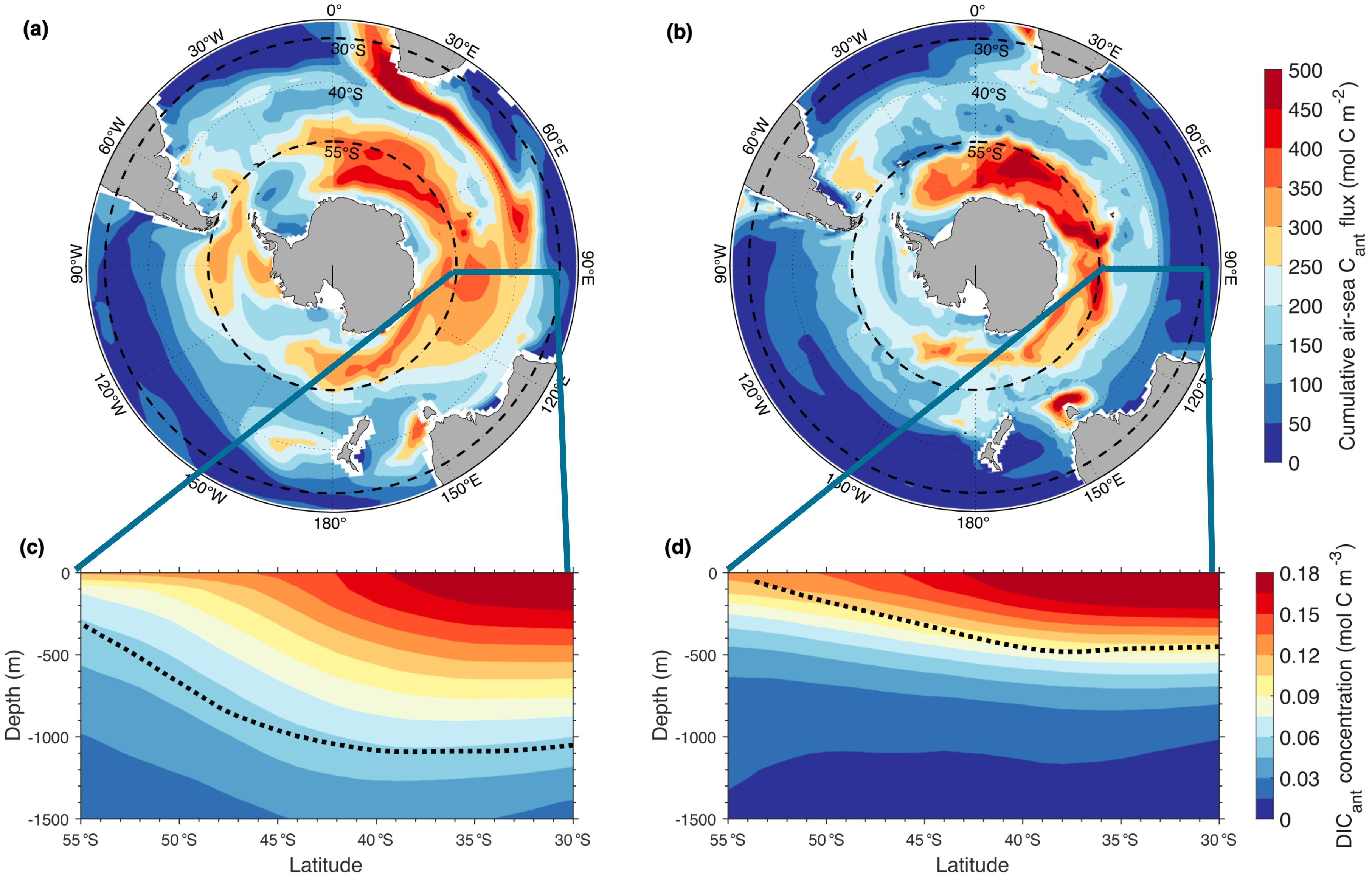
Southern Ocean



Uncertainty => quadruple by end of the century

Bourgeois et al. (2022)

High-uptake models | Low-uptake models

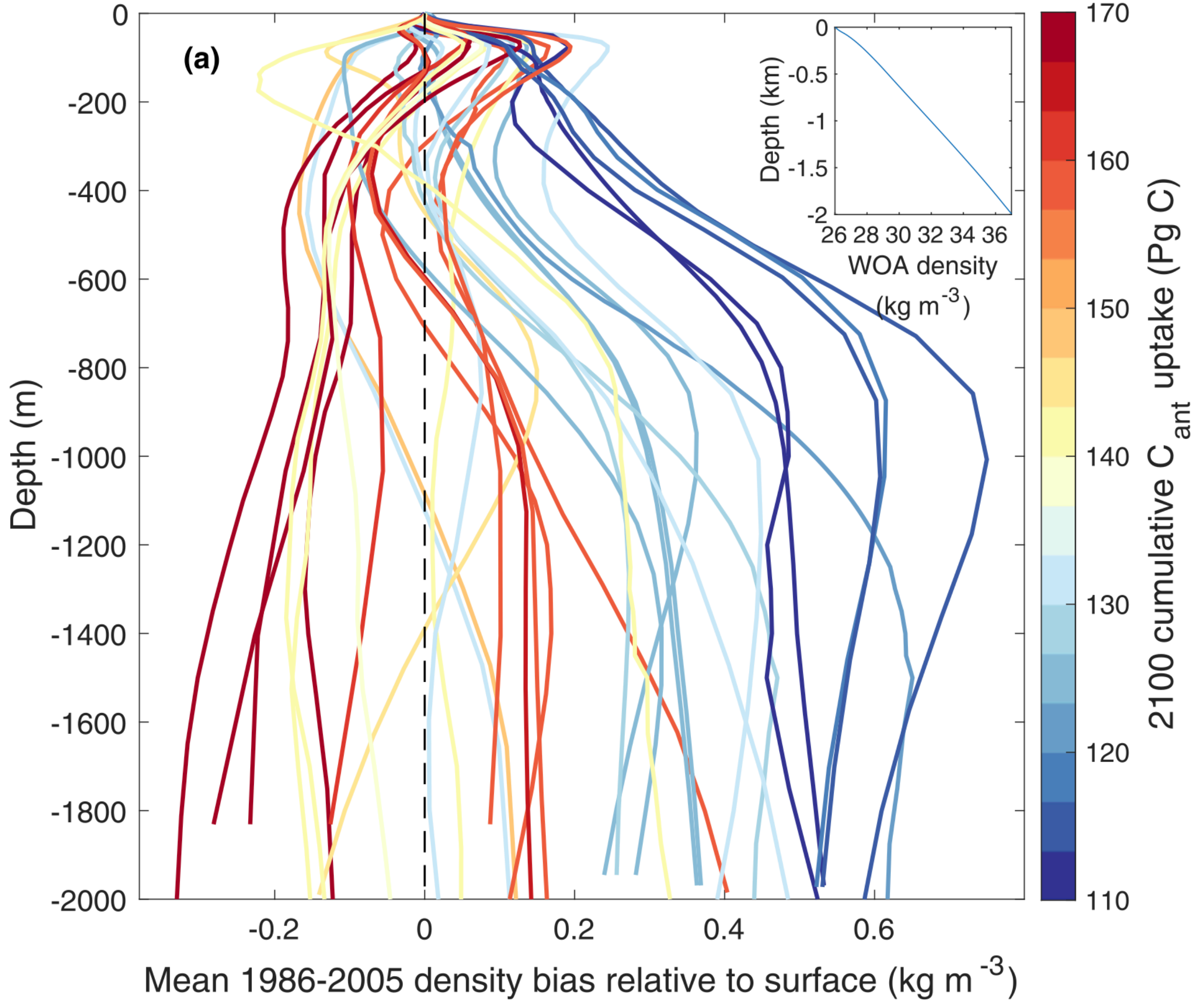


AAIW depths: density isolines crossing the depth of the salinity minimum at 30°S

Bourgeois et al. (2022)

High-uptake models ⟷ Low-uptake models

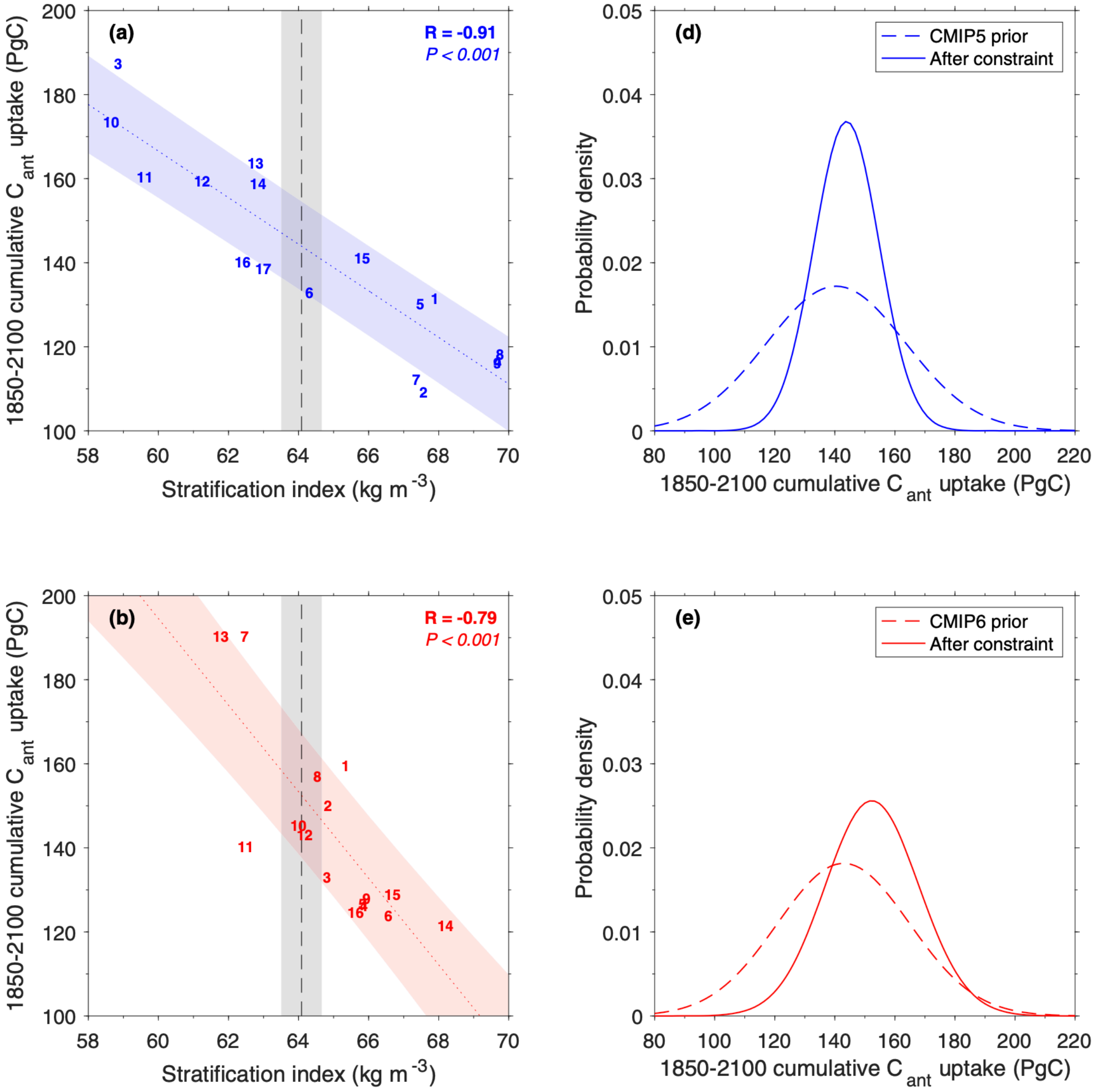
Bias-low at depth, less stratified

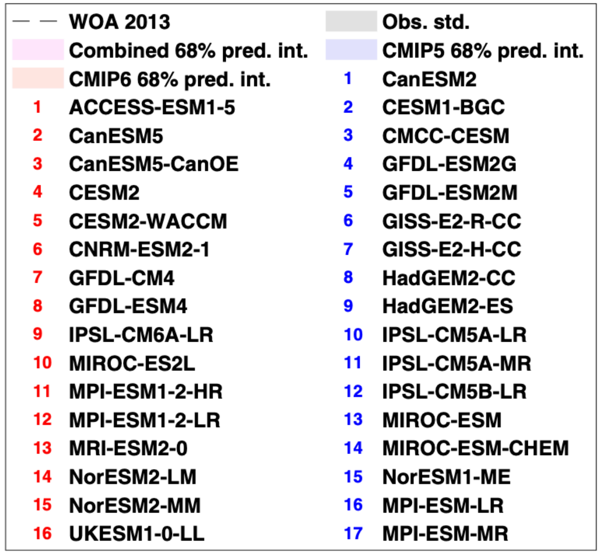


Bias-high at depth, more stratified

Bourgeois et al. (2022)

Constrained future CO_2 sink in the Southern Ocean

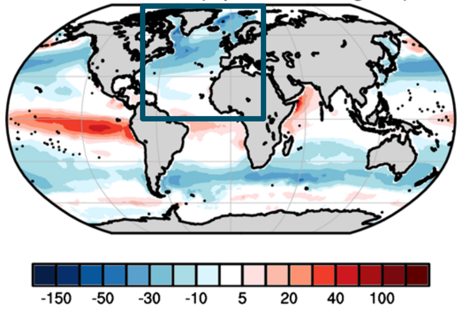


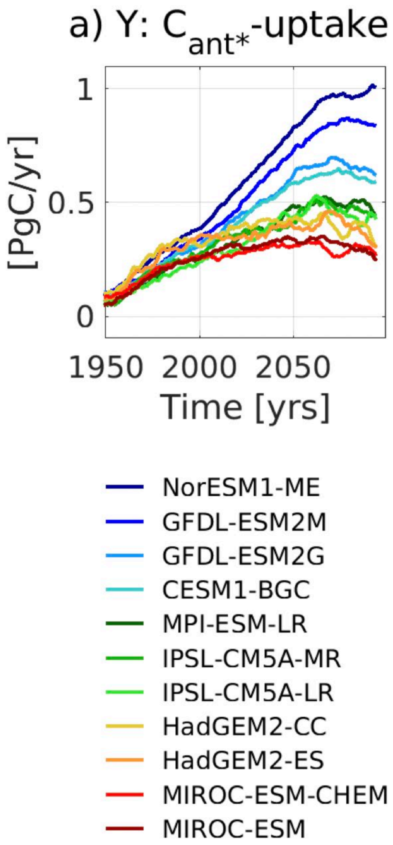


[Pg C]	Ensemble	Prior-constraint	Post-constraint	Uncertainty change
∑Cant	CMIP5	140±23	144±11	**-53%**
∑Cant	CMIP6	143±22	152±15	**-32%**

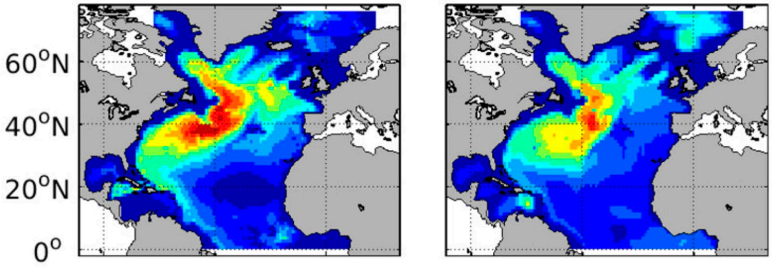
Bourgeois et al. (2022)

North Atlantic





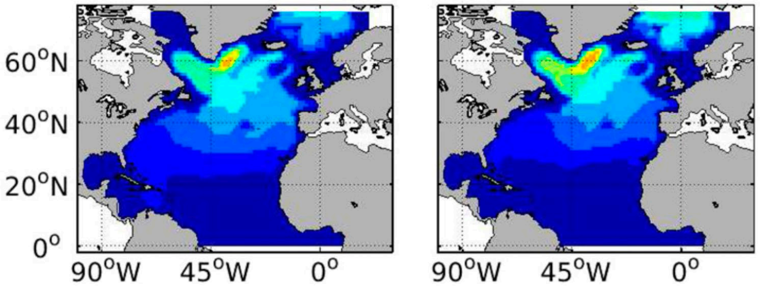
Percentage of Cant below 1000 m



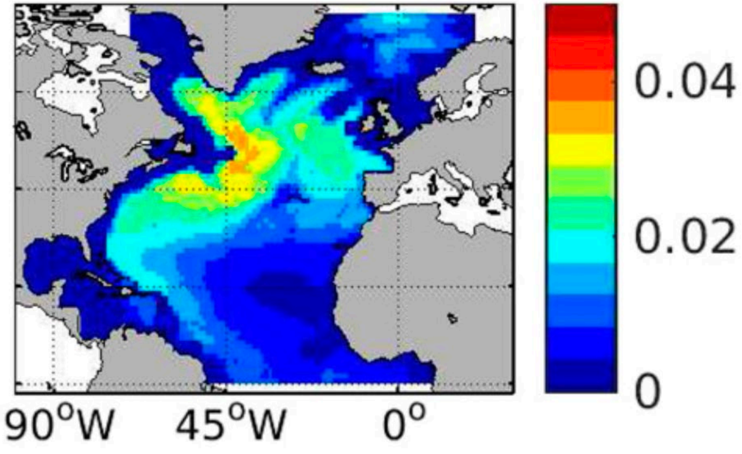
High-uptake models

vs

Low-uptake models



GLODAPv2 (observations)



Goris et al. (2018; in revision)

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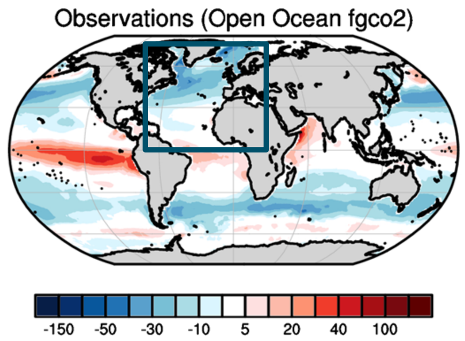
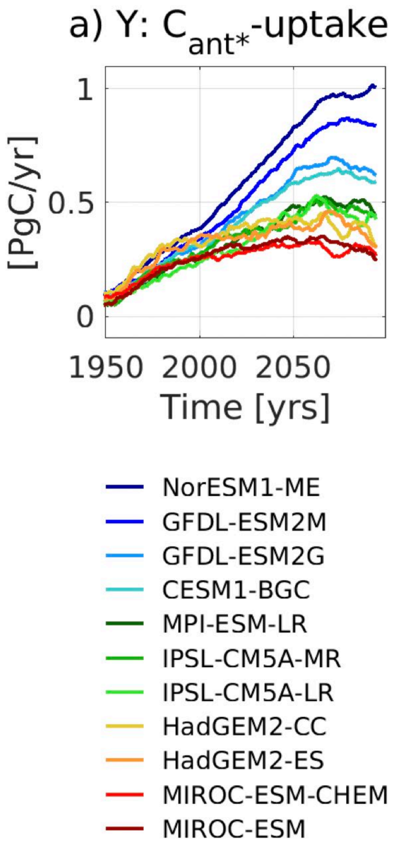
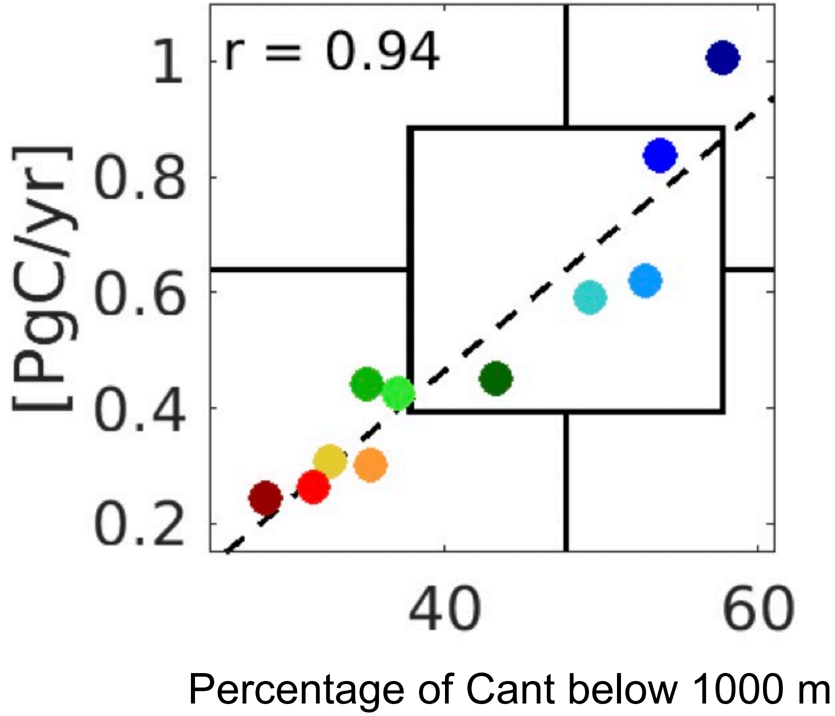


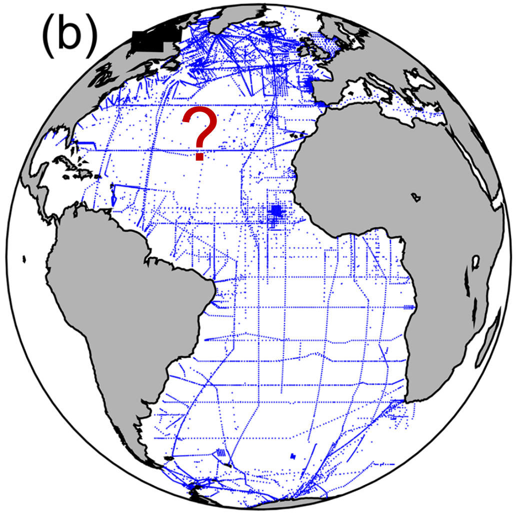
North Atlantic





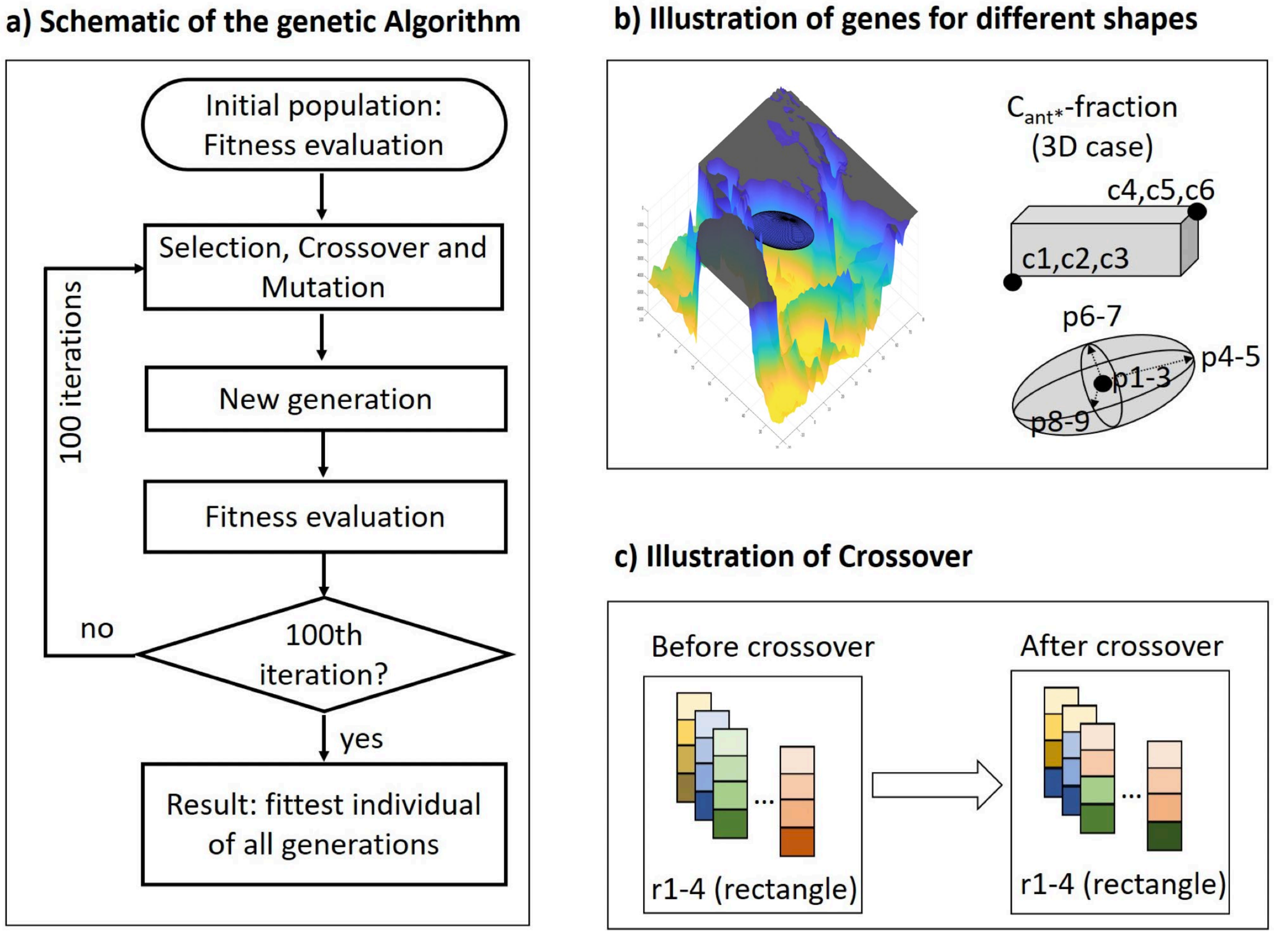
0.64±0.25 [Pg C yr^{-1}]

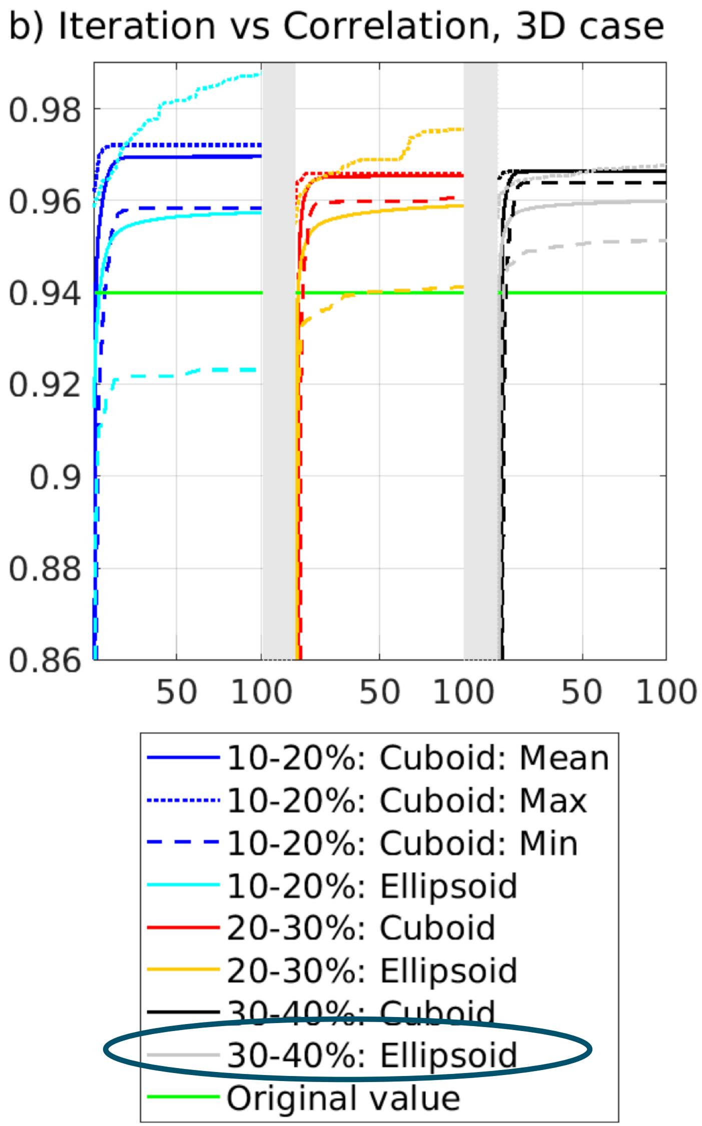
- More observations needed to better constrained future spread
- Measuring deep carbbon system in the North Atlantic is challenging and costly
- Can we optimize the domain that requires observations the most?



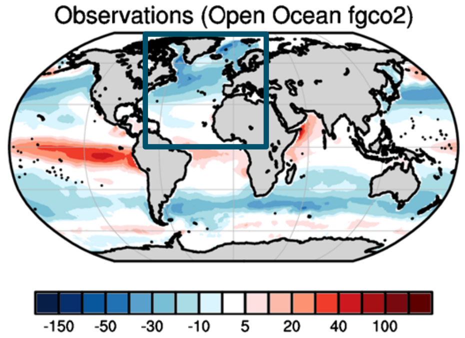
Goris et al. (2018; in revision), Lauvset et al. (2021)

Application of genetic algorithm to optimize EC

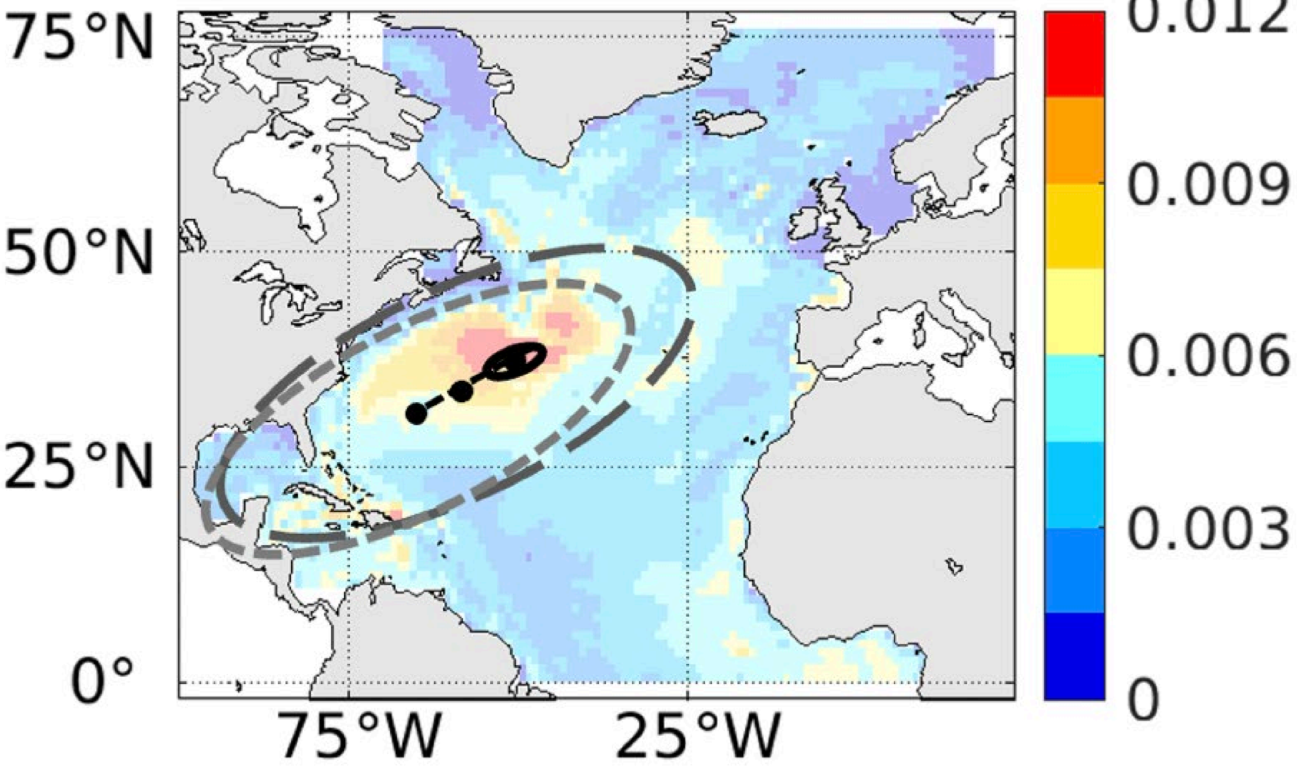




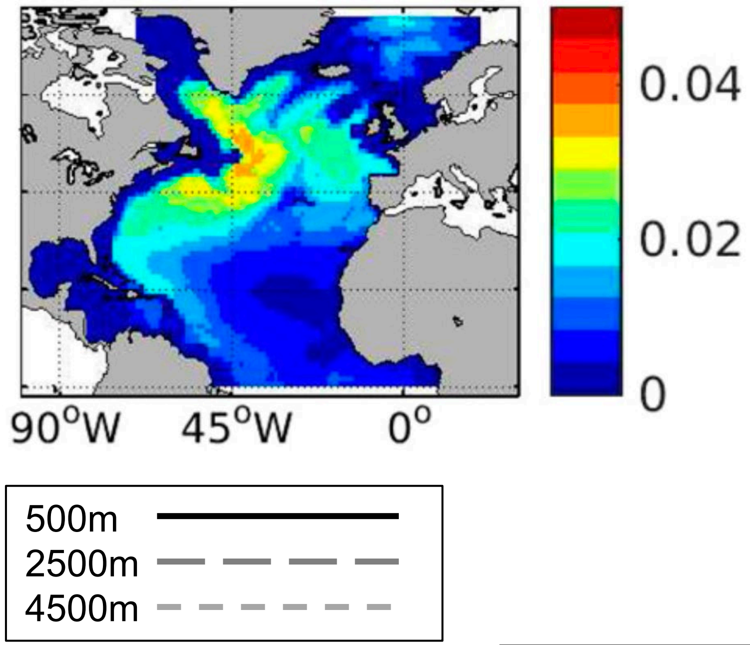
Goris et al. (in revision)



Gulf Stream domain



GLODAPv2 (observations)

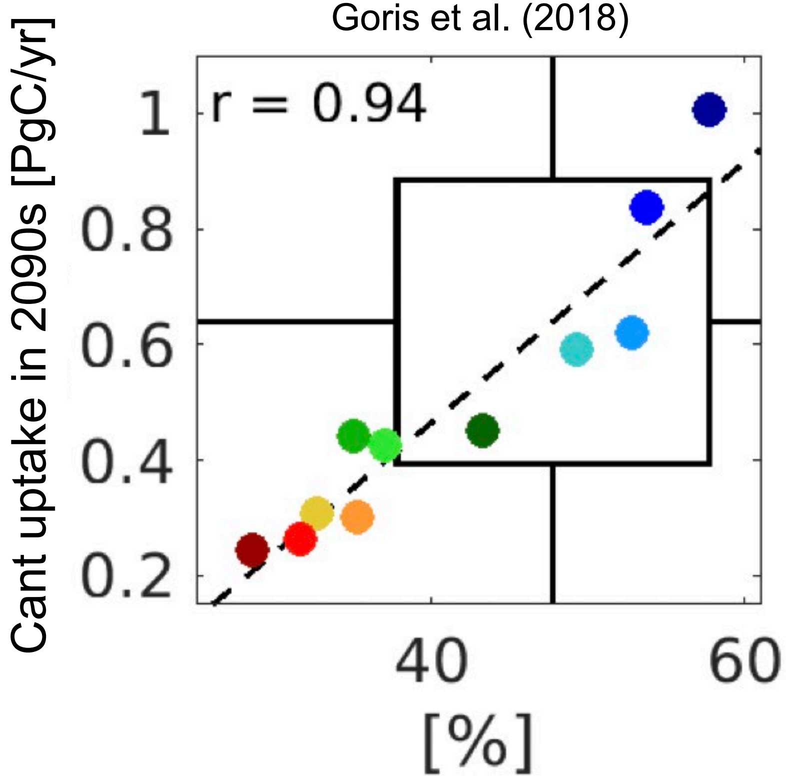


WCRP CMIP World Climate Research Programme

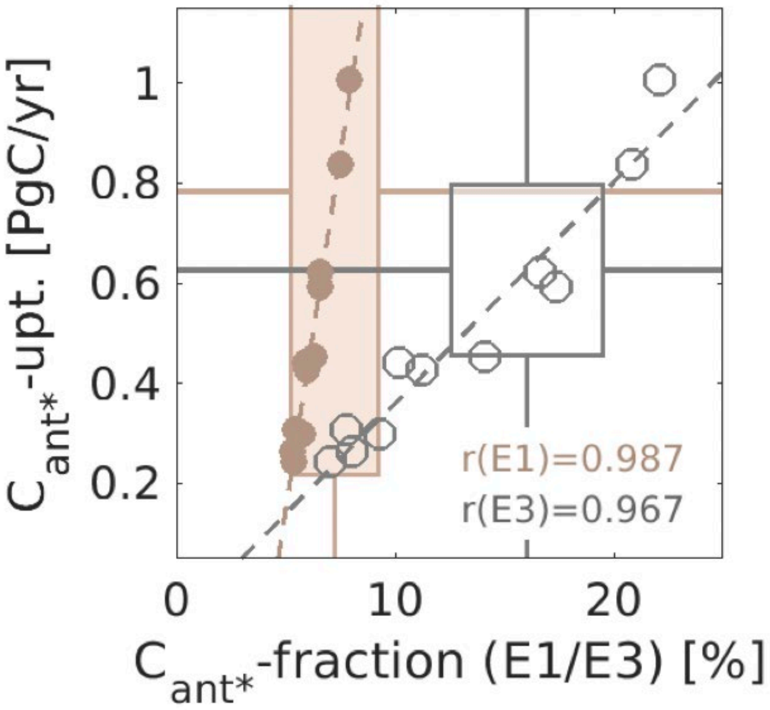
Goris et al. (2018; in revision)

Optimized (tighter) constraint of North Atlantic C uptake

Goris et al. (2018)



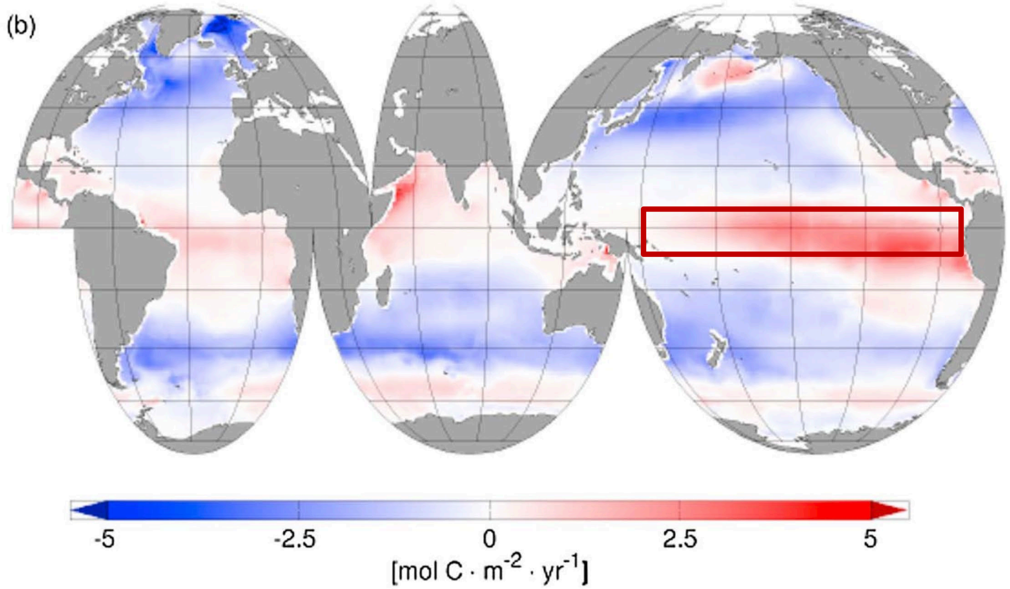
Goris et al. (in revision)



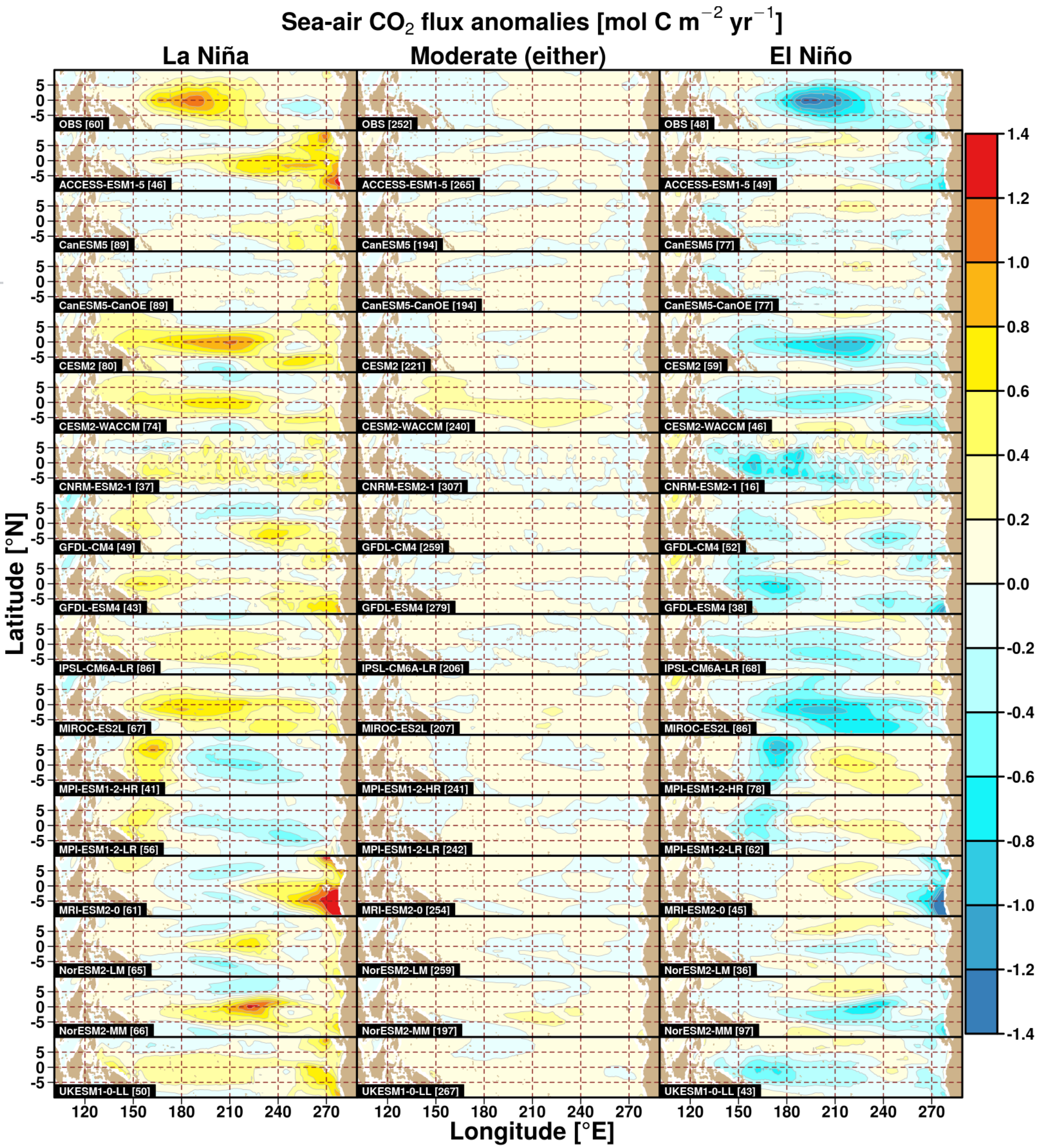
0.50±0.25 [Pg C yr^{-1}] ⟶ 0.64±0.25 [Pg C yr^{-1}] ⟶ 0.63+-0.17 [Pg C yr^{-1}]

Constraining the CO_2 fluxes in the equatorial Pacific

Observed contemporary CO_2 fluxes

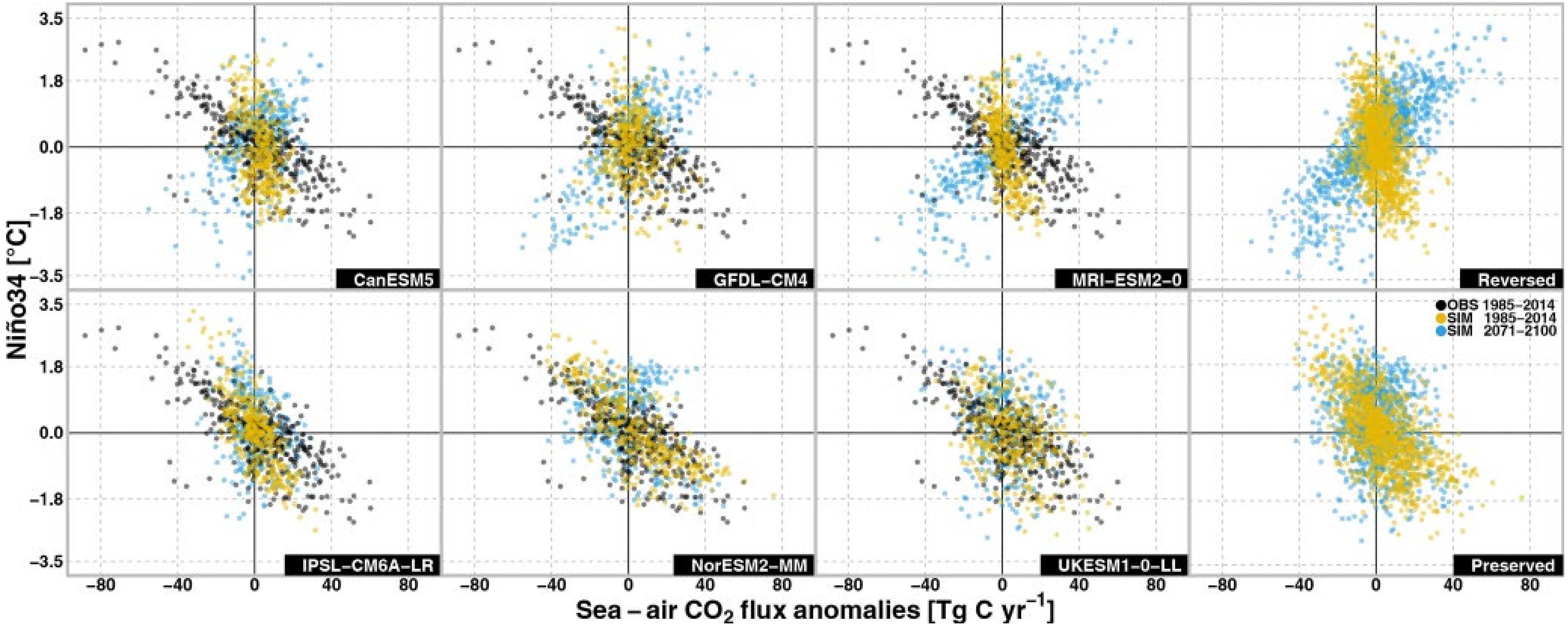


Landschutzer et al. (2014)



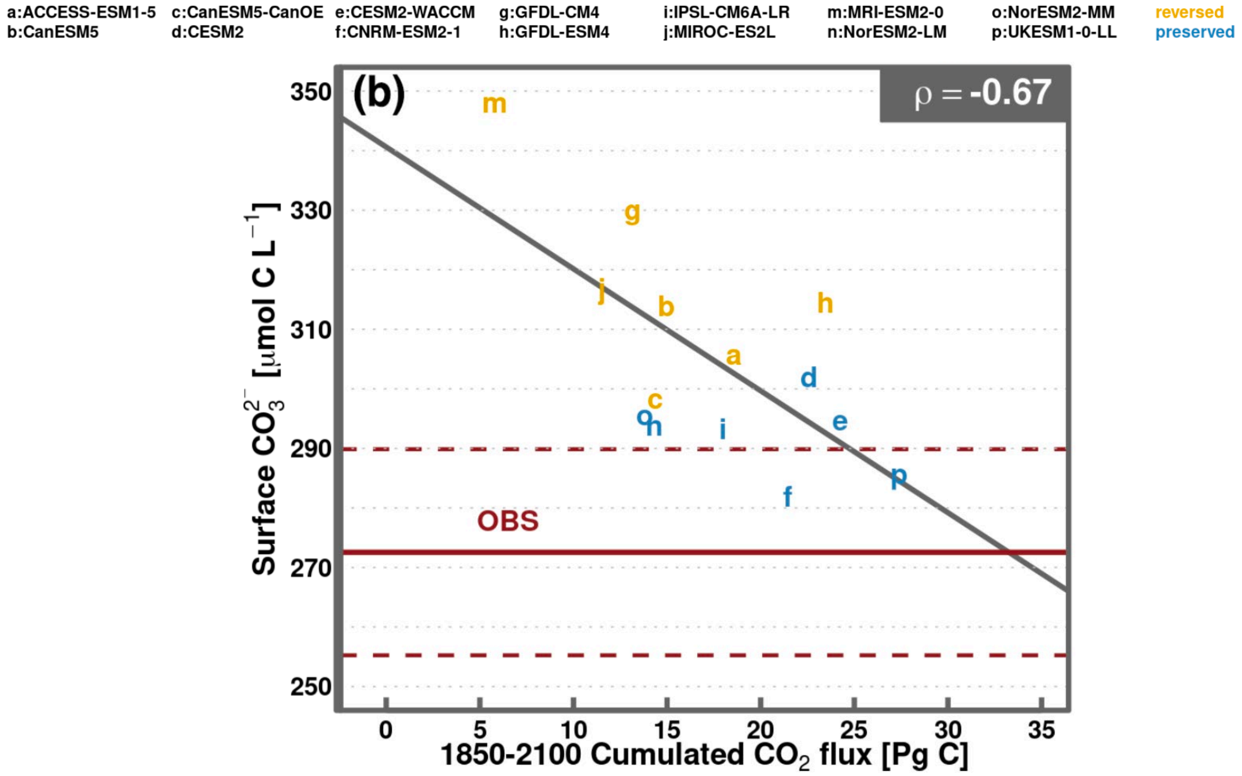
Vaittinada Ayar et al. (2022)

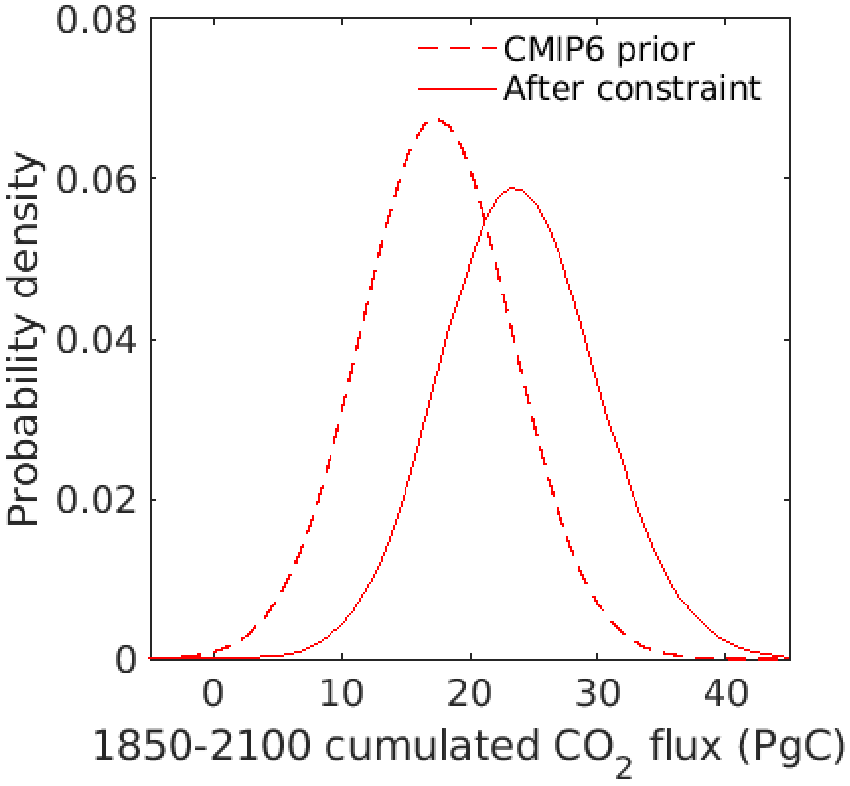
Constraining the CO_2 fluxes in the equatorial Pacific



Vaittinada Ayar et al. (2022)

Constraining the CO_2 fluxes in the equatorial Pacific





17.4±5.9 => 24.6±5.9 Pg C

Vaittinada Ayar et al. (2022)

Summary

- Constraining the growing spread of ocean carbon sink projections are crucial to constrain future climate change and ultimately guide the development of climate mitigation policies.
- We apply an emergent constraint approach to reduce the projections CO_2 uptakes.
- The efficiency of surface-to-deep transport of anthropogenic carbon is commonly identified as the key mechanisms driving the systematic inter-model spread, both in the Southern Ocean and North Atlantic.
- For the North Atlantic region, a genetic algorithm was used to further optimize our identified emergent constraint by isolating the Gulf Stream region as a key regional constraint.
- In the tropical Pacific, bias in the interior biogeochemistry explains the projection spread.
- Our study consolidates the importance of improving representations ventilation mechanisms in models and sustaining carbon chemistry and watermass monitoring network to improve the fidelity of future model projections.

The Research Council of Norway

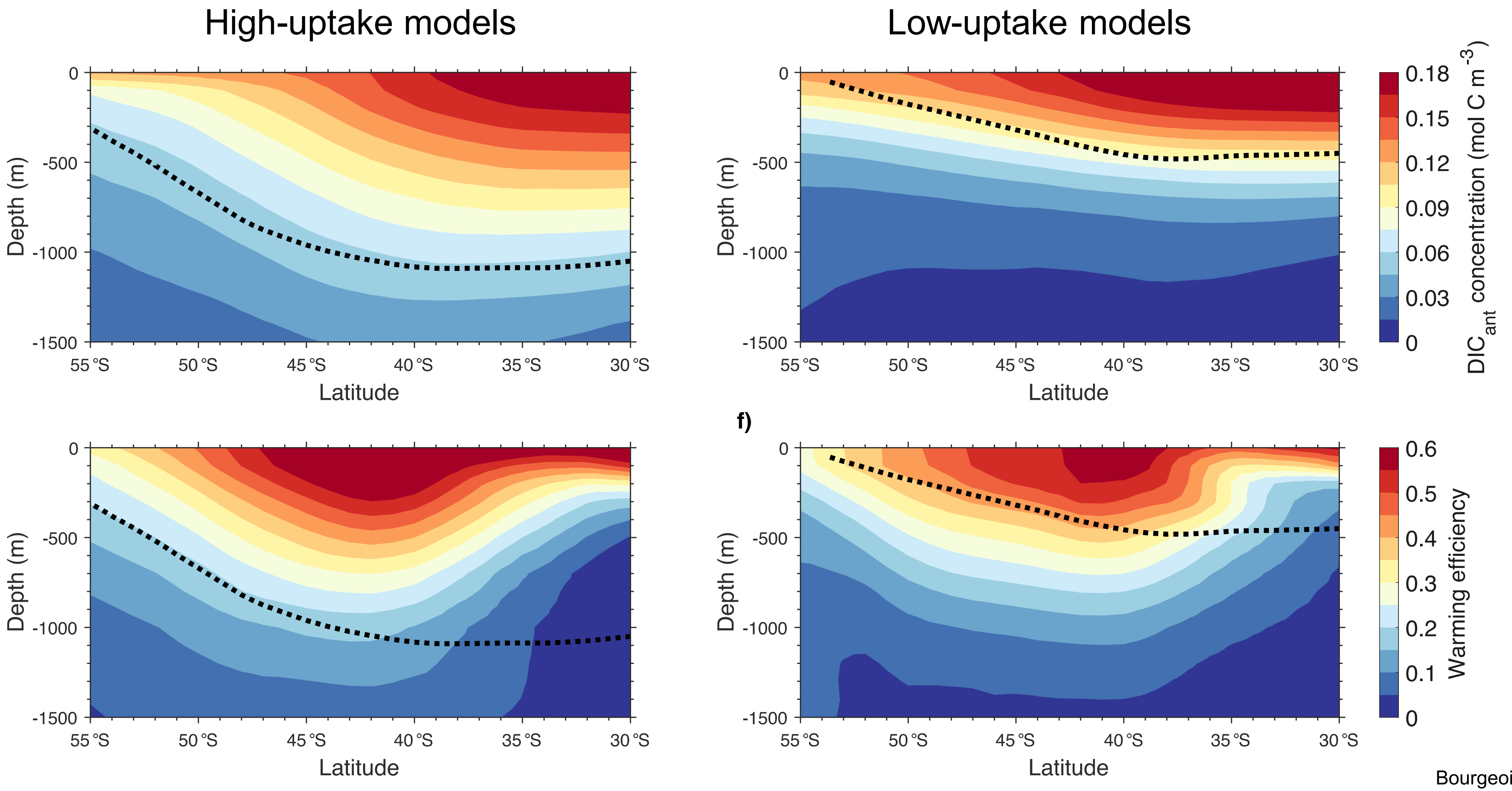
COLUMBIA

Constraining the large uncertainties in Earth system model projections with a Big Data approach

This study has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 820989 (project COMFORT). The work reflects only the author's/authors' view; the European Commission and their executive agency are not responsible for any use that may be made of the information the work contains.

COMFORT

As it turns out, similar systematic bias is simulated for ocean heat uptakes



Bourgeois et al. (2022)

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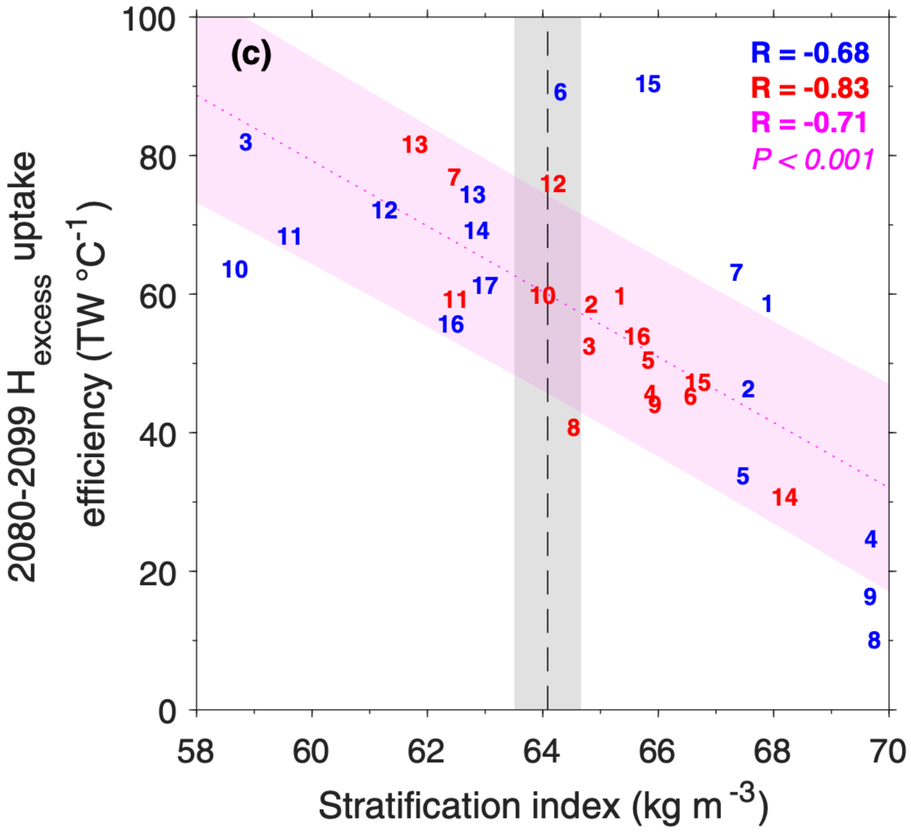
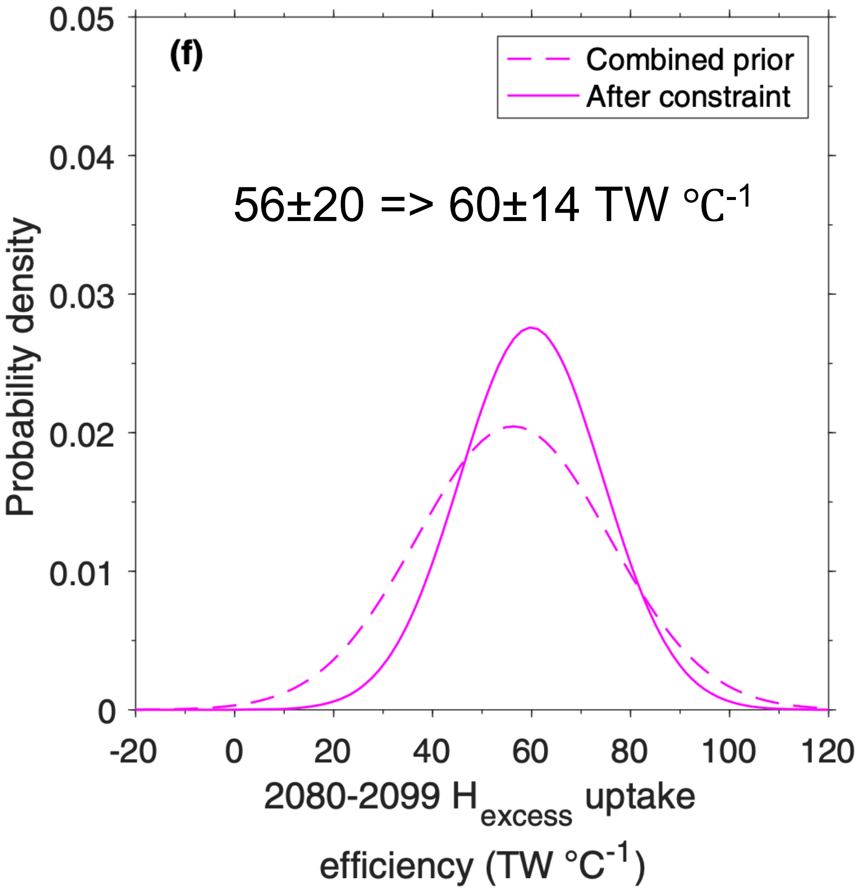
Constrained future excess heat uptake in the Southern Ocean





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