Air-Sea CO_2 Fluxes Localized By Topography in a Southern Ocean Channel SI

Madeleine Youngs et al.

1 Boundary Conditions

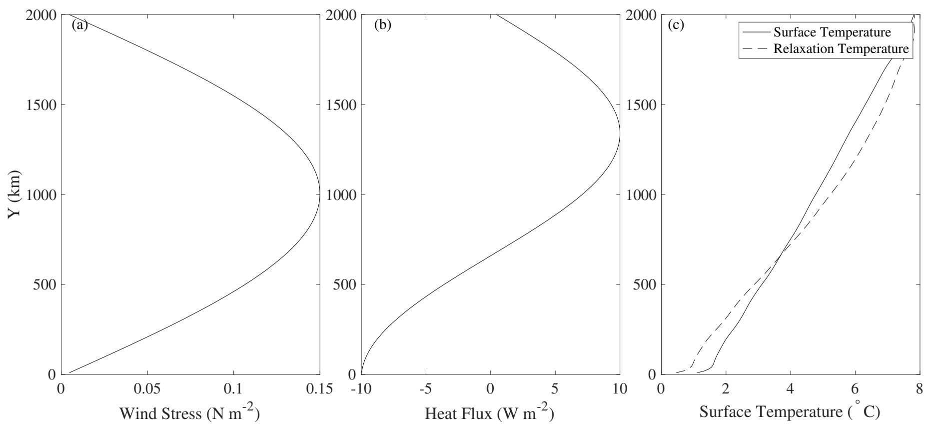

Figure 1: Surface boundary conditions for the physical model. (a) the surface wind stress, (b) surface fixed heat fluxes used generate (c) surface relaxation temperature conditions using the mean from the fixed flux run (solid) with the heat flux (b) to create relaxation surface temperature (dashed). Reproduced from Youngs and Flierl (2023).

2 Biological Model Information

The biological parameters set are a light attenuation k_0, timescale for biological activity α, half saturation phosphate constant K_{PO_4}, and an inorganic/organic carbon rain ratio R_{rat} as seen in SI Table. The light attenuation is calculated as

$$lit = e^{-k_0 z}. \tag{1}$$

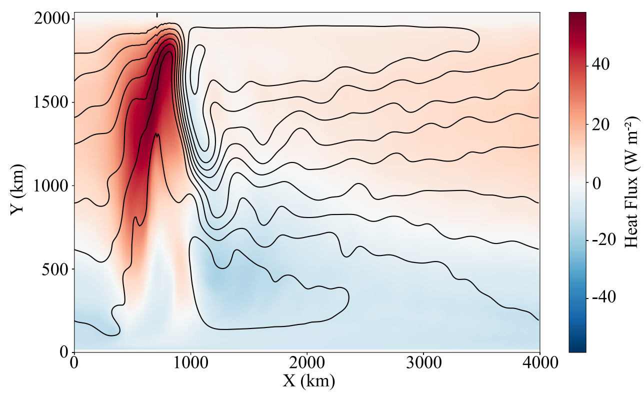

Figure 2: Surface heat flux forcing for the idealized channel model. The black lines show the time-averaged barotropic streamlines. There is enhanced heat flux over the ridge. This is averaged over 40 model years.

The constant used by default is $k_0 = 0.02$ 1/m. Biological growth is co-limited by light and nutrients as given by:

$$S_{bio} = \alpha \frac{lit}{lit + lit0} \frac{PO_4}{PO_4 + K_{PO_4}} \tag{2}$$

and

$$S_{CaCO_3} = \frac{1}{2} R_{\mathrm{rat}} R_{C_T:P} S_{bio} \tag{3}$$

If phosphate is fluxed to the bottom, it is instantly remineralized.

3 Carbon Budget

The divergence of the horizontal DIC advection (A), and the divergence of the vertical DIC advection (B) are the largest terms of the carbon budget, but the

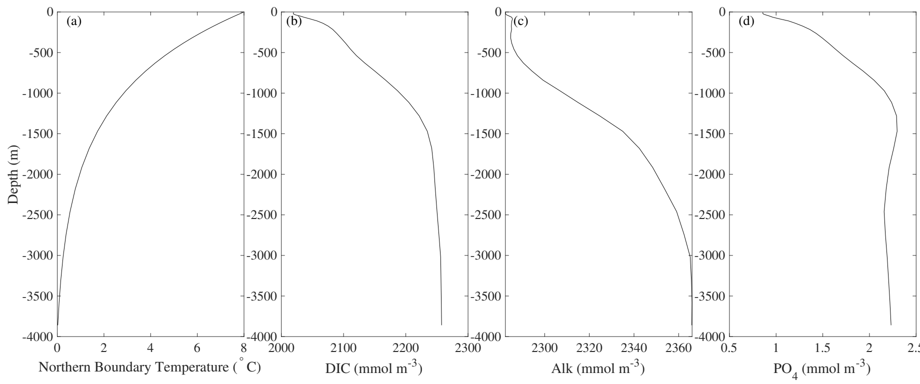

Figure 3: Northern boundary conditions for physical and biogeochemical model. The carbon parameters are averaged from GLODAPv2 averaged at 45 S. (a) Northern boundary temperature, (b) DIC, (c) Alkalinity, (d) Phosphate(PO_4).

symbol	meaning	value
k_0	light attenuation coefficient of water [1/m]	0.02
α	timescale for biological activity [1/s]	$2 \cdot 10^{-3}/(360 \cdot 86400)$
K_{PO4}	half saturation phosphate constant (mol/m^3)	$5 \cdot 10^{-4}$
R_{rat}	inorganic/organic carbon rain ratio	$7 \cdot 10^{-2}$

Table 1: Biological parameters used in the MITgcm simulation and their values.

sum of the two primarily cancel out, and the sum's magnitude is about the same as the other terms. Cancellation of the horizontal and vertical components is characteristic of eddies. Imagine an eddy with a high DIC anomaly in the center translating horizontally past a point. This eddy will result in both horizontal and vertical flux divergence even if there is no net vertical motion in the center of the eddy. The result is a large cancellation.

There is a small component of vertical DIC diffusion (D) in the region over the ridge but south of the jet. The dominant contributions to the air-sea fluxes are the DIC advection (C), and biological activity (F) partially compensates. The residual (I) has a large component to the north of the domain where the DIC is relaxed to the GLODAP values.

4 Float displacement

The SOCCOM floats are an array of profiling floats with biogeochemical sensors (oxygen, nitrate, and/or pH) in the Southern Ocean. These floats are part of the Argo system. The floats sample the water column once every 10 days and rest at 1000 m between samples. The floats are semi-Lagrangian, advecting with the water at 1000 m, but not tracking individual water parcels, which can also move vertically. When deploying the synthetic floats in the model, we assume

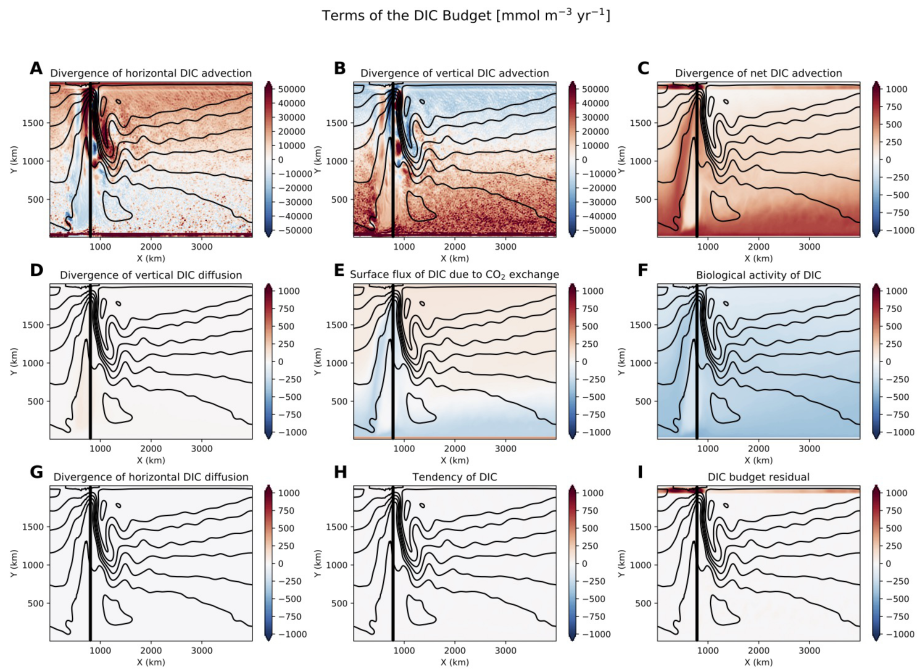

Figure 4: All of the terms of the carbon budget from Lauderdale et al. (2016). The vertical line represents the location of the crest of the ridge.

that the floats mostly follow the flow field at 1000 m with little differential displacement while profiling. We compare the synthetic floats to the SOCCOM float database to validate the comparison. We compare the distribution of float lateral displacements between samples (every 10 days) between the synthetic floats and SOCCOM floats. We find that the distributions of the displacements are very similar between the synthetic and SOCCOM floats (Figure 6).

Moreover, we find that the float displacements are affected by topography in similar ways between the model and observations with both the observed and model floats displaying a wider range of velocities near topography than elsewhere, and particularly slower movement near topography (Figure 7).

Data were collected and made freely available by the Southern Ocean Carbon and Climate Observations and Modeling (SOCCOM) Project funded by the National Science Foundation, Division of Polar Programs (NSF PLR -1425989 and OPP-1936222), supplemented by NASA, and by the International Argo Program and the NOAA programs that contribute to it. The Argo Program is part of the Global Ocean Observing System.

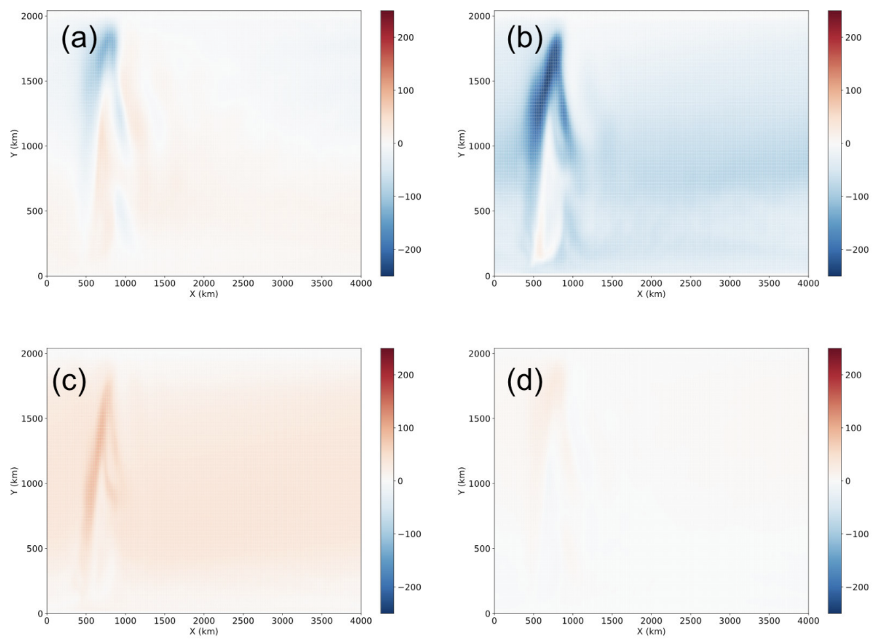

Figure 5: Figure showing the contribution of different terms to air-sea carbon flux differences (weak wind (τ_0 = 0.05 N m^{-2}) - moderate wind (τ_0 = 0.15N m^{-2})) in μ atm. (a) shows the total difference in pCO2 fluxes, (b) shows the contribution from DIC, (c) shows the contribution from Alk, and (d) shows the contribution from temperature. Reproduced from Youngs (2020). In addition, the wind speed used for the gas flux computation was set to 5 m/s everywhere.

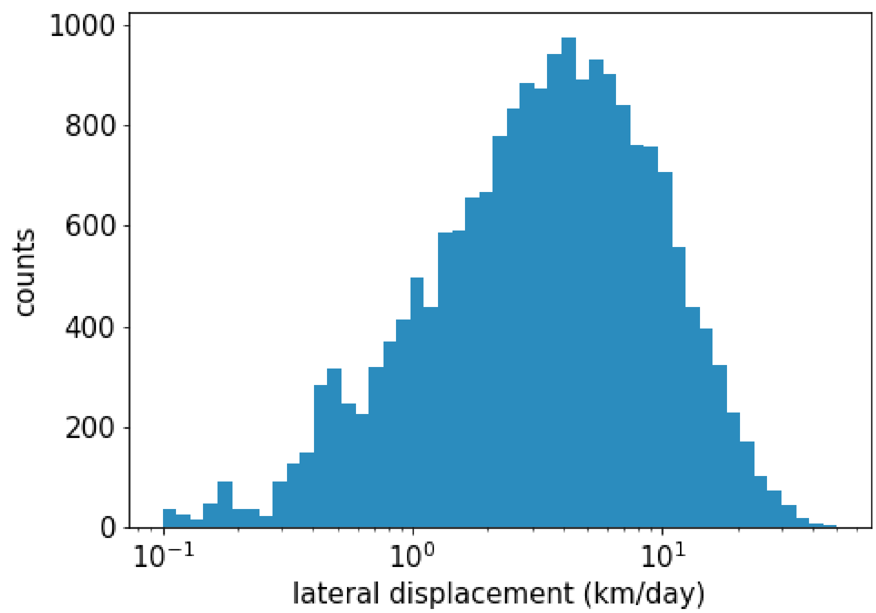

Figure 6: Histogram of the rate of lateral displacement across all SOCCOM floats. The displacements are between float casts so the float velocity is averaged over approximately 10 days.

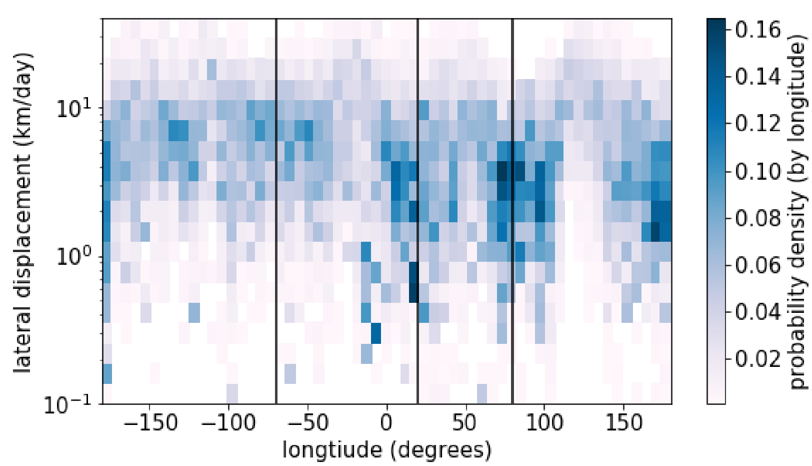

Figure 7: 2D histogram of the float displacement as a function of longitude. The black vertical lines show the locations of topographic features (Drake passage, Southwest Indian Ridge, Kerguelen plateau).

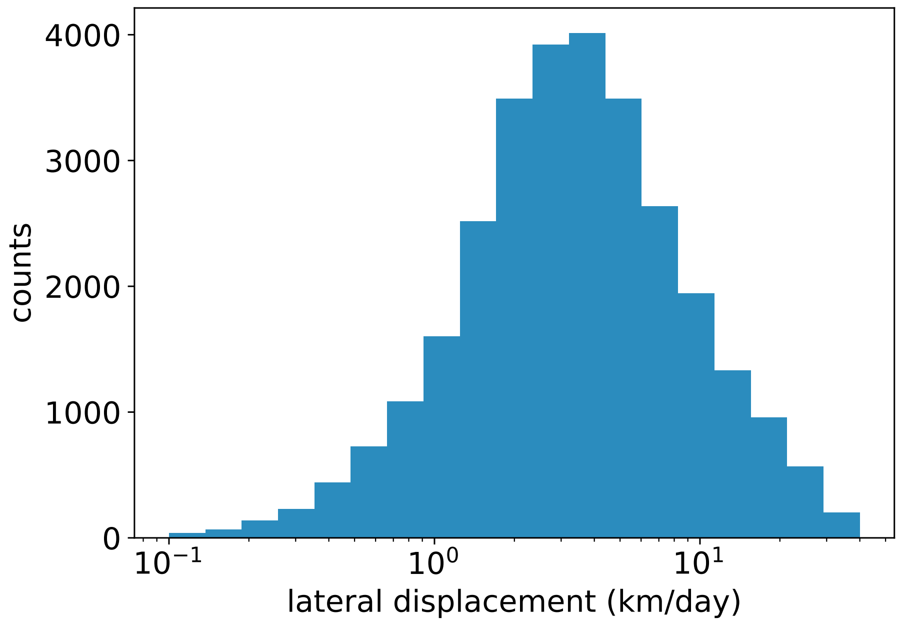

Figure 8: Histogram of the rate of lateral displacement across all model floats. The displacements are between float casts so the float velocity is averaged over approximately 10 days. This compares to the SOCCOM float displacement in Figure 6.

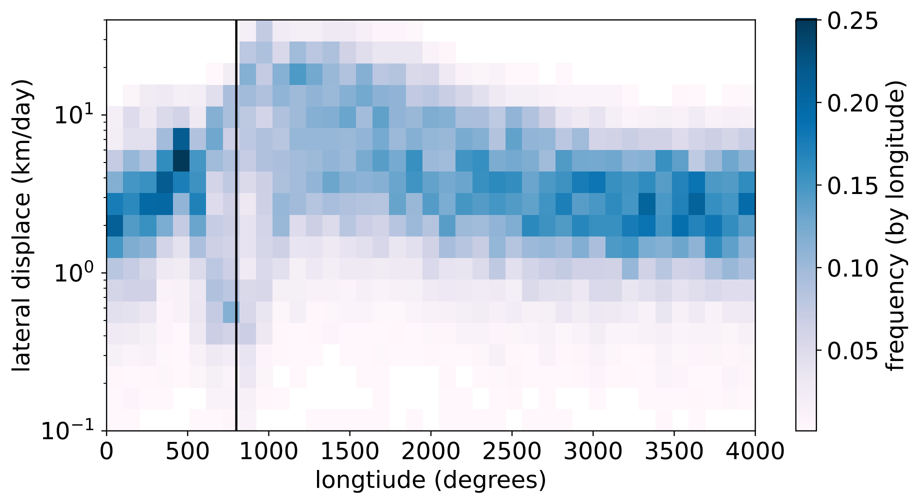

Figure 9: 2D histogram of the model float displacement as a function of longitude. This compares to the SOCCOM float displacement in Figure 7.