

# Global Carbon Budget 2024: Protocol Ocean Models

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**Deadline for submission of simulations: 15 July 2024**

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## Goal

To calculate the annual ocean CO<sub>2</sub> uptake for the Global Carbon Budget 2024

We invite groups that can commit to update their model results annually to contribute to this effort.

Your input will be used to estimate the global ocean CO<sub>2</sub> sink and the regional distribution in the Global Carbon Budget 2024, which we will submit as a living update of Friedlingstein et al. ESSD 2023. We invite one person per model to co-author the paper.

## Model sharing

Your annual mean model output for the globe and for the North, Tropics, and South will be part of an open-access database available with the ESSD paper. The gridded fields of fCO<sub>2</sub> and CO<sub>2</sub> flux will be made *open access*. The additional model output will be made available via Exeter, on request.

## Instructions for Output

HOWTO for upload to Amazon bucket will be provided separately!

When ready, please send an email to Nicolas Mayot ([N.Mayot@uea.ac.uk](mailto:N.Mayot@uea.ac.uk)) and Judith Hauck ([judith.hauck@awi.de](mailto:judith.hauck@awi.de)) with cc to Pierre Friedlingstein ([P.Friedlingstein@exeter.ac.uk](mailto:P.Friedlingstein@exeter.ac.uk)).

### PLEASE update model description tables and nominate author

Please report any new info (for new models) or changes from Table 4 and A2 in the current ESSD paper. For each model, nominate an author for the ESSD Global Carbon Budget 2023, and provide their full address and relevant acknowledgements on the Google Drive:

**Table 4:** [GCB2024 Table 4 ocean](#)

**Table A2:** [GCB2024 Table A2 GOBM processes setup](#)

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## Model Simulation and output for the Global Carbon Budget 2023

**We strongly encourage a multi centennial preindustrial spin-up simulation. This will be enforced in the future, foreseen for 2025 (not yet for 2024 in light of JRA forcing discontinuation in 2024).** We require **four** model simulations covering at least 1959-2023:

**simulation A:** with varying climate forcing conditions and varying atmospheric CO<sub>2</sub>

**simulation B:** with constant climate forcing conditions and constant atmospheric CO<sub>2</sub>.

**simulation C:** with constant climate forcing conditions and varying atmospheric CO<sub>2</sub>.

**simulation D:** with varying climate forcing conditions and constant atmospheric CO<sub>2</sub>

The simulation A should reproduce the interannual variability and trend in the ocean carbon uptake in response to changes in both atmospheric CO<sub>2</sub> and climate. Thus, models should be forced by observed climate (e.g., from reanalysis products) and observed atmospheric CO<sub>2</sub> throughout the entire time period. While there are no specified products recommended, we require continuity in forcing, i.e., only one forcing data should be used for the full time-series. Available forcing data sets for the full time-series are for example [NCEP/NCAR R1](#) and [JRA55](#) or [JRA55-do \(latest updates\)](#).

The simulations with constant climate forcing (B and C) should be consistent with the variable climate simulations (A and D), for example by using a climatology calculated from the variable forcing or looping over a single year.

We provide atmospheric CO<sub>2</sub> that should be used for consistency within the Budget. In the simulations with constant atmospheric CO<sub>2</sub>, the CO<sub>2</sub> should be kept constant at preindustrial levels (278 ppm, equivalent to year 1765 in Meinshausen et al 2011) and it should be started from the spin-

up or from another simulation with constant CO<sub>2</sub> at 278 ppm and not from a simulation with increasing atmospheric CO<sub>2</sub>. **The atmospheric xCO<sub>2</sub> value of 278 ppm will now be strictly enforced as announced already in last year's protocol.**

We will assume that no drift correction and other post-processing (e.g., adjustment for riverine outgassing) has been applied unless you let us know otherwise.

In addition to providing the globally-integrated air-sea CO<sub>2</sub> flux time-series calculated on the native model grid, we request that the raw output of the models is regridded by each group to a standard 1x1 latitude longitude grid (see below for grid convention), and that the resulting regridded data are provided at the indicated frequency for the following fields.

## Required output

1. Annual mean air-sea CO<sub>2</sub> flux time-series in PgC/yr for 1959-2022. **Please provide one file in netcdf format per simulation** which includes the four time-series (Globe, South (<30°S), Tropics (30°S-30°N), North (>30°N)).
2. Gridded monthly output in netcdf format on a regular grid. Please submit the gridded fields on a monthly 1x1 degree grid (0.5 to 359.5°E longitude, -89.5 to 89.5°N latitude), one file for full time-series per variable. Please make sure that your submitted time-series and 3d fields are consistent. For required variables, see below.
3. We require the following information for model evaluation, all as one dimensional time-series 1959-2023: AMOC, Southern Ocean surface salinity, Southern Ocean stratification index, Surface ocean Revelle factor (see Table, and info further down).

## Output requirement tables

Here, we define three tiers:

- Tier 1: The minimum request (with ancillary data) is mandatory for participation in GCB. Data for tier 1 are requested to be on a **regular 1x1 degree grid**.
- Tier 2: Full RECCAP2 request on a **regular 1x1 degree grid** will be made available for groups seeking to investigate specific research questions on the ocean carbon cycle under its own data policy (see below).
- Tier 3: Global and regional CO<sub>2</sub> flux time-series since 1850

Time period tier 1 and tier 2: 1959 – 2023.

### Tier 1: Minimum request

Variable Name	Units	Output frequency	Shape	Long name
<i>Surface ocean or 2D properties</i>				

fgco2_glob	Pg C yr <sup>-1</sup>	monthly	T	Globally integrated air-sea CO <sub>2</sub> flux ( <b>positive downward</b> )
fgco2_reg	Pg C yr <sup>-1</sup>	monthly	iT	Regionally integrated air-sea CO <sub>2</sub> flux ( <b>positive downward</b> ) (using regional bounds), i: number of regions
intDIC_1994_glob	PgC			Globally integrated DIC inventory in the year 1994 (average over 1994)
intDIC_1994_reg	PgC		i	Regionally integrated DIC inventory in the year 1994 (average over 1994)
intDIC_2004_glob	PgC			Globally integrated DIC inventory in the year 2004 (average over 2004)
intDIC_2004_reg	PgC		i	Regionally integrated DIC inventory in the year 2004 (average over 2004)
intDIC_2007_glob	PgC			Globally integrated DIC inventory in the year 2007 (average over 2007)
intDIC_2007_reg	PgC		i	Regionally integrated DIC inventory in the year 2007 (average over 2007)
intDIC_2014_glob	PgC			Globally integrated DIC inventory in the year 2014 (average over 2014)
intDIC_2014_reg	PgC		i	Regionally integrated DIC inventory in the year 2014 (average over 2014)
fgco2	mol m <sup>-2</sup> s <sup>-1</sup>	monthly	XYT	Flux density of the total air-sea CO <sub>2</sub> exchange ( <b>positive downward</b> )
sfco2	µatm	monthly	XYT	Surface ocean CO <sub>2</sub> fugacity (fCO <sub>2</sub> )
fice	-	monthly	XYT	fractional ice-cover (=sea-ice concentration) used for the computation of the air-sea exchange flux [0-1]
dissicos	mol m <sup>-3</sup>	monthly	XYT	sea-surface DIC
talkos	mol m <sup>-3</sup>	monthly	XYT	sea-surface Alkalinity
tos	degC	monthly	XYT	sea-surface temp
sos	-	monthly	XYT	sea-surface salinity (PSS-78)
intdic	mol m <sup>-2</sup>	monthly	XYT	vertically-integrated DIC
AMOC	Sv	monthly	T	maximum of the Atlantic meridional overturning streamfunction at 26°N
SO_SPSS_SSS		monthly	T	Mean Southern Ocean salinity (psu) in the SPSS biome, see RECCAP mask in google folder (variable name 'southern', value=2)
SO_STSS+SPSS_SSS		monthly	T	Mean Southern Ocean salinity (psu) in the SPSS and STSS biome, see RECCAP mask in google folder (variable name 'southern', values=1 and 2)
SO_SI	kg m <sup>-3</sup>	monthly	T	Southern Ocean stratification index, following Bourgeois et al. 2022
Revelle	-	monthly	XYT	Surface ocean Revelle factor

Ancillary data for tier 1:

Variable Name	Units	Shape	Long name
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area	m <sup>2</sup>	XY	Total surface area of each grid cell (regridded)
volume	m <sup>3</sup>	XYZ	Total volume of each grid cell (regridded)
mask_sfc	-	XY	Field indicating the fraction of presence of ocean in a grid cell [0-1]; fraction of surface area
mask_vol	-	XYZ	Field indicating the fraction of presence of ocean in a grid cell [0-1] fraction of volume
Area_tot_native	m <sup>2</sup>	ireg	Total surface ocean area covered by native grid, for global, T, S, N
Vol_tot_native	m <sup>3</sup>		Total ocean volume covered by native grid (global)
Atm_CO <sub>2</sub>	ppm	T	Time-series of atmospheric CO <sub>2</sub> used to drive the model.
RivCin	PgC yr <sup>-1</sup>		River carbon inflow into the ocean, time-average
Burial	PgC yr <sup>-1</sup>		Net C flux into the sediment, time-average

## Tier 2: Full RECCAP request

These data are also requested on the regular 1x1 grid.

Variable Name	Units	Output frequency	Shape	Long name
<b><i>Surface ocean or 2D properties</i></b>				
fgo2	mol m <sup>-2</sup> s <sup>-1</sup>	monthly	XYT	Gas exchange flux of O <sub>2</sub> (positive into ocean)
intpp	mol m <sup>-2</sup> s <sup>-1</sup>	monthly	XYT	vertically-integrated net primary production
epc100	mol m <sup>-2</sup> s <sup>-1</sup>	monthly	XYT	Particle flux of POC at 100 m
epc1000	mol m <sup>-2</sup> s <sup>-1</sup>	monthly	XYT	Particle flux POC at 1000 m
epc100type / epc1000type	mol m <sup>-2</sup> s <sup>-1</sup>	monthly	XYT	particle fluxes at 100 and 1000 m for different particle types (e.g., slow, fast or small, large)
epcalc100	mol m <sup>-2</sup> s <sup>-1</sup>	monthly	XYT	Export flux of CaCO <sub>3</sub> at 100 m
Kw	m s <sup>-1</sup>	monthly	XYT	Air-sea piston velocity
pco2atm	μatm	monthly	XYT	Atmospheric pCO <sub>2</sub> ('pco2atm' [uatm] will vary spatially, as opposed to the spatially uniform 'xco2atm' [ppm] atm CO <sub>2</sub> forcing due to corrections for atm pressure and vapor pressure)
alpha	mol kg <sup>-1</sup> atm <sup>-1</sup>	monthly	XYT	CO <sub>2</sub> solubility
no3os	mol m <sup>-3</sup>	monthly	XYT	Surface Dissolved Nitrate Concentration

po4os	mol m <sup>-3</sup>	monthly	XYT	Surface Total Dissolved Inorganic Phosphorus Concentration
sios	mol m <sup>-3</sup>	monthly	XYT	Surface Total Dissolved Inorganic Silicic acid Concentration
dfeos	mol m <sup>-3</sup>	monthly	XYT	Surface Dissolved Iron Concentration
o2os	mol m <sup>-3</sup>	monthly	XYT	Surface Dissolved Oxygen Concentration
intphyc	mol C m <sup>-2</sup>	monthly	XYT	Vertically-integrated Concentration of total phytoplankton expressed in carbon units
intphynd	mol C m <sup>-2</sup>	monthly	XYT	Vertically-integrated concentration of non-diatom phytoplankton expressed in carbon units (if available)
intdiac	mol C m <sup>-2</sup>	monthly	XYT	Vertically-integrated Concentration of diatom Phytoplankton expressed in carbon units (if available)
intzooc	mol C m <sup>-2</sup>	monthly	XYT	Vertically-integrated concentration of total zooplankton expressed in carbon units
chlos	kg m <sup>-3</sup>	monthly	XYT	Surface Mass Concentration of Total Phytoplankton expressed as Chlorophyll in Sea Water
mld	m	monthly	XYT	user-defined mixed layer depth
zeu	m	monthly	XYT	user-defined euphotic zone depth
zos	m	Monthly	XYT	Dynamic sea level
<b>Interior ocean or 3D properties</b>				
dissic	mol m <sup>-3</sup>	monthly	XYZT	Dissolved inorganic carbon
talk	mol m <sup>-3</sup>	monthly	XYZT	Total Alkalinity
thetao	degC	monthly	XYZT	seawater potential temperature
so	-	monthly	XYZT	Salinity (PSS-78)
epc	mol m <sup>-2</sup> s <sup>-1</sup>	monthly	XYZT	3D field of particle flux of POC
no3	mol m <sup>-3</sup>	monthly	XYZT	Dissolved Nitrate Concentration
po4	mol m <sup>-3</sup>	monthly	XYZT	Total Dissolved Inorganic Phosphorus Concentration
si	mol m <sup>-3</sup>	monthly	XYZT	Total Dissolved Inorganic Silicic Concentration
o2	mol m <sup>-3</sup>	monthly	XYZT	Dissolved Oxygen Concentration

### Tier 3: Extension to 1850

Time period: 1850 - 2021

Variable Name	Units	Output frequency	Shape	Long name
<b>Surface ocean or 2D properties</b>				
fgco2_glob	Pg C yr <sup>-1</sup>	monthly	T	Globally integrated air-sea CO <sub>2</sub> flux (positive downward)

fgco2_reg	Pg C yr <sup>-1</sup>	monthly	iT	Regionally integrated air-sea CO <sub>2</sub> flux ( <b>positive downward</b> ) (using regional bounds), i: number of regions
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## Naming convention

Please generate one file per variable (do not merge different variables into one file). This file should contain full time-series for 2-D-variable. For 3-D variables, split in chunks as need be.

**File names:** Groups are encouraged to follow the CMIP naming convention for file names (see this [link](#)), the file name can be constructed consistent with the following template

**file name =**

**<variable\_id>\_<model\_id>\_<experiment\_id>\_<member\_id>\_<grid\_label>\_<time\_range>\_<version\_id>.nc**

Example file name =

fgco2\_CESM-ETHZ\_A\_1\_gr\_1980-2018\_v20200101.nc

**version\_id:** We suggest to use version numbering of your files, indicating the date of creation as vYYYYMMDD.

**member\_id:** Will be “1” in most of the cases, but can be used to distinguish variants of the same model, such as runs with different forcings. Variant 1 should be considered the standard case used in the analysis.

## Evaluation metrics, additional info

1. Atlantic Meridional Overturning Circulation, AMOC: here defined as maximum of the Atlantic meridional overturning streamfunction at 26°N
2. Mean Southern Ocean salinity in the SPSS biome, see RECCAP mask in google folder (variable name ‘southern’, value=2)
3. Southern Ocean density criterion (simplified from Bourgeois et al., 2022):
  - a. Calculate average in situ density at surface between 30-55S
  - b. Calculate average in situ density at 1000 m depth between 30-55S
  - c. Calculate stratification index as  $SI = \rho(1000m) - \rho(surf)$
4. Surface ocean Revelle factor, XYT

## Data policy

The global annual average of the ocean sink data are available with the Global Carbon Budget publication. Ocean model simulation results are available under the CC-BY-NC license (<https://creativecommons.org/licenses/by-nc/4.0/>). Gridded data of CO<sub>2</sub> flux and surface ocean fugacity of CO<sub>2</sub> (fCO<sub>2</sub>) are available open access.

Additional model output (tier 1 and tier 2) is available upon request. For the current and last year global carbon budget, the full ocean model gridded data are available on request via the Global Carbon Budget website. The GCB-ocean modelling groups have identified studies they will conduct with these data over the coming year. If an external study does not conflict with these studies, the data will be made available. Co-authorship of GCB-ocean modelers depends on the importance of the GCB-ocean data in the study and should be discussed with the GCB-ocean coordinator (J. Hauck) early on in the process. All studies should be circulated to the modelling groups prior to submission.

GCB-ocean data from previous global carbon budget are freely available, with no request for GCB-ocean modelers co-authorship.

## References

- Bourgeois et al., 2022: <https://doi.org/10.1038/s41467-022-27979-5>  
Friedlingstein et al., 2023: <https://essd.copernicus.org/articles/15/5301/2023/>  
Meinshausen et al. 2011: <http://link.springer.com/10.1007/s10584-011-0156-z>