



What Fraction of Ocean Dissolved Organic Carbon Storage is of Terrestrial Origin? Insights From the Carbon Isotope Enabled CESM-MARBL Model



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Motivation

- Constraining the sources (allochthonous vs autochthonous), sinks (abiotic vs biotic), and relative ages of marine dissolved organic carbon (DOC) is important for simulating future global carbon cycling dynamics.
- Marine DOC reservoir is 662 Pg (Table 1), second largest reduced carbon; First is dissolved inorganic carbon (DIC) at 38,000 Pg.⁶

Fraction	Inventory (Pg C)	Production rate (Pg C yr ⁻¹)	Removal rate (μmol C kg ⁻¹ yr ⁻¹)	Δ ¹⁴ C-DOC (‰)	Lifetime (yr)
Labile (LDOC)	<0.2	15-25	10 ²	-50	0.001
Semi-labile (SLDOC)	6 ± 2	3.4	2-9	-50	1.5
Semi-refractory (SRDOC)	14 ± 2	0.34	0.2-0.9	-52	20
Refractory (RDOC)	630 ± 32	0.043	0.003	-546	16,000
Ultra-refractory (URDOC)	>12	1.2x10 ⁻⁵	8x10 ⁻⁷	-837	40,000
Total DOC	662.2			-531	15,500

- Marine biological primary productivity and microbial respiration (autochthonous) produces 0.11-0.18 Pg of RDOC yr⁻¹.
- Global river discharge (allochthonous) supplies 0.17-0.21 Pg of DOC yr⁻¹ to the ocean.²

Research Questions

How does terrestrial DOC contribute to marine DOC reservoir?
How does model DOC tracers and *in situ* measurements compare?

Methodology

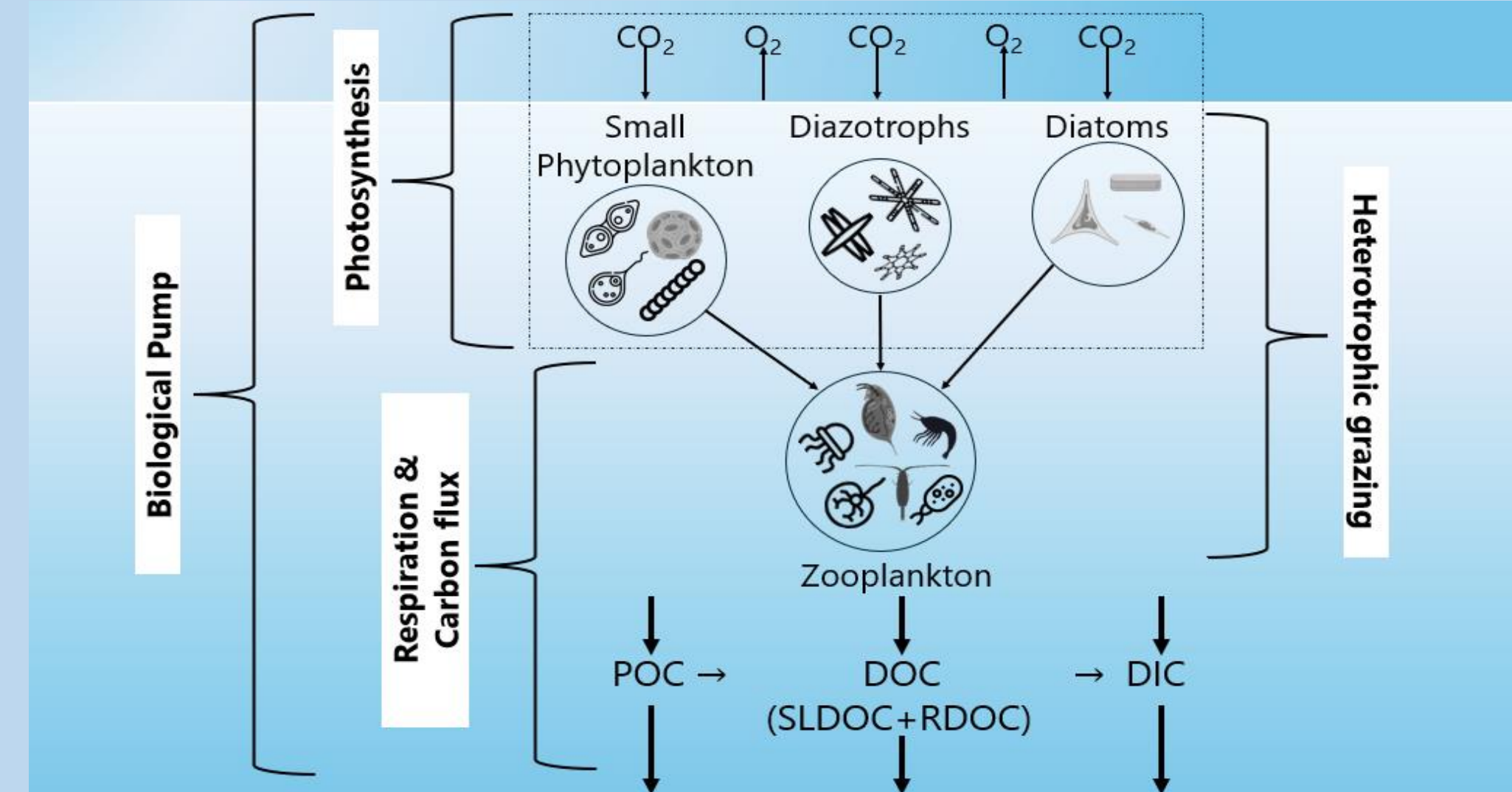


Figure 1. The Marine Biogeochemistry Library (MARBL) within the Community Earth System Model (CESM) V2.8. One zooplankton grazing types on 3 phytoplankton types are routed to particulate organic carbon (POC), DOC (SLDOC+RDOC), and DIC over 60 horizontal depth at a 3°x3° resolution to simulate the biological pump and ocean circulation. 32 tracers, 17 non-living constituents and 15 tracers associated with biomass, are simulated along with carbon δ¹³C and Δ¹⁴C variables at fixed-preindustrial atmospheric CO₂ conditions (284.7 ppm) until steady-state. Boundary conditions simulate atmospheric deposition, photooxidation, sediments/benthic processes, hydrothermal vents, and river inputs indirectly.

- Two simulations (MARBL-CESM) of ocean and sea ice (Fig. 1)
 - River on:** simulates river DOC fluxes based on GlobalNEWS. ^{8,9}
 - Data: Average last 20 yr of 9982 yr steady-state run
 - River off:** simulates no river DOC fluxes
 - Data: Average last 20 yr of 5022 yr steady-state run
- SLDOC** (~8 yr lifetime) and **RDOC** (16,000 yr lifetime) concentrations were summed and mapped (Fig. 2) for calculating **Total DOC** for each model (**TotDOC_{River on}** & **TotDOC_{River off}**).
- Calculate **Terrestrial DOC** = TotDOC_{River on} - TotDOC_{River off}.
- Section plots (150°W, 30°W, and 90°E) for terrestrial DOC (Fig. 3).
- Compare modeled DOC, δ¹³C-DOC, and Δ¹⁴C-DOC content with *in situ* measurements from several locations (Table 2 & Fig. 4).

Table 2. Sampling information of *in situ* DOC concentrations, δ¹³C-DOC, and Δ¹⁴C-DOC measurements.^{3,4,5} Plotted on Fig. 2B.

Fig. 2B	Station	Latitude	Longitude	Date
1	130	-32.5	-144.66	Jan 2010
2	190	-32.5	-105.93	Jan 2010
3	North Central Pacific	31	-159	June 1987
4	Southern Ocean	-54	-176	Dec 1995
5	Station M	34.83	-123	1992
6	Sargasso Sea	31.83	-63.5	1989 & 1991

Results and Discussion

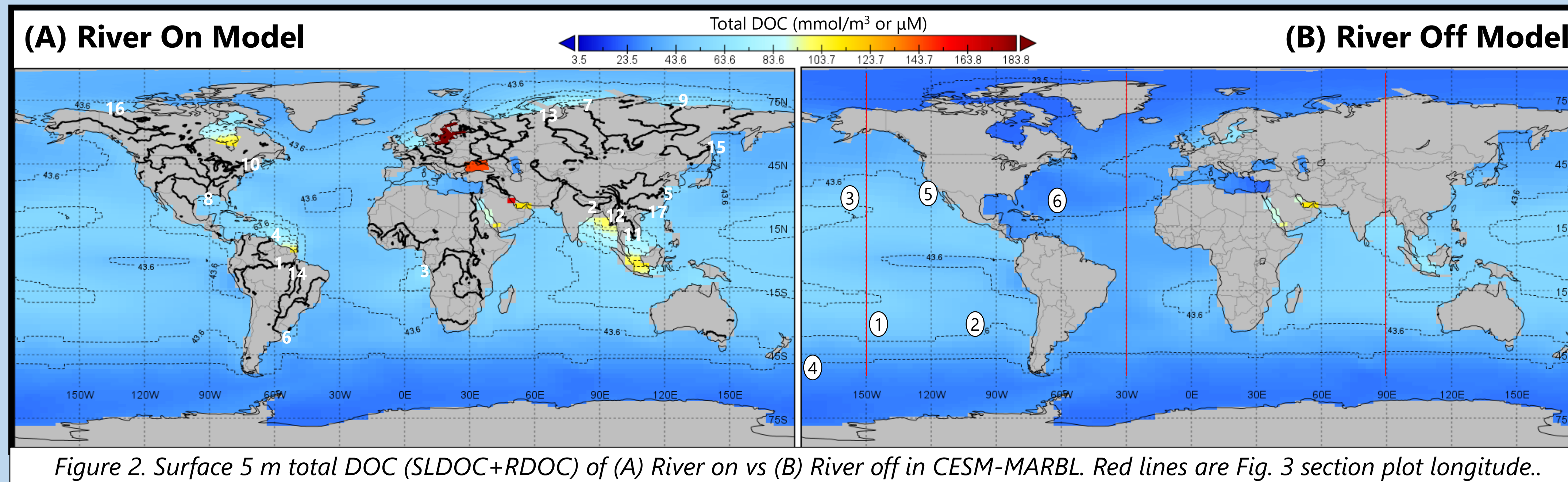


Figure 2. Surface 5 m total DOC (SLDOC+RDOC) of (A) River on vs (B) River off in CESM-MARBL. Red lines are Fig. 3 section plot longitude.

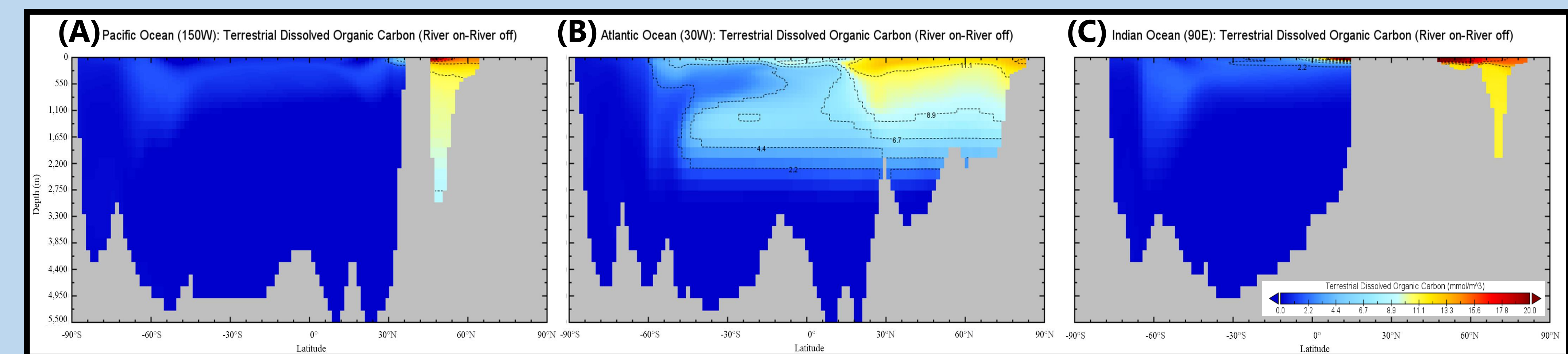


Figure 3. Section plots (Latitude vs depth) at constant lines of longitude for terrestrial DOC at (A) Pacific Ocean 150°W, (B) Atlantic Ocean 30°W, and (C) Indian Ocean 90°E.

	River on	River off
SLDOC	17.64	17.4
RDOC	334.85	325.67
Total	352.49	343.07

Rivers discharge terrestrial DOC (allochthonous) into the ocean that mixes with varying lability and degrees of pre-aging that affect its radiocarbon content. Terrestrial DOC is depleted in δ¹³C (-30‰; C₃ plants -23 to -34‰; C₄ plants -9 to -17‰) and at modern age, while marine DOC is enriched in δ¹³C (-20‰; phytoplankton -18 to -22‰) and at modern age.¹⁰ Rivers may also carry black carbon that is recalcitrant and aged.

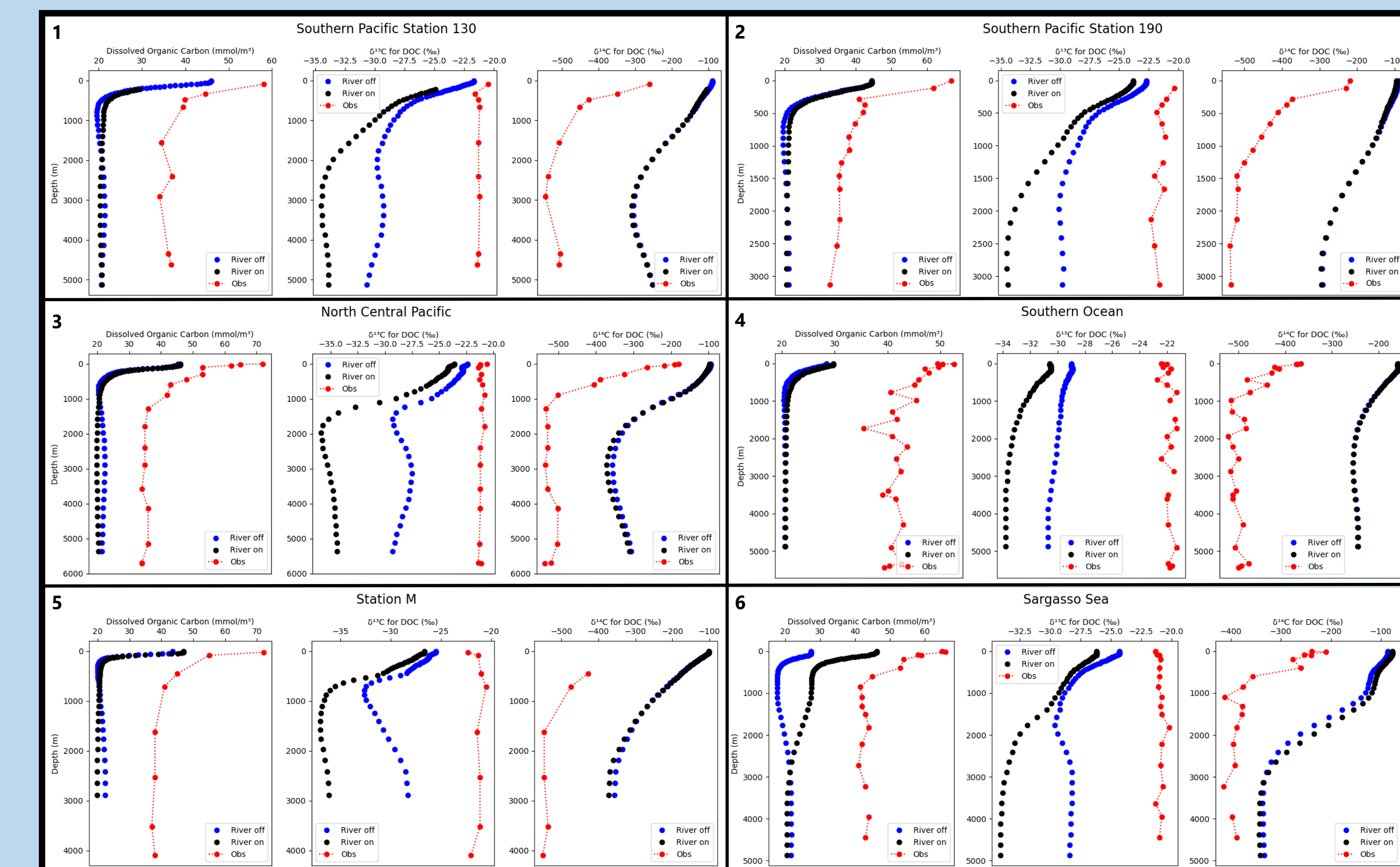
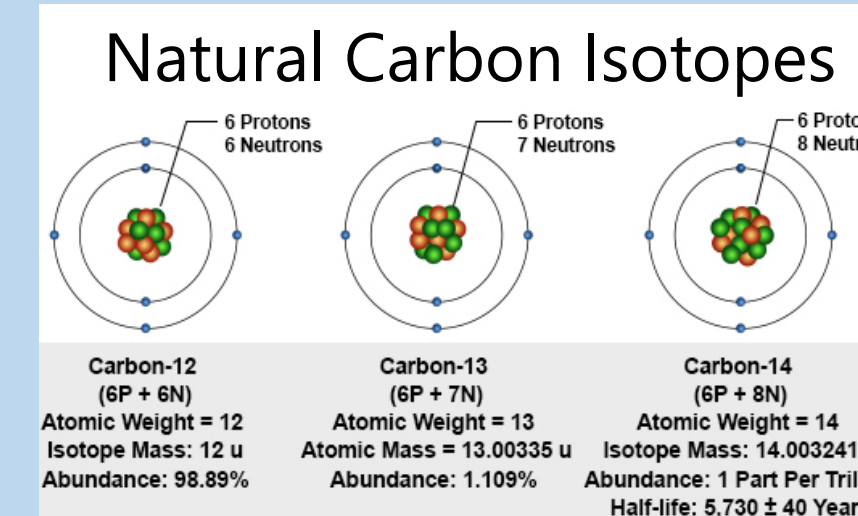


Figure 4. Total DOC concentrations, δ¹³C-DOC, and Δ¹⁴C-DOC depth plots for *in situ* samples (red) compared to model_{River on} output (black) and model_{River off} output (blue) at different ocean regions based on Table 2. Variable y-axis depth.

Model_{River on} DOC is underestimated, δ¹³C-DOC is more depleted, and Δ¹⁴C-DOC is younger than *in situ* observations at all locations. Modeled and observed DOC concentrations follow similar trends, high in surface and low in deep ocean, but model DOC is ~20 μM less than observed DOC. Deep modeled DOC is at 20 μM in all locations. Modeled deep δ¹³C-DOC shows a fractionation effect that is dominated by a biotic remineralization signal that preferentially consumes ¹³C-DOC, causing depleted δ¹³C-DOC signal (>30‰), while observations show no fractional effect (22-20‰), so model δ¹³C-DOC fractionation needs to be removed. Model biases stem from using preindustrial atmospheric CO₂ values (284.7 ppm), ignores the Seuss Effect (decrease δ¹³C in atmosphere) from burning fossil fuels, coarse resolution (3°x3°), and other less defined model parameters; photooxidation at the surface limits deep DOC accumulation.

Conclusions

- Model DOC tracers show terrestrial DOC input of 10-20 μM that spreads across the surface ocean and gets advected down into the deep ocean around >2,700 m with time.
 - Atlantic Ocean has greater DOC flux into deep ocean.
- Terrestrial DOC contributes 9.42 Pg C into the ocean with 0.24 Pg as SLDOC and 9.18 Pg as RDOC** (Table 3).
 - 2.67% of total ocean DOC reservoir is terrestrial DOC
 - 97% of terrestrial DOC into the ocean is in the RDOC form
- Modeled and observed DOC tracers indicate several biases.
 - Modeled deep ocean DOC is 1.5-2 times underestimated indicating higher DOC removal rate.
 - Due to high surface photooxidation parameterization
 - Modeled DOC has a fractionation effect in higher depleted δ¹³C-DOC values.
 - Younger modeled Δ¹⁴C-DOC ages indicates slower physical circulation of the deep ocean.

Future Work

- Modify model with river-specific DOC, δ¹³C-DOC, and Δ¹⁴C-DOC end member values for top 17 largest rivers (Table 4).
- Determine the role and simulate other DOC sources and sinks better in the model, such as photooxidation, hydrothermal vents, and atmospheric black carbon deposition.
- Simulate ocean circulation model with historical atm CO₂ (1850-2014) or future CO₂ forcing scenarios.

Table 4. Top 17 largest rivers by discharge.¹ Plotted on Fig. 2A.

Fig. 2A	River	Discharge (m ³ /s)	Latitude	Longitude	Ocean
1	Amazon	224,000	-2	-55.5	Pacific
2	Ganges	43,900	27.3	77	Indian
3	Congo	41,200	-4.3	15.3	Atlantic
4	Orinoco	37,740	8.1	-64.6	Atlantic
5	Yangtze	35,000	30.8	117.6	Pacific
6	Río de la Plata	27,225	-34.75	-54.96	Atlantic
7	Yenisei	19,800	67.4	86.5	Arctic
8	Mississippi	18,434	32.3	-90.9	Atlantic
9	Lena	17,067	70.7	127.4	Arctic
10	St. Lawrence	16,800	45	-74.7	Atlantic
11	Mekong	16,000	15.1	105.8	Pacific
12	Irrawaddy	15,112	21.9	96	Indian
13	Ob	13,100	66.6	66.6	Arctic
14	Tocantins	11,796	-3.8	-49.7	Atlantic
15	Amur	11,330	50.5	137	Pacific
16	Mackenzie	10,338	67.5	-133.7	Arctic
17	Pearl	9,500	23.5	111.3	Pacific

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- Figures were plotted by NASA Panoply and custom-made python scripts.

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