Parameterizing Carbon Export Below the Euphotic Zone

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I. Abstract

The shunt of photosynthetically derived particulate organic carbon (POC) out of the euphotic zone is an integral component of the "biological pump." POC raining through the twilight zone (z_{eu} – 1 km) and midnight zone (1km-4km) is remineralized back to dissolved inorganic carbon though microbial respiration. Accurately capturing POC flux in models is essential to accurately capture surface ocean pCO2 as well as understanding carbon sequestration. Here, we compare three common POC flux parameterizations in ocean provinces. Namely, exponential decay, Martin curve, and the "ballast hypothesis". Simulations were considered representative of the ecosystem if they captured the observed range of primary production. We assessed model performance using "Target diagrams," a summary diagram that displays how well the model captures the observed mean and the observed variability. Results indicate all the models peform well in the twilight zone also, only the "ballast hypothesis" and Martin curve capture observations in the midnight zone.

II. Methods

- MITgcm setup with 1D framework and 77 vertical levels.
- Nutrient concentrations relaxed to monthly climatology, except when the concentration exceeded climatology in the euphotic zone.
- 11 of the 54 Longhurst provinces (Reygondeau et al., 2013) were simulated (Figure 1).

Exponential Model (Dutkiewicz et al., 2005)
- Constant POC remineralization time scale (K_{poc}).
- All POC is labile and sinks at a constant rate (w_{poc}).

$$[POC] = \text{“labile POC concentration”}$$
$$w_{poc} = \text{“sinking speed of POC”}$$
$$\text{“Remineralization tendency”} = K_{poc}[POC]$$

Ballast Hypothesis (Armstrong et al., 2001)
- Labile and refractory POC.
- POC remineralization time scales (K_x) associated with x: $K_{hard} < K_{opal} < K_{dust} < K_{pic} < K_{poc}$

$$[POC_x] = \text{“POC concentration bound to x”}$$
$$w_x = \text{“sinking speed of x”}$$
$$\text{“Remineralization tendency”} = K_x[POC_x]$$

$$\text{“POC flux”} = w_{poc}[POC] + w_{pic}[POC_{pic}] + w_{opal}[POC_{opal}] + w_{dust}[POC_{dust}]$$

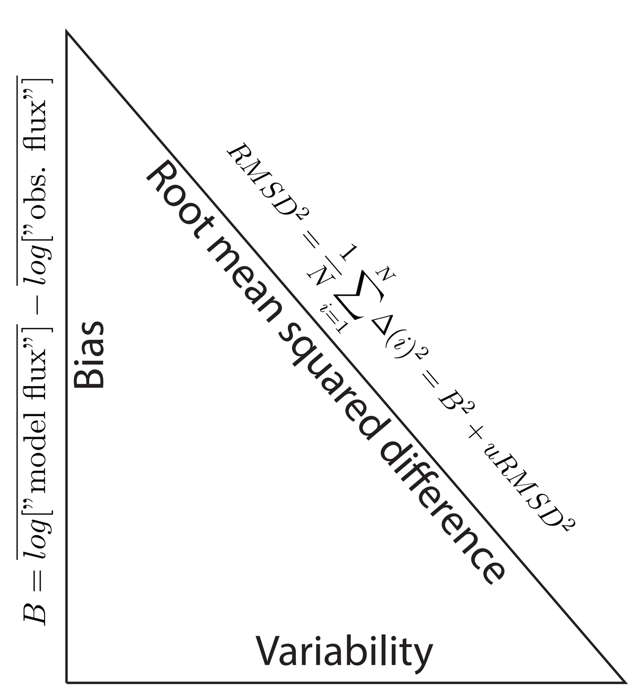
- POC flux is proportional to w_x and inversely proprotional to K_x
- Simulation validated against observed POC flux, a global dataset from flux traps and supplemented with Th234 data in the surface ocean.
- Model skill graphically displayed using "target diagrams" (Jolliff et al., 2009).

III. Results / Conclusions

- All three model capture observations within the twilight zone (Figure 3).
- Martin curve and ballast model capture observations at depth (Figure 2).
- Models capture the mean in twilight zone but underestimate variability (Figure 3).
- Exponential model does not capture observations in the midnight zone (Figure 3).
- The ballast hypothesis captures observations at depth, corroborating Lima et al., 2014

Overarching Conclusion

Ballast hypothesis shows no improvement over the global or regional Martin curve.



$$uRMSD^2 = \frac{1}{N}\sum_{i=1}^{N}[\Delta(i) - B]^2$$

$$\Delta(i) = log[\text{"model flux"}(i)] - log[\text{"obs. flux"}(i)]$$

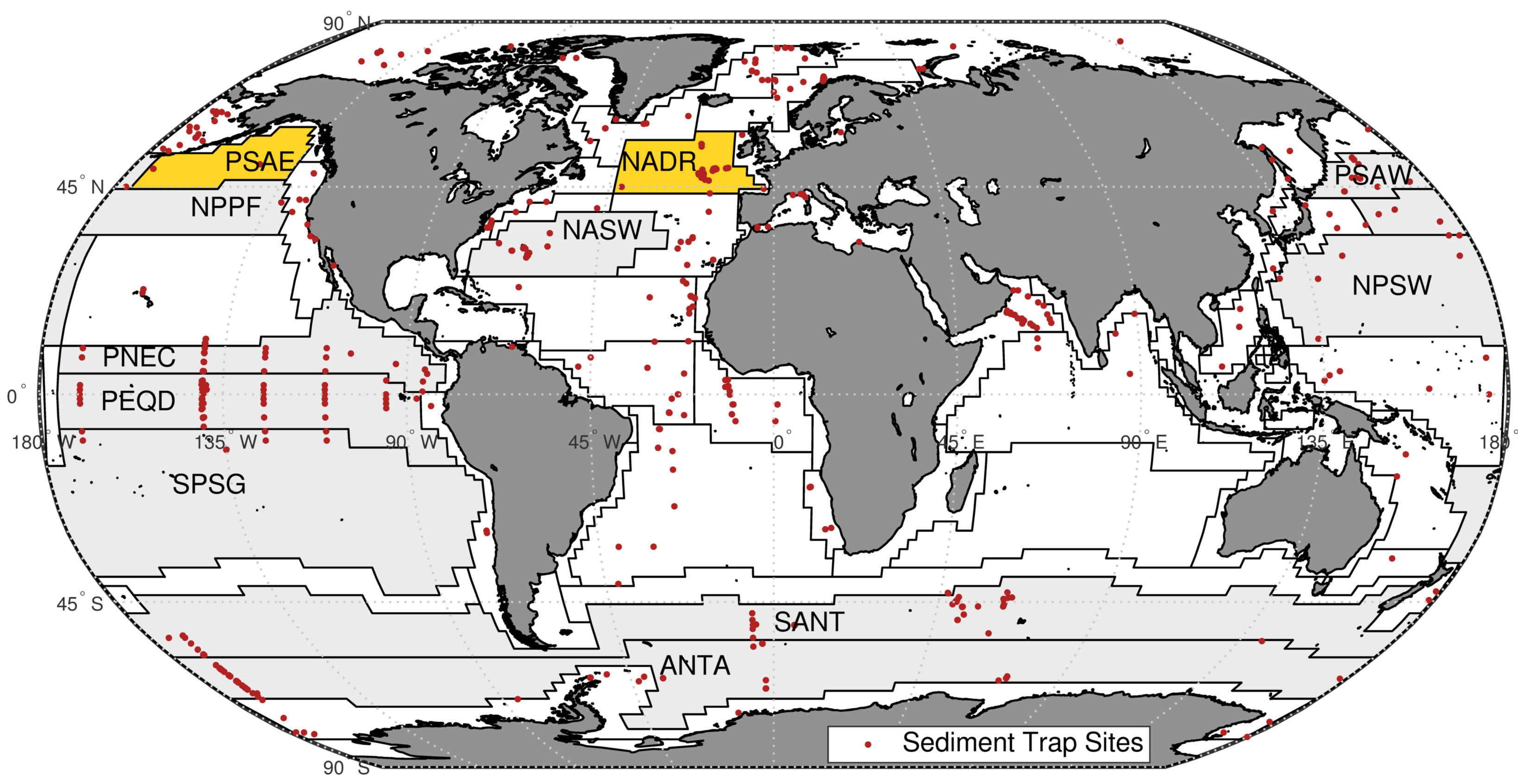


Figure 1: POC flux observations overlain with Longhurst provinces. Red dots indicate sites of moored sediment traps and thorium-234 observations. Shown provinces (11 out of 54) were simulated using a 1D framework. Gold provinces are presented here. Gray provinces can be shown upon request. data availability: http://doi.pangaea.de/10.1594/PANGAEA.855600 (Mouw et al., 2015, in review)

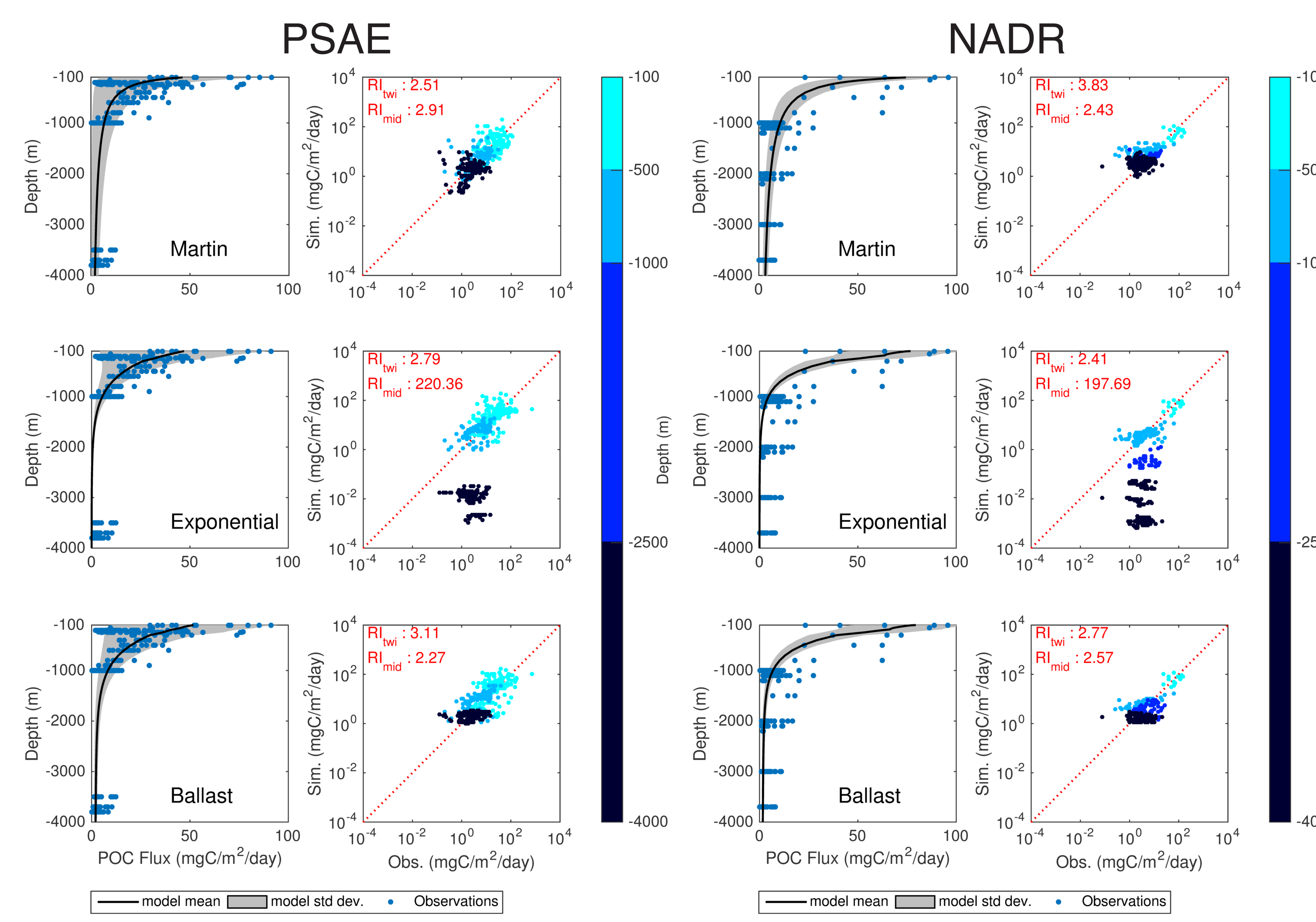


Figure 2: Observed and modeled POC flux at each province. Annual climatology (8 day block median) of POC flux from moored sediment traps is shown in blue. Simulated POC flux using the Martin curve, an exponential model, and "ballast hypothesis" is shown in black and standard deviation is shown in gray. Cross-plot of observed and modeled POC flux is shown beside each POC flux vs. depth plot. Red dashed line indicated a one-to-one line. The reliability index (RI=10^{RMSD}) is shown in red for the twilight zone (twi) and midnight zone (mid).

Model Performance Showing Bias and Variability

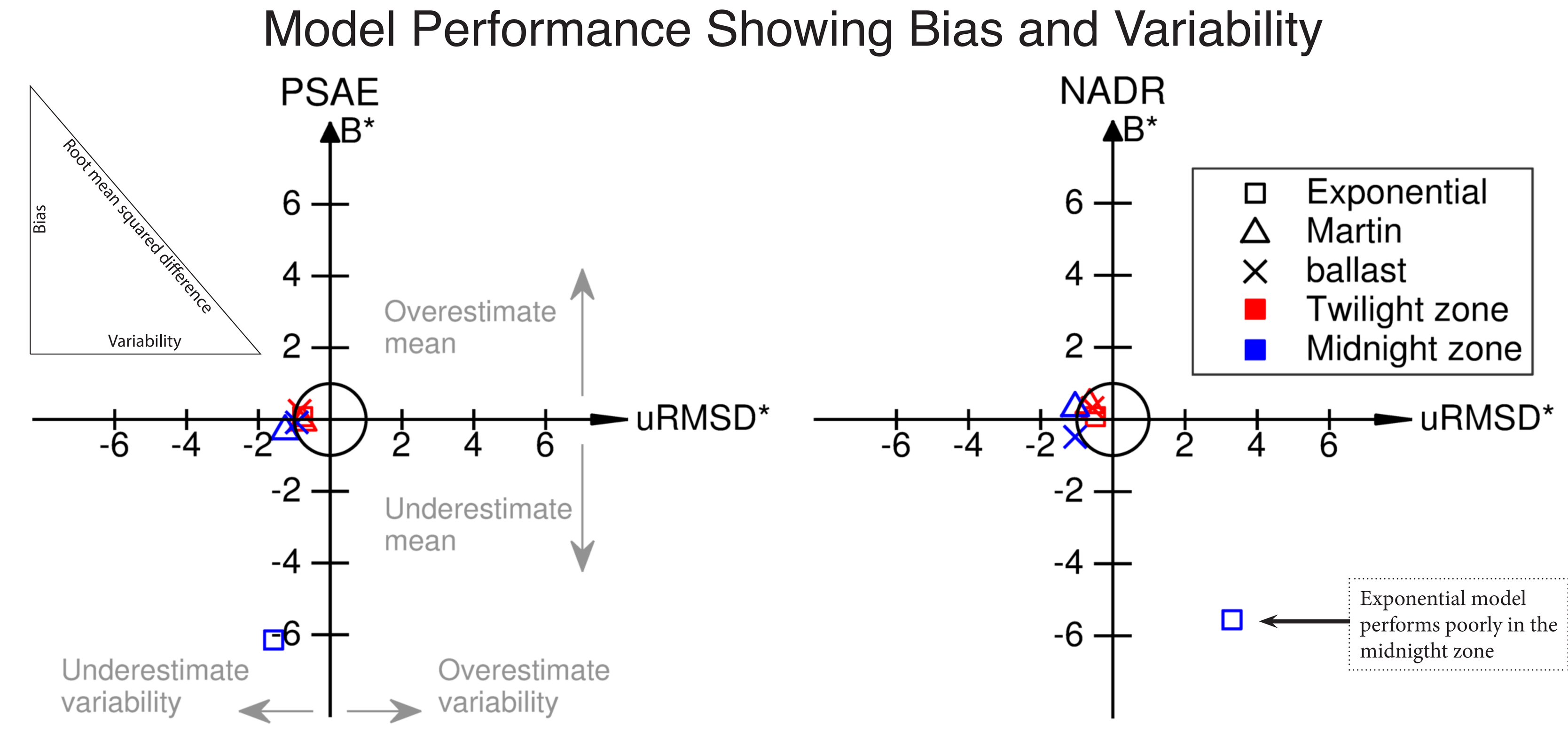


Figure 3: "Target diagrams" comparing model skill between Martin curve, exponential model, and "ballast hypothesis" in the twilight zone and midnight zone. B* and uRMSD* indicate the bias (B) and unsigned root mean squared difference (uRMSD) normalized by the data standard deviation. The radius of the central black circle is the normalized standard deviation of data. Symbols within the circle indicate that the model captures POC flux more accuately than using the mean of the observed data.

References

Armstrong, Robert A., et al. (2001) "A new, mechanistic model for organic carbon fluxes in the ocean based on the quantitative association of POC with ballast minerals." Deep Sea Research Part II: Topical Studies in Oceanography 49.1: 219-236.

Dutkiewicz, Stephanie, et al. (2005) "Interactions of the iron and phosphorus cycles: A three-dimensional model study." Global Biogeochemical Cycles 19.1.

Jolliff, Jason K., et al.(2009) "Summary diagrams for coupled hydrodynamic-ecosystem model skill assessment." Journal of Marine Systems 76.1: 64-82.

Lima, Ivan D., et al. (2014) "Dynamics of particulate organic carbon flux in a global ocean model.".

Mouw, C.B., et al. (2015), Global Ocean Particulate Organic Carbon Flux Merged with Satellite Parameters, doi: 10.1594/PANGAEA.855600.

Martin, John H., et al. (1987) "VERTEX: carbon cycling in the northeast Pacific." Deep Sea Research Part A. Oceanographic Research Papers 34.2: 267-285.

Reygondeau, Gabriel, et al. (2013) "Dynamic biogeochemical provinces in the global ocean." Global Biogeochemical Cycles 27.4: 1046-1058

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