

1. Getting started

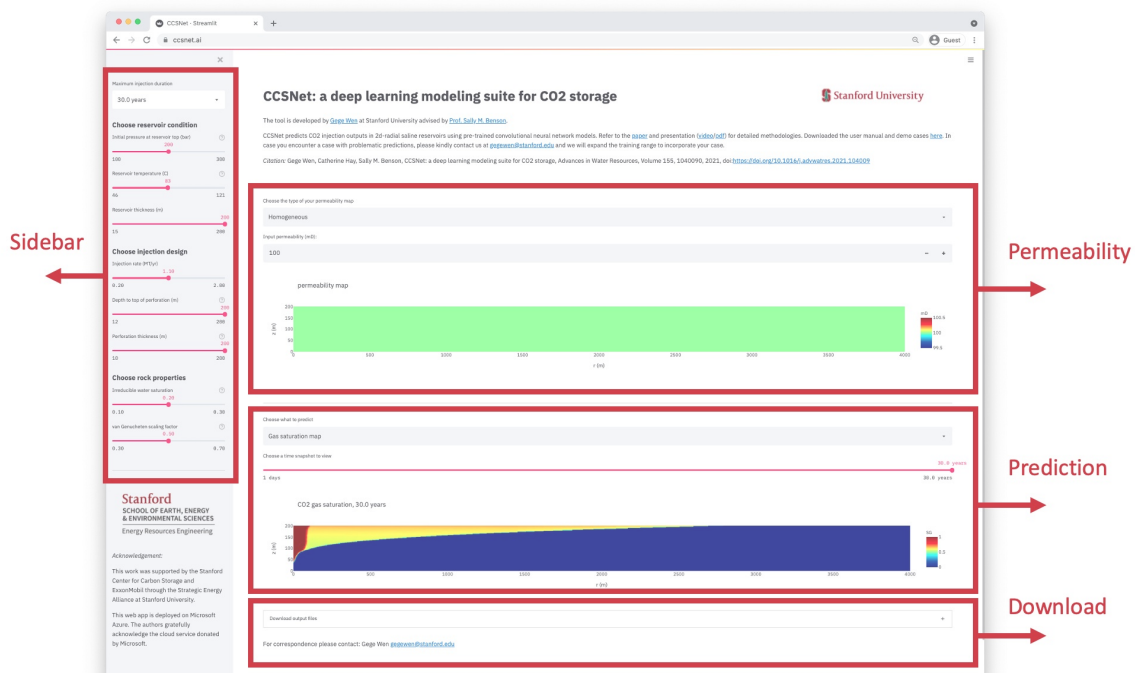
[CCSNet.ai](https://ccsnet.ai) hosts pre-trained convolutional neural network models to provide prediction of CO₂ injection outputs in 2d-radial saline reservoirs. Refer to the [journal article](#) or presentation ([video/pdf](#)) for methodologies.

In case you encounter a permeability map or variable combinations with problematic predictions, please kindly contact us at gegewen@stanford.edu and we will expand the training range to incorporate your case.

1.1 Overview

This screenshot indicates the locations of 4 main sections on the interface - Sidebar, Permeability, Prediction, and Download.

- **Sidebar:** user can choose the maximum injection duration from the top drop down, and 8 variables using the sliders that controls the **reservoir condition**, **injection design**, and **rock properties**.
- **Permeability:** CCSNet incorporates 4 types of permeability maps **Homogeneous**, **Synthetic**, **Heterogeneous**, **Purely Layered**, and **User Upload**.
- **Output:** the app provides **Gas saturation map**, **Pressure buildup map**, **Reservoir pressure map**, **Molar fraction of dissolved phase map**, and **Sweep efficiency factor**, each of which can be rendered instantly in real time. The predictions are upto a 30 years.
- **Download:** the meta data and predictions are available for download as **.xlsx** files in this section.



1.2 General tips

- The web app *automatically* re-renders the output once any input value is being changed. No need to click anything to start the prediction.

- All plots are rendered using interactive visualization tool [plotly](#).
 - Hoover on the figure to read the value. The x, y values shows to the location on r, z axes; the z value shows the value on that cell.
 - The double click on the figure to switch between a pan view of the entire reservoir and a close-up view in the near well region.
 - Drag on the figure to zoom in to return to the default view.

1.3 Sidebar

The **maximum injection duration** dropdown controls 1. the maximum value in the **Choose a time snapshot to view** slider in the output section, and 2. the time when the **Sweep efficiency factor** is evaluated.

Most of the slider variables are independent from each other with the exceptions of **Initial pressure at reservoir top** and **Reservoir temperature**; as well as **Reservoir thickness** and **Injection rate**. The relationship between the first pair of variables is constrained by a reasonable geothermal gradient range between 15-50°C/km.

The relationship between the **Reservoir thickness** and **Injection rate** is constrained by injection rate per meter of reservoir thickness between 0.001-0.01 MT/yr/m. The overall maximum injection rate is 2 MT/yr and minimum injection rate is 0.01 MT/yr.

The **Depth to top of perforation** and **Perforation thickness** sliders together control the injection perforation location. The value of depth follows the labeled on the y-axis of the figures.

The **Irreducible water saturation** controls the relative permeability curves. The **Irreducible water saturation** and **van Genuchten scaling factor** together controls the reference Capillary pressure curve.

Note: the injection well switches from injection rate control to bottom hole pressure (BHP) control once BHP pressure exceeds 600 bar. This limitation is due to [Schulmerger ECLIPSE](#), the numerical simulator used for generating the training data, allows CO₂-water calculation with reservoir condition of upto 600 bars (see [ref1](#), [ref2](#)).

1.4 Permeability

Homogeneous

Use the **Input permeability (mD)** input box to choose the homogeneous permeability in the reservoir. Input permeability map range should be within 3mD and 1,000mD.

Synthetic Heterogeneous

This option generates a random permeability map with user defined geo-statistical parameters using [Stanford Geostatistical Modeling Software \(SGeMS\)](#). Use the **Random seed** input box to produce replicable random permeability maps. The **Mean permeability** ranges from 3 to 2000mD, the **Standard deviation of permeability** ranges from 1 to 2000, **Vertical correlation** ranges from 2 to 500m, the **Lateral correlation** ranges from **Vertical correlation** to 10,000m (because reservoirs are commonly laterally correlated). The minimum permeability cutoff value in the generated map is 0.1mD - permeability value smaller than the cutoff value will be casted to 0.1mD. We include medium options of **Gaussian** and **von Karman**.

The options for the continuity of layers are **Continuous** and **Discontinuous**. When choosing the

Discountinous option, the permeability values will be randomly binned into a user defined number of materials. The Discountinous map still statisfies all of the geo-statistical parameters mentioned above.

Purely layered

Use the Number of Layers slider to choose the available rows in the table for inputting layer thickness and permeability. Follow the guidelines for inputting a purely layered permeability map:

- Thickness of each layer must be between 2 and your reservoir thickness m
- Total thickness of all layers must equal your reservoir thickness m
- Permeability of each layer must be between 0.1 and 2000 mD
- Average permeability of the field must be between 5 and 1000 mD

Note: CCSNet will not render permeability map and predictions with unresolved error message. Make sure you have resolved all error prompt to proceed.

User upload

Follow the guidelines for uploading permeability map:

- Permeability map's outer boundary is 200 m (r) by 100,000 m (z)
- Cell thickness should be 2.0833 m, cell width should be 3.5938 m
- Each map should have 96 rows and 27826 columns
- Permeability map values are in mD
- Store your permeability map in a .txt file where each line is a row of the map

Tip: to obtain optimal prediction accuracy, your uploaded permeability map should be within the training range. refer to Appendix B in the [paper](#) for a list of training permeability map ranges. Refer to [Error handling](#) section for details of *extrapolation* case.

1.5 Predictions

CCSNet provides Gas saturation map, Pressure buildup map, Reservoir pressure map, Molar fraction of dissolved phase map, and Sweep efficiency factor. Use the slider to choose a time snapshot to view.

We use gradually coarsening time snapshots at: 1 days, 2 days, 4 days, 7 days, 11 days, 17 days, 25 days, 37 days, 53 days, 77 days, 111 days, 158 days, 226 days, 323 days, 1.3 years, 1.8 years, 2.6 years, 3.6 years, 5.2 years, 7.3 years, 10.4 years, 14.8 years, 21.1 years, 30.0 years

1.6 Download

Click the expander and use the check box to choose predictions for download.

!Tip! the output files are very large and generating the .xlsx file could take a while. Please make sure you uncheck the boxes after downloading.

2. Examples

We provide the following 3 examples to demonstrate use cases of CCSNet.

- [Find maximum plume radius in a homogeneous reservoir](#)
- [Design best injection perforation location in layered reservoir](#)
- [Estimate sweep efficiency with only geostatistical parameters](#)

2.1 Find maximum plume radius in a homogeneous reservoir

The targeted reservoir is a 200m thick homogeneous reservoir with a permeability of 50mD. The reservoir is located 1500m below the ground surface with a 10m deep water table. The geothermal gradient of the location is 30 °C/km with an average surface temperature of 20 °C. We want to inject CO₂ at a rate of 1.5 MT/yr at the bottom half of the reservoir. How big will the plume be at 30 years? Use the default rock properties.

Choose reservoir conditions:

- Initial pressure at reservoir top (bar):

$$P = \rho g h = 1,000 \frac{kg}{m^3} \times 9.8 \frac{N}{m^2} \times (1,500m - 10m) = 137bar$$

- Reservoir temperature (°C):

$$T = T_{surface} + \frac{\Delta T}{\Delta h} \times h = 20^{\circ}C + 30 \frac{^{\circ}C}{km} \times 1.5km = 65^{\circ}C$$

- Reservoir thickness (m): 200

Choose reservoir conditions:

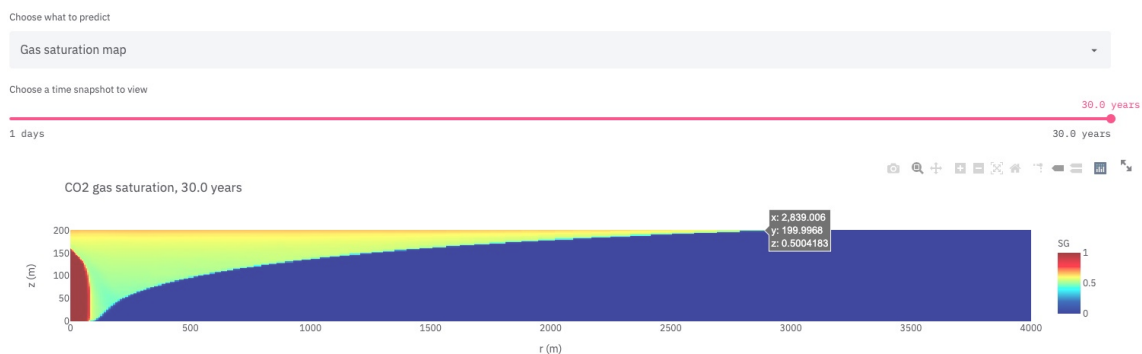
- Injection rate (MT/yr): 1.5M
- Depth to top of perforation (m): 100
- Perforation thickness (m): 100

Choose rock properties:

- Irreducible water saturation: 0.2
- van Genuchten scaling factor: 0.5

Solution:

We can read the plume radius of 2,839m from the output plot.



2.2 Design best injection perforation location in layered reservoir

We have a permeability log of a well and want to design the best perforation location (i.e. smallest plume while constrain the pressure buildup to be less than 30% of original pressure). The reservoir is 100m thick reservoir with 200 bar initial pressure and 80°C reservoir temperature. We want to inject through a 20m thick perforation at 1MT/yr. Use the default rock properties.

- Thickness (m): 40; 5; 20; 60; 25
- Permeability (mD): 200; 0.1; 0.8; 100; 5

Choose reservoir conditions:

- Initial pressure at reservoir top (bar): 120
- Reservoir tempearture (°C): 60
- Reservoir thickness (m): 150

Choose reservoir conditions:

- Injection rate (MT/yr): 1
- Depth to top of perforation (m): ?
- Perforation thickness (m): 20

Choose rock properties:

- Irreducible water saturation: 0.2
- van Genucheten scaling factor: 0.5

Permeability:

Choose the type of your permeability map

Purely Layered

Guidelines for inputting a purely layered permeability map:

Number of Layers

2520

- Thickness of each layer must be between 2 and 150 (your reservoir thickness) m
- Total thickness of all layers must equal 150 (your reservoir thickness) m
- Permeability of each layer must be between 0.1 and 2000 mD
- Average permeability of the field must be between 5 and 1000 mD

Thickness (m):	Permeability (mD):
35	200
10	0.1
20	0.5
60	100
25	5

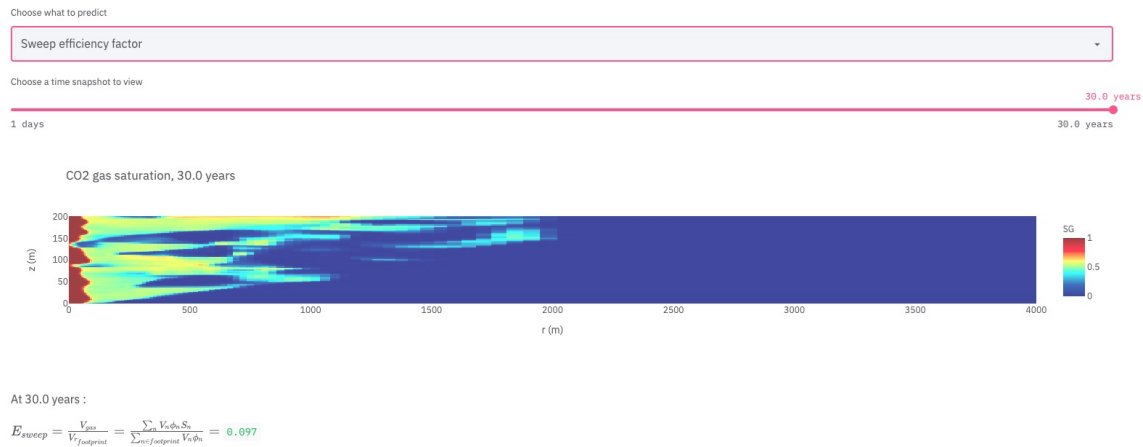
Solution:

	Perf top depth	Perf thickness	Plume radius	Max pressure buildup	% buildup
Secenario 1	20m	20m	3771m	120 bar	120%
Secenario 2	150m	20m	4047m	13 bar	11%
Secenario 3	50m	20m	2739m	14 bar	12%

2.3 Estimate sweep efficiency with only geostatistical parameters

We want to estimate the sweep efficiency in a region but only have some very basic information. Assuming the permeability field with mean permeability is 25, standard deviation of permeability is 20, vertical correlation is 5, and lateral correlation is 200. Use the default values in the sidebar.

Choose **Sweep efficiency factor** option and simply read the values for the above parameter combinations. We can also try a few different **random seed** to get a probable range of the **Sweep efficiency factor**.



3. Error handling

Extrapolation

Deep learning models produce highly accurate results when *interpolating* in the high-dimensional input space. We attempted incorporating as many types of permeability maps as we can to cover a large input space.

However, there can be some types of permeability map not covered in the training data that leads to *extrapolation* in the high-dimensional input space - causing inaccurate predictions.

Therefore, in case you encounter a permeability map with problematic predictions, please kindly contact us at gegewen@stanford.edu and we will expand the training range to incorporate your case.

UH-OH message

Since the web app *automatically* re-renders once any widget is being changed. Therefore, if operating too fast, you might meet my puppy *Doctor*. Refresh the page and the error should be gone. If not, please kindly contact us at gegewen@stanford.edu.



UH-OH

Something went wrong...

Please try again