

`README.md`

iLOSCAR

A web-based interactive carbon cycle model, built upon the classic LOSCAR model.
Forward and inverse mode included.

When using iLOSCAR, cite as:

Zeebe, R.E., 2012. LOSCAR: Long-term ocean-atmosphere-sediment carbon cycle reservoir model v2. 0.4. *Geoscientific Model Development* 5, 149–166.
(GPC paper in review.)

Author

Shihan Li | Department of Oceanography, Texas A&M University, College Station, Texas, 77843, USA

Contributors

Dr. Richard E. Zeebe | Department of Oceanography, University of Hawaii, Manoa Honolulu, Hawaii, 96822, USA

Dr. Shuang Zhang | Department of Oceanography, Texas A&M University, College Station, Texas, 77843, USA

For any questions, please contact shihan@tamu.edu

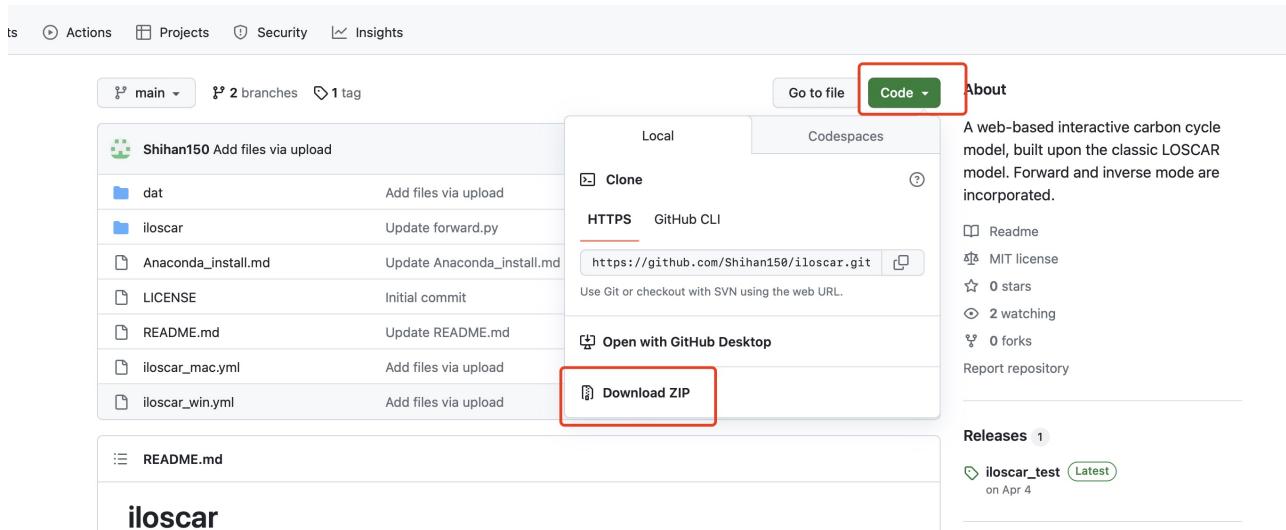
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Install

To successfully install iLOSCAR, please follow the tutorial provided. Note that the 'pip' command installation method is not effective in this case.

To avoid the potential inconvenience caused by the Python package inconsistency, we highly recommend downloading the code directly from <https://github.com/Shihan150/iloscarn> and setting up an Anaconda virtual environment to run iLOSCAR.



0. Anaconda install

Please refer to the [Anaconda_install.md](#) file for detailed instructions on installing Anaconda. If you already have Anaconda installed, you can proceed to the next step.

1. Create a virtual environment and run the model

Mac system

1. Open the Terminal and go to the iloscarn main directory downloaded in the previous step. One example is shown below and you need to specify your own path.

```
(base) shihan@OM629-99226 ~ % cd Documents/github/iloscarn
(base) shihan@OM629-99226 iloscarn %
```

2. Type `conda env create -f iloscar_mac.yml` to install the iloscar environment. It may take ~1 - 5 min.

```
(base) shihan@OM629-99226 iloscar % conda env create -f iloscar_mac.yml
```

3. Type `conda activate iloscar`

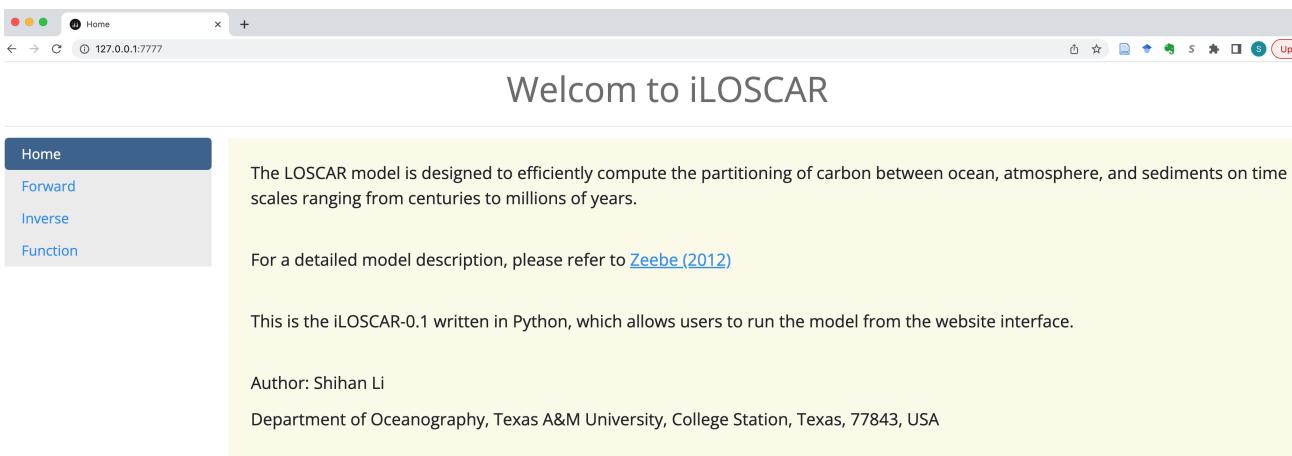
```
(base) shihan@OM629-99226 iloscar % conda activate iloscar  
(iloscar) shihan@OM629-99226 iloscar %
```

4. Go to the code file by typing `cd iloscar`

```
(iloscar) shihan@OM629-99226 iloscar % cd iloscar  
(iloscar) shihan@OM629-99226 iloscar %
```

5. Type `python app.py` and open <http://127.0.0.1:7777/> in your browser to run the model. It may take several to tens of seconds, depending on your machine.

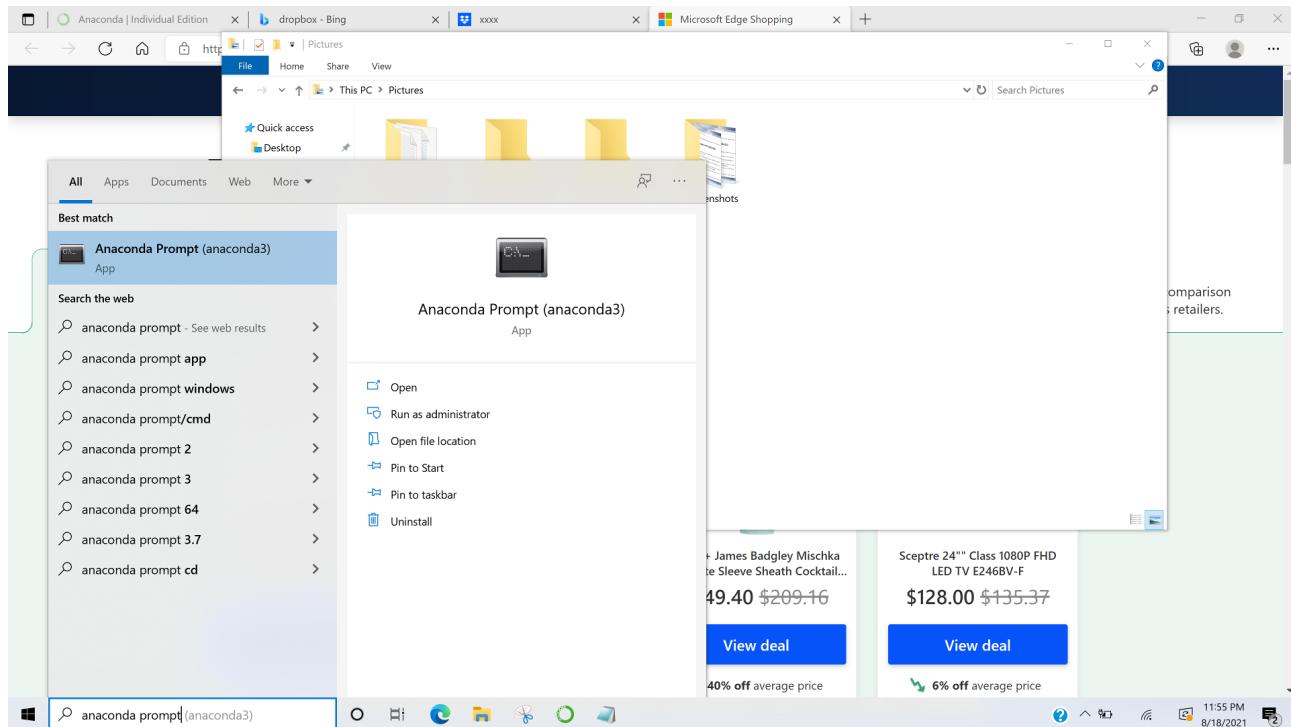
```
(iloscar) shihan@OM629-99226 iloscar % python app.py  
Dash is running on http://127.0.0.1:7777/  
  
* Serving Flask app 'app'  
* Debug mode: on
```



Succeed!

Windows 10

1. Open the start menu and look for **Anaconda Prompt**.



2. Go to the iloscarn main directory downloaded in the previous step. One example is shown below and you need to specify your own path.

3. Type **conda env create -f iloscarn.yml** to install the iloscarn environment. It may take ~1-2 mins.

```
(base) C:\Users\kaway\iloscar-main>conda env create -f iloscarn.yml
```

4. Type **conda activate iloscarn**

```
(base) C:\Users\kaway\iloscar-main>conda activate iloscarn  
(iloscar) C:\Users\kaway\iloscar-main>cd iloscarn
```

5. Type **python app.py** and open <http://127.0.0.1:7777/> in your browser to run the model.

```
(iloscar) C:\Users\kaway\iloscar-main\iloscar>python app.py  
Dash is running on http://127.0.0.1:7777/  
  
* Serving Flask app 'app'  
* Debug mode: on
```

Model description

For the details of iLOSCAR, including the relevant processes, the physical meanings of parameters, model structure, and derivation of equations, please refer to our paper (in preparation) and [Zeebe, 2012, GMD](#).

Model functions

Forward model

In the forward mode, a specific emission trajectory is applied as the forcing and the model will return the temporal evolution of various parameters in the global carbon cycle (see Output files section). The core part is to solve the ODE problem:

$$\$ \$ \{d\vec{y} / dt\} = F(t, \vec{y}) \$ \$$$

This is the ordinary differential equation system that governs the dynamic changes of the model's state variables over time, where t is time, \vec{y} is the vector containing various biogeochemical tracers, and F is the function used to calculate the derivatives of the state variables \vec{y} .

Inverse model

Five inversion options are provided in the inverse model. The aim of the inverse model is to derive the time-dependent carbon emission scenario ($f_{cinp}(t)$) and the isotopic composition of emitted carbon ($\delta^{13}C(t)$, which can minimize the relative errors between observations and corresponding modeling results:

$$\$ \$ f_{cinp}(t), \delta^{13}C(t) = \text{argmin} \sum_{i=1}^n |x_{\text{model}}(t_i) - x_{\text{obs}}(t_i)| / x_{\text{obs}}(t_i) | \$ \$$$

Option	Input	Output
pCO2	pCO2 proxy records	$f_{cinp}(t)$
d13c	d13c proxy records	$f_{cinp}(t)$, needs to assume a constant d13c for the emission
GSpH	Global surface pH records	$f_{cinp}(t)$

Option	Input	Output
pCO2_d13c	pCO2 and mean surface d13C proxy records	$f_{\text{cinp}}(t) + f_{\text{d13C}}(t)$
pH_d13c	pH and mean surface d13C proxy records	$f_{\text{cinp}}(t) + f_{\text{d13C}}(t)$

Smoothing function

A LOWESS smoothing function is available within the module. Users have the flexibility to upload data files and manually adjust the hyperparameters that controls the window fraction used in the LOWESS algorithm. Note that the default temporal resolution for output data is 0.2 kyr. For a comprehensive explanation of the smoothing algorithm, please refer to the following link: [LOWESS Smoothing Algorithm](#).

Model structure

```
iLOSCAR
├── app.py
├── iLOSCAR_backend.py
├── style.py
└── pages
    ├── home.py
    ├── forward.py
    ├── inverse.py
    └── Smoothing.py
├── petm_steady.dat
└── preind_steady.dat
```

Front-end

The web-based interface in iLOSCAR is developed upon the [Dash Package](#), which provides a low-code framework for rapidly building data apps in Python. The `app.py` is used to activate the model and the interface. The contents of the interface are controlled by the `.py` files in the 'pages' folder.

Back-end

The `iLOSCAR_backend.py` contains all the core functions to run the model, including setting up the model parameters and ODE functions, solutions for both forward and inverse model, saving the experiment results, as well as some tool functions such as solving the carbonate system from ALK and DIC.

Initial y file

Two files (***petm_steady.dat*** and ***preind_steady.dat***) are provided, which are the initial state files from the original LOSCAR default settings.

For each experiment, users can update parameters from the front-end, which will be transferred to call the backend functions.

Numeric algorithms

ODE solver for the forward model

The LSODA (an acronym for Livermore Solver for Ordinary Differential equations, with Automatic method switching for stiff and nonstiff problems) algorithm is employed as the ODE solver, given its demonstrated stability when dealing with stiff problems, as highlighted by [Hindmarsh \(1992\)](#). The algorithm is available in the [Python Scipy Package](#).

TOMS 748, a Root-finding algorithm, for the inverse model

To solve the inverse problem, the TOMS 748 root-finding algorithm is applied, which uses a mixture of inverse cubic interpolation and Newton-quadratic steps to enclose zeros of contiguous univariate functions ([Alefeld et al., 1995](#)). This algorithm offers the advantage of a rapid convergence rate, which significantly accelerates the inversion process. Additionally, Algorithm 748 is readily available in the [Python Scipy package](#). Note that two parameters (\$a, b\$) need to be given to determine the boundaries of the algorithm search interval, i.e., \$f(a)\times f(b) < 0\$, where \$f\$ is the function \${x_{\text{model}}}(t_i) - {x_{\text{obs}}}(t_i)\$. In our context, \$a, b\$ represent the possible maximum C burial and emission rates (in Gt), respectively. Default settings are -0.5 and 5, which should work for most applications. Increase the absolute value can reduce the failure probability of the experiment, but at the expense of running speed. Therefore, users need to decide the values carefully according to their domain knowledge, to optimize the model performance.

External input files

Some external files are required to run the model.

Mode	File usage	Format	Requirement
Forward	Initial y0	.dat	1 column, 140 (for modern) or 184 rows; y0 satisfies $dy_0/dt = F(t=t_0, y_0) = 0$

Mode	File usage	Format	Requirement
	Emission file	.dat	When LOADFLAG == 2, two columns (age (yr) + emission mass (Gt/yr)). When LOADFLAG == 3, three columns (age (yr) + emission mass (Gt/yr)+d13c of input (per mil)).
	Save yfinal	.dat	When Save ystart == 1, y(t=tfinal) will be saved into the specified .dat file
Inverse	pCO2 data for inversion	.csv	2 column with headline, age (yr) + pCO2 (ppmv)
	mean surface pH data for inversion	.csv	2 column with headline, age (yr) + pH
	mean surface d13c data for inversion	.csv	2 column with headline, age (yr) + d13c
Function	data to be smoothed	.csv	2 column with headline, age (yr) + data

Output files

In each experiment, the model will output the following data files.

File.csv	Unit	Variable
tcb	(deg C)	OCN temperature
dic	(mmol/kg)	OCN total dissolved inorganic carbon
alk	(mmol/kg)	OCN total alkalinity
po4	(umol/kg)	OCN phosphate
dox	(mol/m3)	OCN dissolved oxygen
dicc	(mmol/kg)	OCN DIC-13
d13c	(per mil)	OCN delta13C(DIC)
d13ca	(per mil)	ATM delta13C(atmosphere)

File.csv	Unit	Variable
pco2a_d13c	(ppmv, per mil)	ATM atmospheric pCO2 and d13c
co3	(umol/kg)	OCN carbonate ion concentration
ph	(-)	OCN pH (total scale)
pco2ocn	(uatm)	OCN ocean pCO2
omegaclc	(-)	OCN calcite saturation state
omegaarg	(-)	OCN aragonite saturation state
fca	(-)	SED calcite content Atlantic
fci	(-)	SED calcite content Indian
fcp	(-)	SED calcite content Pacific
fct	(-)	SED calcite content Tethys (PALEO only)
ccda	(m)	SED calcite compens. depth Atlantic
ccdi	(m)	SED calcite compens. depth Indian
ccdp	(m)	SED calcite compens. depth Pacific
ccdt	(m)	SED calcite compens. depth Tethys (PALEO only)
Surface_dic_alk_d13c_ph	(-)	Mean OCN surface DIC, ALK, d13c, and pH
Carbon_inventory	(mol)	Total carbon and alkalinity in the ocean

Example

(Example data files could be downloaded [here](#).).

For all tables, the first column can be adjusted manually.

1. Forward model example

The general workflow is as follows:

1. Select the desired version in Table 1;
2. Tune relevant parameters in Table 2 and turn off the carbon emission in Table 3;
3. Change the t0 and tfinal in Table 3 and spin up the model for 2 Ma. Check if the steady state is achieved;
4. Utilize the final steady state achieved in the previous step as the initial condition (y0). Enable the carbon emissions and run the model.

To assist users in familiarizing themselves with the process of running iLOSCAR in a forward manner, an example is provided.

1.1 Original PETM example from [Zeebe et al., 2009](#).

Please note that this specific implementation does not include the prolonged carbon release following the main emission event or the inferred reverse circulation described in the original study by Zeebe et al., 2009.

Tuning the steady state

Please note that if you intend to run the default model, you can skip this part as the initial y0 values are provided in our package (preind_steady.dat and petm_steady.dat), which can be used directly.

1. Go to the Forward page

The screenshot shows a web browser window with the URL 127.0.0.1:7777. The title bar says "Welcom to iLOSCAR". On the left, there is a sidebar with four options: "Home" (selected), "Forward" (highlighted with a red box), "Inverse", and "Function". The main content area starts with a paragraph about the LOSCAR model's purpose: "The LOSCAR model is designed to efficiently compute the partitioning of carbon between ocean, atmosphere, and land, on time scales ranging from centuries to millions of years." Below this is a link to "Zeebe (2012)". Further down, it says "This is the iLOSCAR-0.1 written in Python, which allows users to run the model from the website interface." Under "Author", it lists "Shihan Li | Department of Oceanography, Texas A&M University, College Station, Texas, 77843, USA". Under "Contributors", it lists "Dr. Richard E. Zeebe | Department of Oceanography, University of Hawaii, Manoa Honolulu, Hawaii, 96822, USA" and "Dr. Shuang Zhang | Department of Oceanography, Texas A&M University, College Station, Texas, 77843, USA".

2. Set the PALEO parameter to '1', LOADFLAG to '0', and Save ystart to '1'.

The model parameters in Table 2 will adjust automatically to the palaeo settings.

Save ystart determines if the model will export the y values at t=tfinal. The export file name can be manually specified in Table 4. In this example, we use the 'petm_steady.dat'.

Step 1: select the experiment version

Value	Parameter	Options	Comment
1	PALEO	1/0	1: Paleo setup; 0: Modern setup
1	Sediment	1/0	1: Sediment box on; 0: sediment box off
0	LOADFLAG	1/0	1: load initial settings from an external file; 0: off
1	Ocean temperature change	1/0	1: Ocean temperature change (co2-sensitivity) ON 0: Off
1	Save ystart	1/0	1: the experiment aim is to autospin to the steady state and the system variables at t=tfinal will be saved 0: off.

3. Turn off carbon emissions by changing 'emission pattern' to 0 in Table 3.

Step 3: select the carbon emission scenario

Value	Parameter	Unit	Comment
0	emission pattern	3/2/1/0	3: emission scenario with time-dependant d13c 2: emission scenario from the external files 1:carbon emission in uniform distribution 0: no carbon emission

4. Modify 'tfinal' to '2e7' in Table 2.

Step 2: select the model parameters

Value	Parameter	Unit	Comment
0	t0	yr	start time (yr) for the experiment
20000000	tfinal	yr	end time (yr) for the experiment

5. Provide a name for your experiment and run it. I name it as Zeebe2009 here.

Experiment name

The modeling results will be saved in a dictionary after experiment name

6. The running information will be displayed in the following chunk.

@ This is the PALEO setup including Tethys
@ Default initial values are used
@ The carbon injection is OFF

@ The experiment name : Zeebe2009
@ No. ocean basins : 4
@ No. ocean boxes : 13
@ No. ocean tracers : 6
@ Atmospheric Carbon : 1
@ Atmospheric Carbon-13 : 1
@ No. sediment depth levels: 13
@ No. sediment C-13 levels : 13
@ No. equations : 184

@ Starting integration
[tstart tfinal]=[0.00e+00 2.00e+05]

Progressing...

7. Once the integration is complete, the final steady state will be saved to the file specified in Table 4 ('petm_steady.dat' in this case).

The exported file can be used as the initial y_0 for perturbation experiments later.

Integration finished.

46.49s used.

Starting to save the modeling results.

System variables at $t=2.00e+05$ has been saved to ./petm_steady.dat

Perturbation experiment

1. Stay on the same page. In table 1, set LOADFLAG to '1' and Save ystart to '0'.

Step 1: select the experiment version

Value	Parameter	Options	Comment
1	PALEO	1/0	1: Paleo setup; 0: Modern setup
1	Sediment	1/0	1: Sediment box on; 0: sediment box off
1	LOADFLAG	1/0	1: load initial settings from an external file; 0: off
1	Ocean temperature change	1/0	1: Ocean temperature change (co2-sensitivity) ON 0: Off
0	Save ystart	1/0	1: the experiment aim is to autospin to the steady state and the system variables at $t=t_{final}$ will be saved 0: off.

2. In table 2, change ' t_{final} ' to '2e5'.

Step 2: select the model parameters

Value	Parameter	Unit	Comment
0	t_0	yr	start time (yr) for the experiment
200000	t_{final}	yr	end time (yr) for the experiment

3. Select the carbon emission scenario in Table 3. In this example, set: 'emission pattern' == 1, 'emission amount' == 3000,

```
'd13c emission' == -55, 'emission start' == 0,
'emission duration' == 6000.
```

Step 3: select the carbon emission scenario

Value	Parameter	Unit	Comment
1	emission pattern	3/2/1/0	3: emission scenario with time-dependant d13c 2: emission scenario from the external files 1:carbon emission in uniform distribution 0: no carbon emission
3000	emission amount	Gt	total amount of carbon input, only useful when Emission_Pattern == 1
-55	d13c emission	per mil	d13c of input carbon, only useful when Emission_Pattern == 1
0	emission start	yr	start year for the emission, only useful when Emission_Pattern == 1
6000	emission duration	yr	duration for the emission, only useful when Emission_Pattern == 1

4. Run the model.

Optionally, you can click the 'Clean the output' button to clear the experiment information from the previous run.

However, this step is optional, and you can proceed to run the next experiment directly.

Experiment name

Zeebe2009

Run

The modeling results will be saved in a dictionary
after experiment name

Optional → Clean the output

- @ This is the PALEO setup including Tethys
- @ Loaded initial values are used
- @ The carbon injection is ON

Help you check the experiment information

6. Once the integration is complete, the modeling results will be saved in the exp_name folder (e.g., 'Zeebe2009').

The folder will be located in the same directory where you ran your Python code.

Modeling mean surface DIC, ALK, pH and d13c, pCO₂, and CCD for each ocean basin will be displayed when integration succeeds.

Integration finished.

10.17s used.

Starting to save the modeling results.

It is faster than the previous steady state run. It is because we use Numba to compile our code, which may take 15-30 seconds in different machines. In this run, the compilation results from the previous run can be used directly, thus taking less time .

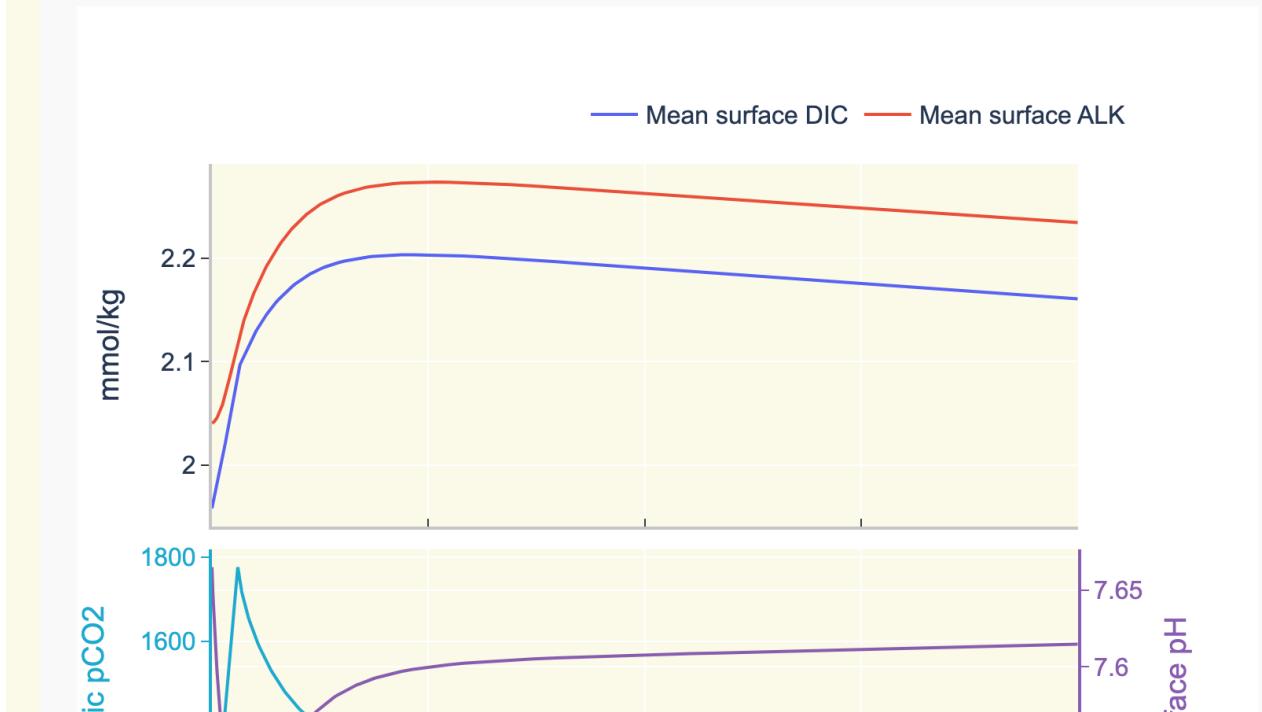
Modeling results have been saved to Zeebe2009 folder.

The experiment succeeds. Congratulations!

The final average surface pH is: 7.61

The final average surface d13c is: 1.83

The final pCO₂ is: 1247.31



2. Inverse model example

The general workflow for the inverse model is as follows:

1. Tune the parameters and obtain the initial steady state y_0 using the forward model page.
2. Go to the inverse model page and specify the file names that contain the target records.
3. Adjust the parameters based on the tuning results obtained from the forward model.
4. Run the inverse model.

2.1 Inverse twin experiment

To evaluate the performance of the inverse algorithm, an identical twin test can be conducted. In this type of test, a preliminary run of the forward model is performed to generate a synthetic 'truth' dataset that can be used for subsequent inversion experiments. This allows for a straightforward assessment of the accuracy of the inverse algorithm.

2.1.1. Preliminary run

- In the Forward page, maintain all the default settings in Table 1 and 2, except for setting 'tfinal' to '4e4'.
- Set the 'emission pattern' to 3 in Table 3, and input 'pulse_emi.dat' in the second row of Table 4. Note that the file name should be provided as a relative path.
- 'puluse_emi.dat' file represents two emission events:
a fast and short event (3000 Gt in 3 kyr) and a slow and long event (10000 Gt in 35 kyr).
This dataset serves as an excellent example for checking the performance of the inversion algorithm.
- Provide a name for the experiment and run it.

Step 3: select the carbon emission scenario

Value	Parameter	Unit	Comment
3	emission pattern	3/2/1/0	3: emission scenario with time-dependant d13c 2: emission scenario from the external files 1:carbon emission in uniform distribution 0: no carbon emission
1000	emission amount	Gt	total amount of carbon input, only useful when Emission_Pattern == 1
-55	d13c emission	per mil	d13c of input carbon, only useful when Emission_Pattern == 1
0	emission start	yr	start year for the emission, only useful when Emission_Pattern == 1
3000	emission duration	yr	duration for the emission, only useful when Emission_Pattern == 1

Step 4: select required external file, path information included

File name	Comment
./preind_steady.dat	Required only when LOADFLAG == 1 in Step 1
./dat/pulse_emi.dat	Required only when Emission pattern == 2 or 3 in Step 3
./preind_steady.dat	Required only when Save ystart == 1

Experiment name

twin_exp

The modeling results will be saved in a dictionary
after experiment name

Run

Cancel

Clean the output

2.1.2. Prepare data for inversion

- Navigate to the twin_exp folder.
- Locate the pCO2 results in the pCO2_d13c.csv file.
- Select the desired pCO2 values and save them as twin_pco2_for_inv.csv.
- Keep in mind that the modeling results may have a high temporal resolution, so it is recommended to select a subset of data to ensure reasonable inversion times.
- Repeat the same process for the mean surface pH and surface d13C results. Select the relevant values and save them accordingly for use in the inversion experiment.

2.1.3. Inverse experiment (457.08s used)

- Go to the Inverse page.

From the dropdown menu, select 'pCO2 + mean surface d13c'. Manually input the target file names.

Welcome to iLOSCAR

Select the target variable

- pCO2
- Mean surface ocean d13c
- Global surface pH
- pCO2 + mean surface
d13c**
- pH + mean surface d13c

- In Table 3, specify the boundary values for the Toms748 root-finding algorithm. These values represent the expected minimum and maximum degassing rates. The closer the range, the faster the experiment will run, but there is a higher chance of failure. The default values of -0.1 and 2 Gt/yr should be suitable for most applications.

Step 3: choose the carbon emission scenario

Value	Parameter	Unit	Comment
-55	d13c emission	per mil	d13c of input carbon, required for the single version
-0.1	Lower boundary in bracket for toms748 method. Absolute value equivalent to expected maximum organic burial rate	Gt/yr	Default settings can work for most applications. Adjust the value for extreme case
2	Higher boundary in bracket for toms748 method. Value equivalent to maximum degassing rate	Gt/yr	Increase the absolute value can reduce the failure probability of experiment, but at the expense of running speed

- Provide a name for the experiment and run the model.
- If you need to terminate the ongoing experiment, simply click the 'Cancel' button.

Experiment name

The modeling results will be saved in a dictionary after experiment name

Run

Cancel

Clean the output

- If you encounter an error similar to the figure below, it means that some degassing rates exceed the default upper boundary in Table 3. Adjust the values in the second and third rows of Table 3 accordingly.

⌚ Callback error updating ..info_integration_inv... 2:22:13 PM

Callback error updating
..info_integration_inv.children...ysol_inv.data...tsol_inv.data..

```
line 358, in model_run
ems_new, results = toms748(cost_function, toms_low , toms_high,
File "/Users/shihan/opt/anaconda3/envs/iloscari/lib/python3.9/site-
packages/scipy/optimize/_zeros_py.py", line 1374, in toms748
result = solver.solve(f, a, b, args=args, k=k, xtol=xtol, rtol=rtol,
File "/Users/shihan/opt/anaconda3/envs/iloscari/lib/python3.9/site-
packages/scipy/optimize/_zeros_py.py", line 1221, in solve
status, xn = self.start(f, a, b, args)
File "/Users/shihan/opt/anaconda3/envs/iloscari/lib/python3.9/site-
packages/scipy/optimize/_zeros_py.py", line 1121, in start
raise ValueError("a, b must bracket a root f(%e)=%e, f(%e)=%e " %
ValueError: a, b must bracket a root f(-2.000000e+00)=-5.335239e+02,
f(5.000000e+00)=-4.983734e+01
```

- Once the inverse experiment is successful, the results will be displayed.

Progressing...

450.16s used.

The calculated emission scenario has been saved to double_inversion_emission.csv and double_inversion_emission_d13c.csv

Starting to save the modeling results.

Inversed emission trajectory are saved here

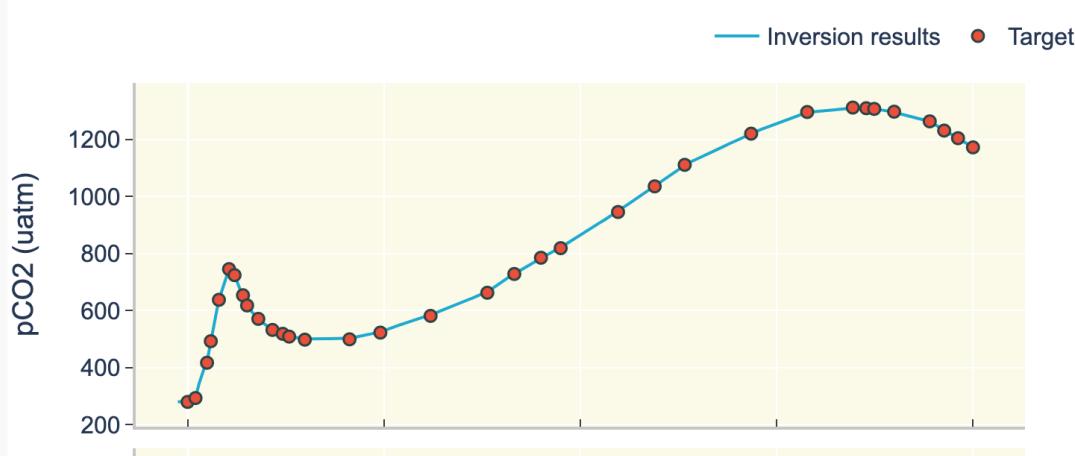
Modeling results have been saved to twin_inverse folder.

The experiment succeeds. Congratulations!

The final average surface pH is: 7.79

The final average surface d13c is: -0.12

The final pCO₂ is: 1173.31



2.2 PETM experiment after Gutjahr et al., 2017

1. Derive the steady state y_0

- Go to the Forward page.
- In Table 1, set PALEO == 1, LOADFLAG == 0, Save ystart == 1
- In Table 2, set tfinal == 1e7, pCO₂_ref == 834, pCO₂_initial == 834, silicate weathering0 = 7.5, carbonate weathering0 = 17.5, d13c volcanic == -1.5
- In Table 4, input './gutjahr2017.dat' in the third row.
- Provide a name for the experiment and run the model.

2. Inversion experiment (838s)

- Go to the Inverse page.

- Download the 'Gutjahr_pH.csv' and 'Gutjahr_d13c.csv' from the [link](#).
- In Table 1, set PALEO == 1, LOADFLAG == 1
- In Table 2, set pCO2_ref == 834, pCO2_initial == 834, silicate weathering0 = 7.5, carbonate weathering0 = 17.5, d13c volcanic == -1.5
- In Table 4, input './gutjahr2017.dat'
- Provide a name for the experiment and run the model.
- Succeed!

@ Starting inversion

Progressing...

838.00s used.

The calculated emission scenario has been saved to double_inversion_emission_pH.csv and double_inversion_emission_d13c_pH.csv

Starting to save the modeling results.

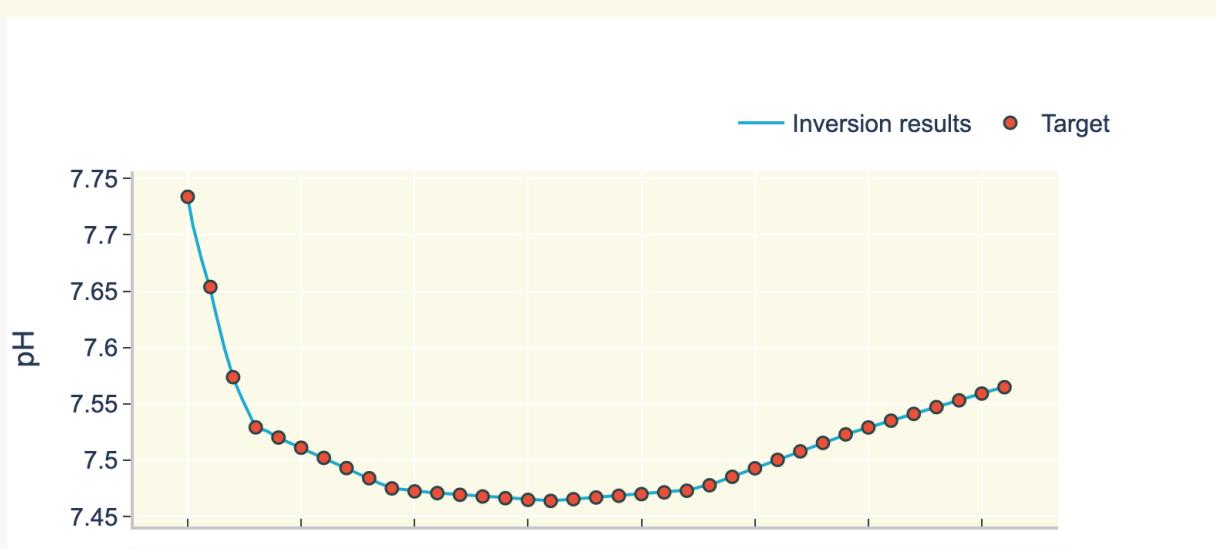
Modeling results have been saved to gutjahr_test folder.

The experiment succeeds. Congratulations!

The final average surface pH is: 7.56

The final average surface d13c is: 1.35

The final pCO2 is: 1787.31



2.3 PTB experiment after Wu et al., 2023

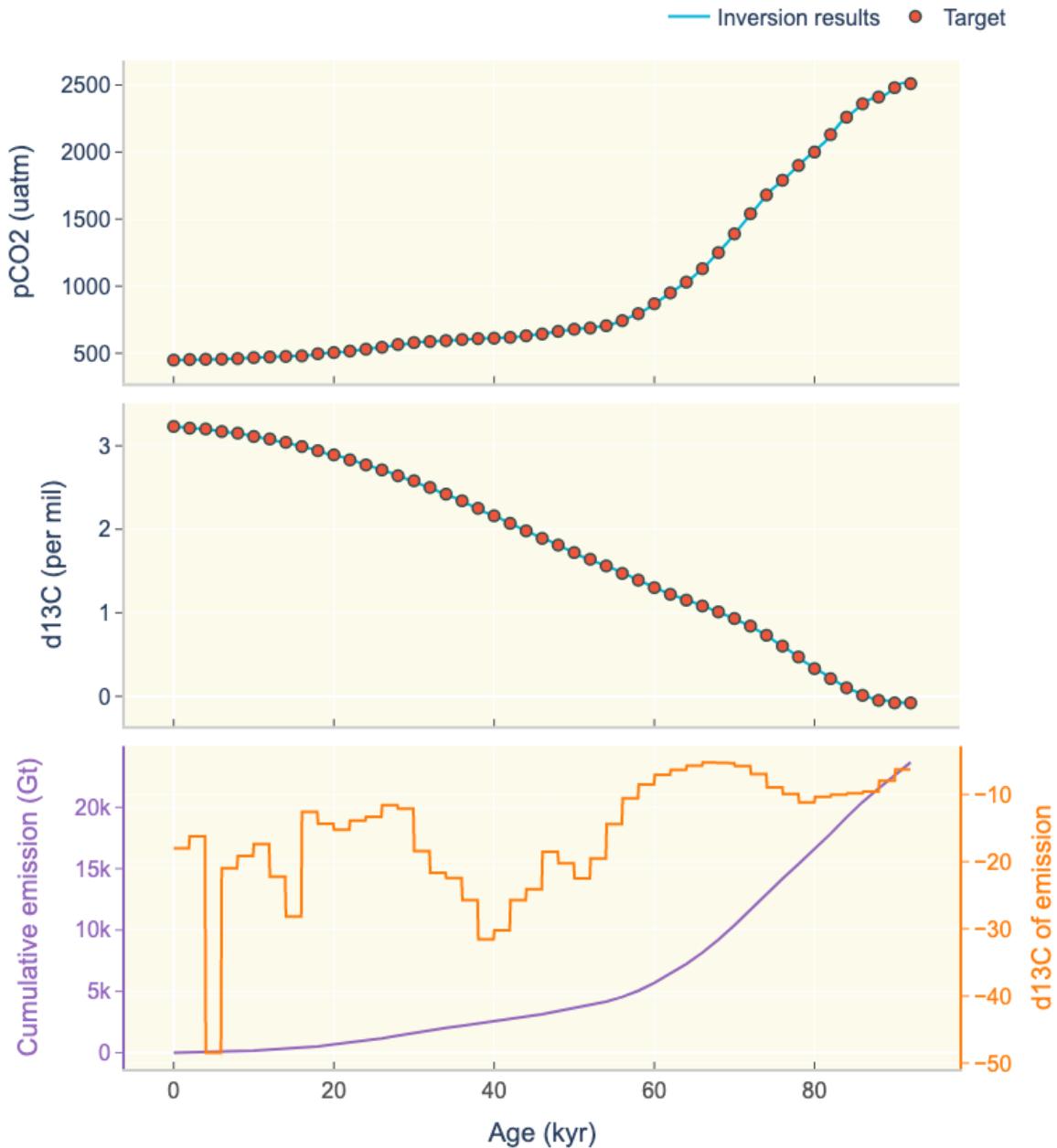
1. Derive the steady state y_0

- Go to the Forward page.
- In Table 1, set PALEO == 0, LOADFLAG == 0, Save ystart == 1
- In Table 2, set tfinal == 1e7, pCO2_ref == 425, pCO2_initial == 449, , fsh == 5, silicate weathering0 = 12, carbonate weathering0 = 17, d13c volcanic == -1.3, ca concentration == 0.013, mg concentration == 0.042
- In Table 4, input './wu2023.dat' into the third row.
- Provide a name for the experiment and run the model.

2. Inversion experiment (s)

- Go to the Inverse page.
- Download the 'wu_pco2.csv' and 'wu_d13c.csv' from the [link](#).
- In Table 1, set PALEO == 0, LOADFLAG == 1
- In Table 2, set pCO2_ref == 425, pCO2_initial == 449, fsh == 5, silicate weathering0 = 12, carbonate weathering0 = 17, d13c volcanic == -1.3, ca concentration == 0.013, mg concentration == 0.042, nsi == 0.4, ncc == 0.4
- In table 3, set lower and higher boundary as [-0.1, 1], which will accelerate the model
- In Table 4, input './wu2023.dat'
- Provide a name for the experiment and run the model.

- Succeed!



Common bugs

1. The age of target records must be in year unit.
2. The inversion algorithm failed to converge and the error message is similar to the figure below.

⌚ Callback error updating ..info_integration_inv... 2:22:13 PM

```
Callback error updating
..info_integration_inv.children...ysol_inv.data...tsol_inv.data..
```

```
line 358, in model_run
ems_new, results = toms748(cost_function, toms_low , toms_high,
File "/Users/shihan/opt/anaconda3/envs/iloscarr/lib/python3.9/site-
packages/scipy/optimize/_zeros_py.py", line 1374, in toms748
result = solver.solve(f, a, b, args=args, k=k, xtol=xtol, rtol=rtol,
File "/Users/shihan/opt/anaconda3/envs/iloscarr/lib/python3.9/site-
packages/scipy/optimize/_zeros_py.py", line 1221, in solve
status, xn = self.start(f, a, b, args)
File "/Users/shihan/opt/anaconda3/envs/iloscarr/lib/python3.9/site-
packages/scipy/optimize/_zeros_py.py", line 1121, in start
raise ValueError("a, b must bracket a root f(%e)=%e, f(%e)=%e " %
ValueError: a, b must bracket a root f(-2.000000e+00)=-5.335239e+02,
f(5.000000e+00)=-4.983734e+01
```

To avoid the error, try:

- i. make sure that the initial modeling proxy value (pH, pCO₂, d¹³C) matches the given initial proxy records.
- ii. adjust the values in the second and third rows of Table 3 accordingly. Increasing the absolute values is a safe method, but will reduce the speed.