Global Carbon Budget 2022: Protocol Ocean Models

Deadline for submission of simulations and data-products: 08 July 2022

Goal: To calculate the annual ocean CO_2 uptake for the Global Carbon Budget 2022

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

Your input will be used to estimate the global ocean CO_2 sink and the regional distribution in the Global Carbon Budget 2022, which we will submit as a living update of Friedlingstein et al. ESSD 2022. 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 fCO2 and CO_2 flux will be made *open access*, tightly linked to our fair use data policy.

Model Simulation and output for the Global Carbon Budget 2022

We require **four** model simulations covering at least 1959-2021:

simulation A: with varying climate forcing conditions and varying atmospheric CO_2
simulation B: with constant climate forcing conditions and constant atmospheric CO_2.
simulation C: with constant climate forcing conditions and varying atmospheric CO_2.
simulation D: with varying climate forcing conditions and constant atmospheric CO_2

The simulation A should reproduce the interannual variability and trend in the ocean carbon uptake in response to changes in both atmospheric CO_2 and climate. Thus, models should be forced by observed climate (e.g., from reanalysis products) and observed atmospheric CO_2 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_2 but you can use your own estimation as long as it is based on observations. In the simulations with constant atmospheric CO_2, the CO_2 should be kept constant at preindustrial levels (278 ppm) and it should be started from the spin-up or from another simulation with constant CO_2 at 278 ppm and not from a simulation with increasing atmospheric CO_2.

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_2 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, for data-products and models, please provide:

1. Annual mean air-sea CO_2 flux time-series in PgC/yr for 1959-2021. **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

Models output:

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_2 flux time-series since 1850

Note minor changes compared to the original RECCAP2 request (in red: adding oxygen fluxes, monthly 3D fields, fCO_2 instead of pCO_2).

Time period tier 1 and tier 2: 1959 – 2021.

Tier 1: Minimum request:

Variable Name	Units	Output frequency	Shape	Priority	Long name
		Surface ocean or 2D properties			
fgco2_glob	Pg C yr^{-1}	monthly	T	1	Globally integrated air-sea CO_2 flux (**positive downward**)
fgco2_reg	Pg C yr^{-1}	monthly	iT	1	Regionally integrated air-sea CO_2 flux (**positive downward**) (using regional bounds), i: number of regions
intDIC_1994_glob	PgC			1	Globally integrated DIC inventory in the year 1994 (average over 1994)
intDIC_1994_reg	PgC		i	1	Regionally integrated DIC inventory in the year 1994 (average over 1994)
intDIC_2007_glob	PgC			1	Globally integrated DIC inventory in the year 2007 (average over 2007)
intDIC_2007_reg	PgC		i	1	Regionally integrated DIC inventory in the year 2007 (average over 2007)

fgco2	mol m^{-2} s^{-1}	monthly	XYT	1	Flux density of the total air-sea CO_2 exchange (**positive downward**)
sfco2	µatm	monthly	XYT	1	Surface ocean CO_2 fugacity (fCO_2)
fice	-	monthly	XYT	1	fractional ice-cover (=sea-ice concentration) used for the computation of the air-sea exchange flux [0-1]
dissicos	mol m^{-3}	monthly	XYT	1	sea-surface DIC
talkos	mol m^{-3}	monthly	XYT	1	sea-surface Alkalinity
tos	degC	monthly	XYT	1	sea-surface temp
sos	-	monthly	XYT	1	sea-surface salinity (PSS-78)
intdic	mol m^{-2}	monthly	XYT	1	vertically-integrated DIC

Ancillary data for tier 1:

Variable Name	Units	Shape	Priority	Long name
area	m^2	XY	1	Total surface area of each grid cell (regridded)
volume	m^3	XYZ	1	Total volume of each grid cell (regridded)
mask_sfc	-	XY	1	Field indicating the fraction of presence of ocean in a grid cell [0-1]; fraction of surface area
mask_vol	-	XYZ	1	Field indicating the fraction of presence of ocean in a grid cell [0-1] fraction of volume
Area_tot_native	m^2	ireg	1	Total surface ocean area covered by native grid, for global, T, S, N
Vol_tot_native	m^3		1	Total ocean volume covered by native grid (global)
Atm_CO_2	ppm	T	1	Time-series of atmospheric CO_2 used to drive the model.
RivCin	PgC yr^{-1}		1	River carbon inflow into the ocean, time-average
Burial	PgC yr^{-1}		1	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	Priority	Long name
Surface ocean or 2D properties					
fgo2	mol m-2 s-1	monthly	XYT	1	Gas exchange flux of O_2 (positive into ocean)
intpp	mol m^{-2} s^{-1}	monthly	XYT	1	vertically-integrated net primary production

epc100	mol m^{-2} s^{-1}	monthly	XYT	1	Particle flux of POC at 100 m
epc1000	mol m^{-2} s^{-1}	monthly	XYT	2	Particle flux POC at 1000 m
epc100*type* / epc1000*type*	mol m^{-2} s^{-1}	monthly	XYT	2	particle fluxes at 100 and 1000 m for different particle types (e.g., slow, fast or small, large)
epcalc100	mol m^{-2} s^{-1}	monthly	XYT	1	Export flux of $CaCO_3$ at 100 m
Kw	m s^{-1}	monthly	XYT	2	Air-sea piston velocity
pco2atm	µatm	monthly	XYT	2	Atmospheric pCO2 ('pco2atm' [uatm] will vary spatially, as opposed to the spatially uniform 'xco2atm' [ppm] atm CO2 forcing due to corrections for atm pressure and vapor pressure)
alpha	mol kg^{-1} atm^{-1}	monthly	XYT	3	CO2 solubility
no3os	mol m^{-3}	monthly	XYT	2	Surface Dissolved Nitrate Concentration
po4os	mol m^{-3}	monthly	XYT	2	Surface Total Dissolved Inorganic Phosphorus Concentration
sios	mol m^{-3}	monthly	XYT	2	Surface Total Dissolved Inorganic Silicic acid Concentration
dfeos	mol m^{-3}	monthly	XYT	2	Surface Dissolved Iron Concentration
o2os	mol m^{-3}	monthly	XYT	2	Surface Dissolved Oxygen Concentration
intphyc	mol C m^{-2}	monthly	XYT	1	Vertically-integrated Concentration of total phytoplankton expressed in carbon units
intphynd	mol C m^{-2}	monthly	XYT	2	Vertically-integrated concentration of non-diatom phytoplankton expressed in carbon units (if available)
intdiac	mol C m^{-2}	monthly	XYT	2	Vertically-integrated Concentration of diatom Phytoplankton expressed in carbon units (if available)
intzooc	mol C m^{-2}	monthly	XYT	1	Vertically-integrated concentration of total zooplankton expressed in carbon units
chlos	kg m^{-3}	monthly	XYT	1	Surface Mass Concentration of Total Phytoplankton expressed as Chlorophyll in Sea Water
mld	m	monthly	XYT	1	user-defined mixed layer depth
zeu	m	monthly	XYT	1	user-defined euphotic zone depth
Interior ocean or 3D properties					
dissic	mol m^{-3}	monthly	XYZT	1	Dissolved inorganic carbon
talk	mol m^{-3}	monthly	XYZT	1	Total Alkalinity
thetao	degC	monthly	XYZT	1	seawater potential temperature
so	-	monthly	XYZT	1	Salinity (PSS-78)
epc	mol m^{-2} s^{-1}	monthly	XYZT	1	3D field of particle flux of POC
no3	mol m^{-3}	monthly	XYZT	2	Dissolved Nitrate Concentration

po4	mol m^{-3}	monthly	XYZT	2	Total Dissolved Inorganic Phosphorus Concentration
si	mol m^{-3}	monthly	XYZT	2	Total Dissolved Inorganic Silicic Concentration
o2	mol m^{-3}	monthly	XYZT	2	Dissolved Oxygen Concentration

Tier 3:

Time period: 1850 - 2021

Variable Name	Units	Output frequency	Shape	Priority	Long name
Surface ocean or 2D properties					
fgco2_glob	Pg C yr^{-1}	monthly	T	1	Globally integrated air-sea CO_2 flux (**positive downward**)
fgco2_reg	Pg C yr^{-1}	monthly	iT	1	Regionally integrated air-sea CO_2 flux (**positive downward**) (using regional bounds), i: number of regions

Instructions for Output

Please send an email with a link to the annual mean time-series and **tier1** gridded data to Judith Hauck and Nicolas Mayot (judith.hauck@awi.de, N.Mayot@uea.ac.uk, cc 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 6 in the current ESSD paper. For each model, nominate an author for the ESSD Global Carbon Budget 2021, and provide their full address and relevant acknowledgements on the Google Drive:

https://docs.google.com/spreadsheets/d/1zpATa6aT0MBycaZtU1UzhbFveur_Wmy2kdpUkMK-OR4/edit#gid=0

Contact: Judith Hauck (Judith.hauck@awi.de), Nicolas Mayot (N.Mayot@uea.ac.uk) and Pierre Friedlingstein (P.Friedlingstein@exeter.ac.uk)

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_2 flux and surface ocean fugacity of CO_2 (fCO_2) are available open access.

Additional model output (tier 1 and tier2) is available upon request. For the current and last year global carbon budget, the full ocean model gridded data are available on request (judith.hauck@awi.de). 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.