Global Biogeochemical Cycles

Supporting Information for

An assessment of CO_2 storage and sea-air fluxes for the Atlantic Ocean and Mediterranean Sea between 1985 and 2018.

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Text 1.- Description of Atlantic RECCAP1 Regions and Mediterranean Sea

NASPG.- A wide range of oceanographic processes converge in the NA subpolar gyre (NASPG), generating high pCO_2 variability, both spatial and temporal. This has led to challenges in terms of understanding, assessing and modeling, despite the growing observational capacity deployed in the last two decades in this region. During the RECCAP1 period (1990-2009), Schuster et al. (2013) assessed an average CO_2 uptake of -0.21 ± 0.06 Pg C yr^{-1} (10% of the global uptake) between 49ºN and 79ºN, and west of 19ºE (8.6 million km^2, 2.3% of the ocean surface) with a measured rate of 2.03 ± 0.58 mol C m^{-2} yr^{-1}, showing that it is one of the regions with the highest CO_2 uptake despite its limited surface area. The same study reaffirms that this uptake rate is consistent with the different methodologies evaluated, based on both observations and different types of numerical models. Many studies, both observational and biogeochemical modeling, have been devoted to understand the seasonal, interannual and long-term variability of FCO_2, which has proved to be a complex task (Thomas et al., 2008; Olsen et al., 2008; Ullman et al., 2009; Watson et al., 2009; Tjiputra et al., 2012; Breeden and McKinley, 2016; Fröb et al., 2019; Leseurre et al., 2020). In general, they all show an increase in pCO_2 driven by anthropogenic forcing with different rates depending on the studied year interval, season, and location within the NASPG.

The seasonal FCO_2 cycle in the NASPG is strongly affected by extensive biological activity during spring-summer that maintains low pCO_2 levels, despite the increasing temperature, and by considerable heat loss during winter that promotes significant vertical mixing increasing pCO_2 and nutrient input. Both processes are subject to significant spatiotemporal variability related to the North Atlantic Oscillation (NAO) climate mode, but also to the Atlantic Multidecadal Oscillation (AMO) (Schuster et al., 2013). McKinley et al. (2011) showed that it takes at least 25 years for the anthropogenic-driven trend to dominate over shorter-term changes with the observations being best understood as the result of decadal variability associated with the AMO. On the other hand, the C_{ant} storage rate in the interior of the NASPG has been observed to be clearly affected by the NAO (Pérez et al., 2008; Steinfeldt et al., 2009; Pérez et al., 2013) especially in its western part (Labrador and Irminger Seas) and driven by changes of the thickness of the winter mixing layer (Steinfieldt et al., 2009). Recently, Gruber et al. (2019) showed that the subpolar gyre between 1994 and 2007 has shown a strong reduction of the C_{ant} storage rate (~1 mol m^{-2} yr^{-1}) associated with the change of the NAO index with high NAO values between 1990-95, and low values between 2002 to 2007. In any case, the average storage rate for the NASPG was 1 mol m^{-2} yr^{-1} between 1994 and 2007. Models showed no clear relationship between NAO and FCO_2, with a few exceptions (Thomas et al., 2008; Tjiputra et al., 2012). In contrast, there is observational support for the impact of the NAO on FCO_2 via the high FCO_2 values observed in 1993-1996, coinciding with high NAO indices, and the low FCO_2 between 2004-2007, during a period of low NAO, and the subsequent increase during 2014-2018 during a period of increasing NAO (Leseurre et al., 2020; Fröb et al., 2019).

NAST.- In the previous RECCAP study, the subtropical North Atlantic (NAST, 18° to 49° N, 23.7 million km^2, 7.2% of the ocean surface) was shown to be a CO_2 sink, with a net FCO_2 of -0.26 ± 0.06

PgC yr^{-1} between 1990 and 2009 (Schuster et al., 2013), with a high contribution from C_{ant} while the natural CO_2 uptake being driven mainly by net heat loss with a lower impingement of biological activity (Gruber et al., 2009). The mean FCO_2 rate (− 0.91 mol C m^{-2} yr^{-1}) is similar to the FCO_2 derived from BATS station observations (Bates et al., 2014), despite that the eastern return branch of the subtropical gyre (ESTOC site) shows lower values (Santana-Casiano et al., 2007). At both sites, the interannual variability of FCO_2 correlates with sea surface temperature (SST) and mixed layer depth anomalies (Gruber et al., 2002; Santana-Casiano et al., 2007). SST is the main driver of the seasonal cycle in the subtropics, driving a FCO_2 efflux anomaly in summer and uptake in winter. Here, the biological activity has less impact on FCO_2 compared to that in NASPG, given the relatively low level of nutrients in the surface mixing layer. Seasonality is lower in the eastern region with respect to the BATS station, and so is its correlation with the NAO index, which shows a positive correlation (less or negative NAO, negative FCO_2 and CO_2 uptake) at BATS (Gruber et al., 2002;Tjiputra et al., 2012). The GOBMs show that the maximum CO_2 emission in summer is notably higher and later compared to that of other methodologies. The previous ocean biogeochemical models tend to underestimate biological productivity in the stratified subtropical gyre. On the other hand, based on a variety of observations (Pérez et al., 2013; Brown et al., 2021), the annual C_{ant} accumulation (ca. 1.3 mol C m^{-2} yr^{-1}) is higher than the mean CO_2 uptake, indicating net northward advection of C_{ant}.

Equatorial Atlantic.- After the tropical Pacific, the tropical Atlantic is the second largest oceanic source of CO_2 to the atmosphere, with an annual emission of 98-110 Tg C (Takahashi et al., 2009; Landschützer et al., 2014) due to frequent upwelling of cold, CO_2-rich water in the eastern Atlantic. The mean tropical Atlantic (**18°S-18°N**) CO_2 flux has been determined to be approximately 110 TgC yr^{-1} (reference year 2000; Takahashi et al., 2009) or 98 TgC yr^{-1} (average 1998 to 2011; Landschützer et al., 2014). For this same region, in the previous RECCAP1, Schuster et al. (2013) evaluated a CO_2 efflux of 120 ± 40 TgC yr^{-1} between 1990 and 2009 based on different methodologies, which are indistinguishable from each other. This efflux is much lower than the estimated between 5ºS to 5ºN from 1982 and 1983 (Andrié et al., 1986), just in the core of the equatorial upwelling (0.38 mol-$Cm^{-2}yr^{-1}$). The present efflux is currently only about half of what it was in pre-industrial times, as natural CO_2 degassing is substantially offset by strong C_{ant} uptake (Gruber et al., 2009). These authors also mentioned that an important part of this natural efflux is due to the riverine contribution of organic matter. The surface pCO_2 exhibits high interannual variability associated with the El Niño Southern Oscillation and has been shown to be highly correlated with the Tropical North Atlantic index. The eastward zonal expansion of CO_2-rich waters upwelled in the equatorial upwelling system explains the high net CO_2 outgassing (Andrié et al., 1986). Another source of variability in this region is the contribution of the Amazon River, which accounts for almost 20% of the global river discharge into the oceans that contribute to attenuate the CO_2 flux to the atmosphere (Körtzinger, 2003; Lefèvre et al., 2010; Ibanhez et al., 2016).

SAST.- The subtropical South Atlantic region (44ºS to 18ºS, west of 19ºE) is a sink for atmospheric CO_2 (Schuster et al., 2013; Rödenbeck et al., 2015), driven almost equally by natural and anthropogenic forcing (Gruber et al., 2009). This region is relatively poorly sampled, and the domain north of 31ºS acts as a source in spring and as a sink in autumn (González-Dávila et al., 2009). In the long term, it shows a CO_2 sink with an average rate of 140 ± 40 TgC yr^{-1} between 1990 and 2009, combining areas with a net efflux north of the 23ºC isotherm (Ito et al., 2005) and with absorption south of it. It has been suggested that strong upwelling events in the eastern part contribute to generate significant interannual variability (Schuster et al., 2013). However, the variability shown for pCO_2 in the biome SA-STPS by Rödenbeck et al. (2015) is relatively low. Long-term CO_2 flux trends have been shown to be discrepant depending on the methodology used (Schuster et al., 2013).

Mediterranean Sea.- The Mediterranean Sea (MED hereinafter) is the only mid-latitude ocean basin where open-ocean deep convection occurs. The convection is driven by a loss of buoyancy that occurs mainly in the Eastern basin, giving place to the Levantine Intermediate Water, and in the Gulf of Lions (NW MED) and the Adriatic and Aegean Seas where intermediate and deep-water mass formation takes place. Circulation patterns in the MED are mainly responsible for the high C_{ant} storage estimated in the basin, as dense water mass formation events have the potential to transfer C_{ant} into the deeper layers. Using transient tracer data from 2001, the C_{ant} column inventory in the MED was estimated to be 1.7 PgC (Schneider et al., 2010), considerably higher than that for the Atlantic and Pacific oceans in the same latitude band. A high variability of surface pCO_2 and marine carbonate system is observed due to the high heterogeneity of physical and trophic regimes in the two main Mediterranean sub-basins (Krasakopoulos et al., 2009; Ingrosso et al., 2016; Urbini et al., 2020; De Carlo et al., 2013; Kapsenberg et al., 2017; Petihakis et al., 2018; Sisma-Ventura et al., 2017; Lefèvre, 2010; Wimart-Rousseau et al., 2021). A recent basin-wide analysis reveals a significant temporal trend of sea-air CO_2 flux during the 1999-2019 period, with values ranging from 5.5 to 16.5 Tg C yr^{-1}/yr with the highest values detected in the western basin (Cossarini et al., 2021). This reanalysis also shows that from 2010-2019, the MED exhibits near neutral conditions with respect to the atmosphere, with a mean annual value of – 37.5 Tg C yr^{-1}, and indicated that the MED has shifted from being a net source of CO_2 during the 1980s to a net sink during the 2000, due to increased primary production. Despite the observed spatial variability in FCO_2, areas of dense water mass formation are specific sites of strong CO_2 uptake. The increase in the CO_2 uptake over the last two decades has been 50% higher in the western basin with respect to the eastern basin, so that C_{ant} subduction that has been further favored by regular water mass formation events (Touratier et al., 2016), and a consequent more active biological carbon pump.

Supplementary Table S1. List of observational data products analyzed in this study. More detailed descriptions of the pCO_2 products are shown in Supplementary Table S2 of DeVries et al. (2023)

Product Name	**References**	**Comments**	**Fields**
CMEMS-LSCE-FFNN	Chau et al. (2022)	Global	pCO_2, FCO_2
CSIR-ML6	Gregor et al. (2019)	Global	pCO_2, FCO_2
JenaMLS	Rödenbeck et al. (2013; 2022)	Global	pCO_2, FCO_2
JMAMLR	Iida et al. (2021)	Global	pCO_2, FCO_2
LDEO-HPD	Gloege et al. (2022)	Global	pCO_2, FCO_2
MPI-SOMFFN	Landschützer et al. (2016)	Global	pCO_2, FCO_2
NIES-MLR3	Zeng et al. (2022)	Global	pCO_2, FCO_2
OceanSODA ETHZ	Gregor and Gruber (2021)	Global	pCO_2, FCO_2
UOEX-Wat20	Watson et al. (2020)	Global	pCO_2, FCO_2
eMLR-C*	Gruber et al. (2019)	Global	ΔC_{ant}[§]
Green’s Function	Khatiwala et al. (2009)	Global	C_{ant}[#]

[§] ΔC_{ant} reconstruction using DIC and other physical and biogeochemical parameters by Gruber et al. (2019).

[#] C_{ant} reconstruction using water mass age-tracers

Supplementary Table S2. List of Global/Regional Ocean Biogeochemical Models (G/ROBMs) and inverse model analyzed in this study. More detailed descriptions of the G/ROBMs are shown in Supplementary Table S1 of DeVries et al. (2023).

Model Name	**References**	**Comments**	**Simulation**
CESM-ETHZ[§#]	Doney et al. (2009); Lindsay et al. (2014); Yang and Gruber (2016)	Global	A,B,C,D
CNRM-ESM2-1[§#]	Berthet et al. (2019); Séférian et al. (2019); Séférian et al. (2020)	Global	A,B,C,D
EC-Earth3[§#]	Döscher et al. (2022)	Global	A,B,C,D
FESOM-REcoM-LR[§#*]	Sein et al. (2018); Hauck et al. (2020)	Global	A,B,C,D
MOM6-Princeton[§]	Liao et al. (2020); Stock et al. (2020)	Global	A,B
MPIOM-HAMMOC[§]	Paulsen et al. (2017); Mauritsen et al. (2019)	Global	A,B,C,D
MRI-ESM2-1[§#*]	Nakano et al. (2011); Urakawa et al. (2020)	Global	A,B,C,D
NorESM-OC1.2[§#*]	Schwinger et al. (2016)	Global	A,B,C,D
ORCA025-GEOMAR[§#*]	Kriest and Oschlies (2015); Chien et al. (2022)	Global	A,B,C,D
ORCA1-LIM3-PISCES[§#]	Aumont et al. (2015)	Global	A,B,C,D
PlankTOM12[§#]	Le Quéré et al. (2016); Wright et al. (2021)	Global	A,B,C,D
OCIM-v2021[#]	DeVries (2022)	Global inverse model	A,B,C
ROMS-Atlantic-ETHZ[§]	Louchard et al. (2021)	Regional	A

[§] Models used in the FCO_2 calculations

[#] Models used in the water column C_{ant} calculations

[*] Models without any riverine CO_2 flux

Supplementary Table S3. The preindustrial riverine CO_2 outgassing (RCO) derived from Aumont et al. (2001) using their Figure 4b, Jacobson et al. (2007) and Lacroix et al. (2020) scaled up to Regnier et al. (2022). The comparison with the expected differences between pCO_2 products and GOBMs are added.

Biomes	Area	RCO Lacroix et al. 2020 rescaled		RCO Aumont et al. 2001		RCO Jacobson et al. 2007		eRCO ensemble mean	FCO_2 pCO2 products mean	FCO_2 GOMBs mean	ΔFCO_2 OBS - GOMBs	ΔFCO_2 OBS - (GOMBs +RCO_Lacroix'20)	ΔFCO_2 OBS - (GOMB +eRCO)
	10^{12} m^2	Pg C yr^{-1}	gC m^{-2} yr^{-1}	gC m^{-2} yr^{-1}	Pg C yr^{-1}	gC m^{-2} yr^{-1}	Pg C yr^{-1}	Pg C yr^{-1}	Pg C yr^{-1}	Pg C yr^{-1}	Pg C yr^{-1}	Pg C yr^{-1}	Pg C yr^{-1}
NA SPSS	9.57	0.026 ±0.004	2.8	5	0.048 ±0.014	3.0	0.029 ±0.010	0.035 ±0.012	-0.238	-0.295	0.057	0.031	0.022
NA STSS	6.49	0.026 ±0.003	4.1	3.5	0.023 ±0.007	1.0	0.006 ±0.006	0.019 ±0.011	-0.127	-0.149	0.022	-0.004	0.003
NA STPS	22.50	0.126 ±0.010	5.6	1.5	0.034 ±0.010	2.6	0.060 ±0.030	0.073 ±0.048	-0.044	-0.020	-0.024	-0.150	-0.097
A EQU	8.88	0.038 ±0.004	4.3	2.4	0.021 ±0.006	4.7	0.042 ±0.022	0.034 ±0.011	0.046	0.035	0.011	-0.027	-0.023
SA STPS	19.60	0.053 ±0.009	2.7	1.5	0.029 ±0.009	1.0	0.020 ±0.005	0.034 ±0.017	-0.003	-0.029	0.026	-0.027	-0.008
MED SEA	2.37								-0.001	-0.012	0.011		
ATLANTIC	69.20	0.269 ±0.031	3.9	2.2	0.155 ±0.047	2.3	0.157 ±0.039	0.194 ±0.054	-0.367	-0.470	0.103	-0.177	-0.102

Recommended regional RCO: Spatial distribution is the gridded field from Lacroix et al. (2020). The gridded field requires an upscaling from 0.2 to 0.65 PgC yr^{-1} (Regnier et al., 2022). Upscaled RCO fields are available here: https://reccap2-ocean.github.io/river/. In each biome, the RCO values are spatially integrated resulting in the values shown in the third column. Uncertainties are estimated proportionally to the area of each biome considering the global uncertainty (±0.3 PgC yr-1) according to DeVries et al. (2023). Also, Aumont et al. (2001) evaluate a higher CO_2 emission due to RCO in the Southern Hemisphere considering that the temporal rate of oxidation of fluvial organic matter is more refractory and lasts much longer in the ocean and is therefore transported to regions much farther away from where the inputs occur. Other useful RCO estimates are included: Jacobson et al. (2007)- Table S1 in Gruber et al. (2009).

The uncertainty estimated from the standard deviation of the set of three RCO products of 0.054 PgC yr^{-1} is consistent with that expected from the global uncertainty (±0.3 PgC yr^{-1}) considering the relative area of the Atlantic to the Global Ocean.

Two biomes NA STSS and SA STPS present differences in FCO_2 between pCO_2 products and GOBMs consistent with that expected from considering the RCO. In the NA SPSS, GOBMs estimated large CO_2 uptake 0.060 PgC yr^{-1} above the mean of the pCO_2 products. The RCO ranged from 0.026 (rescaled Lacroix et al., 2020) to 0.048 PgC yr^{-1} (Aumont et al., 2001). This would suggest that the GOBMs are assessing CO_2 uptake higher than expected from observations by about -0.025 PgC yr^{-1} in NA SPSS (only a 10% of the average). Thus, in this biome RCO incorporation reduces the difference in FCO_2 between pCO_2 products and GOBMs. In the Atl Equ biome, the difference in FCO_2 between both ensembles pCO_2 products and GOBMs was significantly lower than expected from the ensemble RCO. What would appear to be a good agreement between the pCO_2 products and GOBM values would therefore be a higher CO_2 emission to the atmosphere of about 0.023 PgC yr^{-1} in GOBMs with respect to the pCO_2 products. This rate is very similar to the deficit in the storage rate of C_{ant} in this biome when GOBMs was compared with the Gruber et al. (2019) estimations. The biome with the largest discrepancy is the NA STPS, where even the set of three estimates of the RCO has a high dispersion (±0.048 PgC yr^{-1}), and at the same time shows a strong contrast with the difference between the CO_2 flux obtained with pCO_2 products and GOBMs -0.023 versus 0.073 PgC yr^{-1}). This discrepancy would be even greater (-0.023 versus 0.126 PgC yr^{-1}) following RECCAP2's recommendation to use the Lacroix et al. (2020) values rescaled to Regnier et al. (2022) overall value of 0.65 PgC yr^{-1}. All this suggests that the inappropriate inclusion of carbon and nutrient inputs from RCO has a high impact on CO_2 fluxes in this biome, generating strong uncertainties in the assessment of the anthropogenic contribution.

Supplementary Table S4. Sea-air CO_2 Fluxes (1985-2018) from observations, GOBMs, a ROBM and a data-assimilation model in Tg C yr^{-1}. Gray cells stand for GOBMs that do not include any riverine CO_2 outgassing effect. For individual products, uncertainties are expressed as the standard deviation of the detrended linear annual mean. For ensemble means, uncertainties are expressed as the standard deviation across the ensemble. UoEx Wat20 is not contained in the ensemble mean of pCO_2 products. A separate estimate of the isolated impact of skin temperature corrections *(in cursives*) on integrated fluxes is provided based on the results of Dong et al. (2022).

pCO_2-products	**ATL**	**NA SPSS**	**NA STSS**	**NA STPS**	**AEQU**	**SA STPS**	**MED**
CMEMS_LSCE_FFNN	-334±21	-226±15	-126±8	-37±11	45±4	12±8	-1±2
CSIRML6	-341±28	-230±10	-128±8	-42±10	46±4	13±7	
JENA_MLS	-393±58	-251±32	-146±21	-51±23	61±9	2±20	-8±4
JMA_MLR	-497±52	-291±20	-133±8	-55±18	33±6	-51±11	
LDEO_HPD	-397±58	-258±25	-137±13	-53±18	47±6	0±15	5±2
MPI_SOMFFN	-315±65	-201±22	-118±9	-46±17	44±5	7±21	
NIES_ML3	-295±24	-206±8	-106±5	-34±8	41±2	9±5	1±1
OceanSODAETHZ	-362±36	-238±10	-125±10	-37±12	52±3	-16±9	3±3
Average pCO_2 products	**-365±64**	**-238±29**	**-127±12**	**-44±8**	**46±8**	**-3±21**	**0±4**
UOEX_WAT20	-444±69	-221±28	-140±16	-89±25	33±7	-26±23	
Skin-SST effect	*-65*	*-5*	*-12*	*-35*	*-8*	*-3*	
GOBMs							
CESM_ETHZ	-239±37	-157±8	-79±9	44±17	14±5	-54±12	
CNRM_ESM2_1	-593±49	-315±23	-161±20	-65±20	43±6	-74±21	-20±6
EC_Earth3	-534±31	-299±16	-146±9	-61±13	33±5	-50±11	-12±2
FESOM_REcoM_LR	-810±45	-409±28	-215±17	-76±16	26±5	-104±16	-32±3
MOM6_Princeton	-434±43	-354±17	-180±8	-5±19	37±7	88±18	-20±3
MPIOM_HAMOCC	-312±39	-315±21	-112±12	27±11	52±5	32±13	
MRI_ESM2_0	-458±31	-291±15	-120±6	-32±15	38±6	-41±12	-12±2
NorESM	-443±33	-299±12	-196±8	-13±16	51±7	21±14	-9±3
ORCA1	-529±42	-309±19	-161±12	-45±17	32±10	-29±18	-17±2
ORCA025_GEOMAR	-444±35	-307±14	-166±8	-24±14	26±5	26±13	-1±2
NEMO_PlankTOM5	-371±34	-189±12	-109±7	30±15	33±5	-130±14	
Average GOBMs	**-470±151**	**-295±69**	**-149±41**	**-20±41**	**35±11**	**-29±65**	**-11±10**
ROBMs							
ROMS_ETHZ	-614±44	-379±15	-176±9	-8±20	4±6	-63±14	
Assimilated models							
OCIM_v2021	-577±49	-391±28	-126±9	-125±17	98±5	-20±13	-14±2

Supplementary Table S5. FCO$_2$ trends (TgC yr^{-1} dec^{-1}) from observations, GOBMS, a ROBM and a data-assimilation model for 1985-2000 and for 2000-2018, the last between brackets. Significance levels (p-level) less than 0.01 and 0.05 are indicated by two and one '*' respectively.

pCO$_2$ products	ATL	NA SPSS	NA STSS	NA STPS	AEQU	SA STPS	MED
CMEMS-LSCE-FFNN	-111±8** [-144±10]**	-64±4** [-29±6]**	-17±3** [-34±3]**	-11±4* [-29±5]*	-1±1 [-13±1]	-16±2** [-40±2]**	-2±0** [1±1]**
CSIR ML6	-70±7** [-136±10]**	-25±3** [-41±4]**	-7±3* [-27±3]*	-12±3** [-27±5]**	1±1 [-12±2]	-28±2** [-29±3]**	
JENA-MLS	-111±28** [-153±24]**	-42±14* [-41±16]*	7±9 [-38±8]	-23±13 [-33±10]	-15±6* [-13±3]*	-34±10** [-31±8]**	-4±2* [3±2]*
JMA-MLR	97±15** [-78±11]**	61±7** [-3±4]**	1±2 [-19±3]	21±7** [-33±5]**	3±3 [-12±2]	11±5* [-11±3]*	
LDEO-HPD	6±22 [-111±25]	1±5 [-23±14]	0±5 [-32±5]	-3±8 [-29±8]	6±3 [-8±2]	1±7 [-15±7]	2±1** [-4±7]**
MPI-SOMFFN	58±7** [-156±19]**	8±5 [-49±8]	-9±3** [-32±3]**	15±4** [-27±7]**	9±1** [-11±1]**	35±3** [-37±7]**	
NIES-MLR3	-24±6** [-83±5]**	-8±2** [-21±3]**	-4±1** [-14±1]**	-6±2* [-21±2]*	-2±1* [-5±1]*	-4±1** [-20±1]**	1±0* [-2±0]*
OceanSODAETHZ	-36±8** [-145±11]**	-13±3** [-39±3]**	-3±3 [-33±3]	-13±3** [-35±4]**	1±2 [-7±1]	-10±3** [-30±4]**	3±1 [-1±1]
UOEX_WAT20	48±14** [-188±16]**	-33±16 [-65±10]	9±6 [-34±4]	30±12* [-33±6]*	12±3** [-10±1]**	29±7** [-46±5]**	
GOBMs							
CESM-ETHZ	-16±12 [-47±16]	-3±3 [-6±4]	2±3 [-7±3]	1±6 [-12±7]	-3±2 [-7±2]	-14±4** [-17±5]**	
CNRM-ESM2-1	-53±17** [-52±16]**	-17±7* [6±10]*	-13±8 [-12±7]	-5±6 [-1±9]	-7±3* [-7±2]*	-9±7 [-36±9]	-2±1 [-2±3]
EC-Earth3	-55±11** [-48±15]**	-34±5** [-6±8]**	-3±3 [-10±3]	-18±5** [-13±6]**	-2±2 [-4±2]	0±4 [-13±5]	1±0 [-1±1]
FESOM-REcoM-LR	-53±16** [-73±20]**	-18±8 [-35±12]	-23±7** [-16±7]**	-11±6 [-7±6]	2±2 [-1±2]	-4±5 [-14±7]	0±1 [-1±2]
MOM6-Princeton	-37±13* [-90±17]*	-9±4* [-45±5]*	-11±2** [-18±4]**	-12±6 [-8±8]	-7±3* [-4±3]*	0±6 [-13±8]	2±1 [-2±1]
MPIOM-HAMOCC	-54±13** [-56±15]**	-21±6** [-19±9]**	-2±3 [-8±4]	-12±5* [-4±5]*	-2±2 [-8±1]	-15±4** [-16±6]**	
MRI-ESM2_0	-43±10** [-65±13]**	-26±4** [-15±7]**	-7±2** [-7±2]**	-9±5 [-14±6]	-5±3* [-10±3]*	4±4 [-17±4]	0±1 [-1±1]
NorESM-OC1.2	-56±11** [-77±14]**	-32±4** [-23±5]**	-10±3** [-16±3]**	1±6 [-6±7]	-3±3 [-5±3]	-13±4** [-26±5]**	0±1 [-2±1]
ORCA1-LIM3PISCES	-54±11** [-67±15]**	-35±5** [-19±8]**	-2±3 [-18±3]	-16±5** [-12±5]**	-4±2* [-4±2]*	2±5 [-12±5]	0±1 [-1±1]
ORCA025-GEOMAR	-43±11** [-23±16]**	-22±3** [-2±6]**	-8±3* [-5±3]*	-11±5* [-5±6]*	-4±2 [-1±2]	1±4 [-10±5]	1±1 [0±1]
NEMO-PlankTOM5	-40±11** [-52±15]**	-4±4 [-2±5]	-3±2 [-9±3]	-8±6 [-8±7]	-5±2* [-9±2]*	-21±5** [-23±6]**	
ROBMs							
ROMS_ETHZ	-188±19** [-141±21]**	-66±6** [-53±7]**	-28±3** [-20±4]**	-24±8** [-10±9]**	-17±2** [-12±3]**	-47±5** [-41±6]**	
Assimilation model							
OCIMv2021	-45±16* [-111±18]*	-9±8 [-42±12]	0±3 [-15±4]	-12±7 [-24±6]	-3±2 [-4±2]	-20±5** [-23±5]**	-1±1 [-3±1]

Supplementary Table S6. Anthropogenic CO_2 storage change rates (1994-2007), and respective uncertainties, from GOBMs, data-assimilation model OCIMv2021, one DIC observation-based product (Gruber et al., 2019) and one inversion method based on age-based tracer measurements (Khatiwala et al., 2009) for the Atlantic Ocean and its biomes (see Methods). The mean uncertainty of the GOBMs ensemble is calculated in each region as the standard deviation of the nine-model estimates. The GOBMs mean rate from 1985 to 2018 is shown in italic. The MED is not included in the total Atlantic to facilitate direct comparison with the estimate from Gruber et al. (2019). C_{ant} storage changes from Gruber et al. (2019) have been extrapolated in the NA SPSS biome to regions north of 65°N assuming unchanged vertical distributions. The percentage increase obtained in this way was applied to Khatiwala et al. (2009) product. [§] C_{ant} uptake for Med Sea was estimated from CFCs by Schneider et al. (2010).

ΔC_{ant} storage rates [1994–2007] (PgC yr^{-1})	ATLANTIC	NA SPSS	NA STSS	NA STPS	AEQU	SA STPS	Med
GOBMs							
CESM-ETHZ	0.347	0.041	0.036	0.119	0.029	0.122	0.0128
CNRM-ESM2-1	0.572	0.109	0.085	0.223	0.048	0.107	0.0242
EC-Earth3	0.504	0.090	0.080	0.182	0.038	0.114	0.0107
FESOM_REcoM_LR	0.527	0.095	0.105	0.177	0.032	0.118	0.0228
MRI-ESM2-1	0.561	0.112	0.085	0.194	0.038	0.132	0.0291
NorESM-OC1.2	0.643	0.116	0.119	0.227	0.040	0.141	0.0224
ORCA025-GEOMAR	0.534	0.088	0.090	0.182	0.036	0.138	0.0157
ORCA1-LIM3PISCES	0.512	0.107	0.089	0.175	0.033	0.108	0.0135
PlankTOM12	0.330	0.023	0.023	0.088	0.035	0.161	0.0075
GOBM mean	**0.523** ±0.107	**0.087** ±0.033	**0.080** ±0.031	**0.175** ±0.045	**0.037** ±0.006	**0.127** ±0.018	**0.0176** ±0.007
GOBM mean*	*0.518 ±0.107*	*0.090 ±0.034*	*0.080 ±0.030*	*0.181 ±0.044*	*0.038 ±0.006*	*0.129 ±0.018*	*0.0175 ±0.007*
Assim. model							
OCIMv2021	**0.680** ±0.006	**0.127** ±0.001	**0.107** ±0.001	**0.236** ±0.002	**0.054** ±0.001	**0.156** ±0.001	**0.0186** ±0.001
C_{ant} reconstruction							
Gruber et al. 2019	**0.723** ±0.082	**0.087** ±0.007	**0.098** ±0.005	**0.254** ±0.017	**0.058** ±0.018	**0.216** ±0.041	-
Khatiwala et al. 2009	0.630 ±0.107	0.149 ±0.025	0.105 ±0.018	0.199 ±0.034	0.040 ±0.007	0.137 ±0.023	0.03 ±0.01[§]

Supplementary Table S7. Anthropogenic sea-to-air CO_2 fluxes outputs (1994-2007) from GOBMs and a data-assimilation model (OCIMv2021). The mean uncertainty of the GOBMs ensemble is calculated, in each region, as the standard deviation of the nine-model estimates. The GOBMs mean C_{ant} fluxes from 1985 to 2018 are shown in italic. The MED is included in the total Atlantic. The area of each region (m^2) is shown below the region's names. (*) [1985 –2018]

ΔC_{ant} storage rates [1994 – 2007] (PgC yr^{-1})	**ATLANTIC** ($68.7 \cdot 10^{12}$)	**NA SPSS** ($9.37 \cdot 10^{12}$)	**NA STSS** ($6.14 \cdot 10^{12}$)	**NA STPS** ($22.7 \cdot 10^{12}$)	**AEQU** ($8.69 \cdot 10^{12}$)	**SA STPS** ($19.6 \cdot 10^{12}$)	**Med** ($2.26 \cdot 10^{12}$)
GOBMs							
CESM-ETHZ	-0.317	-0.049	-0.049	-0.078	-0.034	-0.095	-0.012
CNRM-ESM2-1	-0.392	-0.135	-0.060	-0.087	-0.023	-0.075	-0.012
EC-Earth3	-0.365	-0.117	-0.059	-0.080	-0.025	-0.076	-0.009
FESOM_REcoM_LR	-0.411	-0.113	-0.082	-0.087	-0.022	-0.089	-0.017
MRI-ESM2-1	-0.418	-0.127	-0.067	-0.088	-0.032	-0.087	-0.017
NorESM-OC1.2	-0.491	-0.155	-0.084	-0.112	-0.032	-0.094	-0.014
ORCA025-GEOMAR	-0.373	-0.115	-0.065	-0.079	-0.028	-0.077	-0.009
ORCA1-LIM3-PISCES	-0.370	-0.121	-0.059	-0.080	-0.026	-0.074	-0.010
PlankTOM12	-0.289	-0.059	-0.040	-0.068	-0.034	-0.080	-0.008
GOBM mean	**-0.381** ± 0.059	**-0.110** ± 0.034	**-0.063** ± 0.014	**-0.084** ± 0.012	**-0.028** ± 0.005	**-0.083** ± 0.008	**-0.012**± 0.004
GOBM mean*	*-0.379 ± 0.059*	*-0.110 ± 0.034*	*-0.062 ± 0.014*	*-0.085 ± 0.012*	*-0.029 ± 0.004*	*-0.082 ± 0.009*	*-0.012 ± 0.003*
Assim. model							
OCIMv2021	-0.443	-0.129	-0.056	-0.118	-0.019	-0.104	-0.017

Supplementary Table S8. FCO$_2$ comparison with RECCAP1. In RECCAP1, the mean FCO2 estimate for the period 1990-2009 was evaluated as -0.42±0.07 PgC yr-1 based on the climatology of Takahashi et al. (2009) in the Atlantic Ocean from 79ºN to 44ºS, while the FCO2 estimate from the GOBMs was -0.49 PgC yr-1. To compare with the corresponding RECCAP2 estimate, the FCO2 for the latitudinal zone between 35 and 44ºS (area 6.24 1012 m2) should be added, as well as a correction for the different time periods evaluated in RECCAP1 and RECCAP2 (Hauck et al., 2023b).

PgC yr^{-1}	Global Ocean Biogeochemistry Models	Observation-based estimates
RECCAP2 best estimate Atlantic Ocean **1985-2018 (~35ºS-79ºN)**	**-0.470 ±0.150**	**-0.367 ±0.067**
RECCAP2 best estimate Atlantic Ocean **1985-2018** with RECCAP1 definition of the Atlantic Ocean (**44ºS-79ºN**)	**-0.610 ±0.157**	**-0.503 ±0.068**
RECCAP2 best estimate Atlantic Ocean **1990-2009** with RECCAP1 definition of the Atlantic Ocean (**44ºS-79ºN**)	**-0.59 ±0.16**	**-0.46 ±0.07**
RECCAP1 estimate 1990-2009	**-0.49 ±0.05**	**-0.42 ±0.07**