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### Key Points:

- We present a synthesis of BCP mesopelagic transfer efficiency metrics across open-ocean biomes using multiple methods
- Error analysis shows that large uncertainties prevent attributing BCP transfer efficiency variations to geographical differences
- Diversity of methods for estimating metrics adds uncertainty, stressing the need for standardised protocols to collect and process data

### Supporting Information:

Supporting Information may be found in the online version of this article.

### Correspondence to:

A. Rufas,  
[Anna.RufasBlanco@earth.ox.ac.uk](mailto:Anna.RufasBlanco@earth.ox.ac.uk)

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




**Conceptualization:** A. Rufas, S. Khatiwala, A. P. Martin  
**Data curation:** A. Rufas, K. M. Bisson  
**Formal analysis:** A. Rufas  
**Funding acquisition:** S. Khatiwala, A. P. Martin  
**Methodology:** A. Rufas, S. Khatiwala, K. M. Bisson  
**Software:** A. Rufas  
**Visualization:** A. Rufas  
**Writing – original draft:** A. Rufas, S. Khatiwala, H. A. Bouman  
**Writing – review & editing:** A. Rufas, S. Khatiwala, K. M. Bisson, A. P. Martin, H. A. Bouman

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## Can We Constrain Geographical Variability in the Biological Carbon Pump's Transfer Efficiency From Observations?

A. Rufas<sup>1</sup> , S. Khatiwala<sup>2</sup> , K. M. Bisson<sup>3,4</sup> , A. P. Martin<sup>5</sup> , and H. A. Bouman<sup>1</sup> 

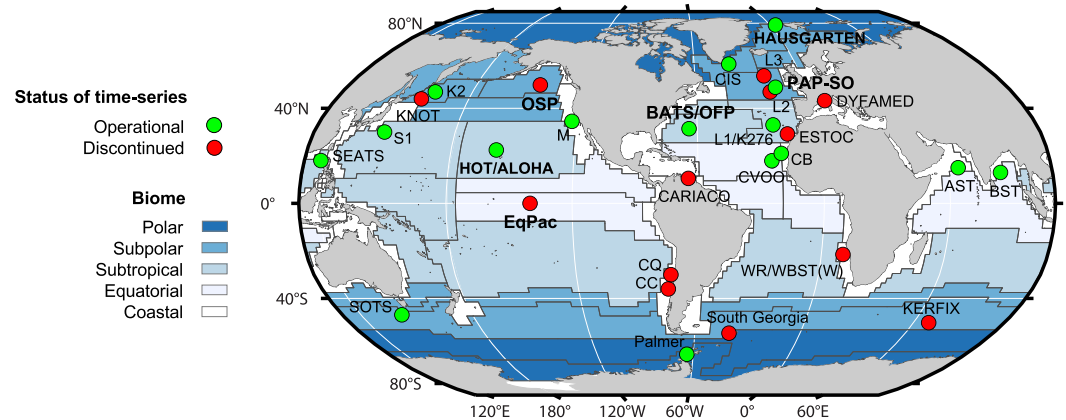
<sup>1</sup>Department of Earth Sciences, University of Oxford, Oxford, UK, <sup>2</sup>School of International Liberal Studies, Waseda University, Tokyo, Japan, <sup>3</sup>Earth Science Division, Ocean Biology and Biogeochemistry Program, NASA Headquarters, Washington, DC, USA, <sup>4</sup>Department of Botany and Plant Pathology, Oregon State University, Corvallis, OR, USA, <sup>5</sup>National Oceanography Centre, Southampton, UK

**Abstract** The biological carbon pump (BCP) transfers large amounts of carbon from the atmosphere into the ocean's interior, contributing to carbon sequestration. Studies on latitudinal variability in organic carbon transfer to depth have yielded inconsistent results, likely due to methodological differences. To address this, we compiled particulate organic carbon (POC) flux data and BCP metrics from time-series locations across biogeographically distinct ocean regions. We integrated multiple BCP observational techniques, including diverse collection and processing protocols, capturing diverse facets of POC flux at varying spatio-temporal resolutions. To ensure comparability, we harmonized errors and used Monte Carlo error propagation to calculate uncertainties consistently. Our analysis reveals large local uncertainties that obscure expected latitudinal variations in BCP metrics. While such variations may exist, they remain difficult to identify with current observational data. Our findings underscore the need for sustained POC flux observations, standardization of protocols, and intercalibration of technologies to identify geographic BCP patterns.

**Plain Language Summary** The biological carbon pump (BCP) transfers carbon dioxide from the atmosphere into the deep ocean through sinking organic particles, helping sequester carbon for long periods. Temperature is thought to strongly control how efficiently this particulate organic carbon is transferred into the ocean's interior. However, this presumed temperature control, with its large-scale geographic latitudinal variability, remains contested. Studies disagree on whether temperature enhances or reduces the efficiency of the transfer of organic particles from the surface to the deep ocean. Differences in particle collection and statistical analysis methods across research projects create significant uncertainties in assessing BCP transfer efficiency across oceanic regions. To explore these uncertainties, we analyzed BCP transfer efficiency data from six data-rich locations representing different biomes, applying a consistent error analysis approach. We found that local uncertainties are so large that they obscure expected larger-scale geographic latitudinal patterns driven by temperature, raising questions about whether such patterns exist. Our findings suggest that current observational data do not support the presence of latitudinal patterns in BCP metrics. If these patterns do exist, sustained POC flux observations, standardised data collection and processing protocols, and intercalibration of observational technologies will be essential to identify them accurately.

## 1. Introduction

The biological carbon pump (BCP) transfers CO<sub>2</sub> from the atmosphere into the deep ocean primarily through the gravitational sinking of biologically produced marine particles (Boyd et al., 2019; Volk & Hoffert, 1985), a process that contributes to oceanic carbon sequestration. Much of the particulate organic carbon (POC) produced by the surface ocean food web and exported to depth is remineralized to CO<sub>2</sub> in the mesopelagic zone before reaching 1,000 m, a key depth for long-term oceanic carbon sequestration (Passow and Carlson (2012), but see Ricour et al. (2023)). The BCP's efficiency in transferring POC flux through the mesopelagic zone is represented by the metric transfer efficiency (T<sub>eff</sub>). It has been suggested that T<sub>eff</sub> varies geographically with latitude (as well as over seasons), with certain oceanic regions argued to be more efficient in transferring POC flux beyond 1,000 m depth, making them more efficient oceanic carbon sinks. These geographical patterns in T<sub>eff</sub> are hypothesized to be controlled by a variety of factors, such as seawater temperature, plankton community structure and net primary production, which affect particle degradation rates, particle ballasting and particle palatability to food-web consumers. However, there is no consensus on the distribution of these patterns. Some studies indicate that T<sub>eff</sub> is higher in the warm, subtropical oceans (Buesseler & Boyd, 2009; Guidi et al., 2015; Henson



**Figure 1.** Geographic location of historical ship-based time-series research programs with particulate organic carbon (POC) flux data in deep-water sites (>1,000 m), with active stations (green) as of 2024. In bold are the six time-series research programs used in this study: the US Joint Global Ocean Flux Study (JGOFS) Equatorial Pacific process study experimental site (EqPac), the Hawaii Ocean Time-series (HOT) station ALOHA (HOT/ALOHA), the Bermuda Atlantic Time-Series/Oceanic Flux Program joint site (BATS/OFP), the Porcupine Abyssal Plain time-Series Observatory (PAP-SO), Ocean Station Papa (OSP), and the Long-Term Ecological Research observatory HAUSGARTEN. These sites use sediment traps on fixed-point moorings, encompassing both long-term, time-series (spanning many years) and temporary moorings (with a shorter time span but no less than 1 year). Gray contours delineate the 54 biogeochemical provinces from Longhurst (2006), color-coded by marine biome. Station details were sourced from OceanSITES (<http://www.oceansites.org/>), IGMETS (<https://igmets.net/>) and a Woods Hole Oceanographic Institution's sediment trap compilation (Benway, 2013).

et al., 2012; Lam et al., 2011), while others suggest it is higher in cold, high-latitude and equatorial upwelling regions (Cram et al., 2018; DeVries & Weber, 2017; Marsay et al., 2015; Weber et al., 2016). This existing discrepancy may be an indication that uncertainties in the observational datasets may be too large to diagnose a relation with temperature with confidence. Given that the BCP's  $T_{\text{eff}}$  has an impact on atmospheric  $\text{CO}_2$  levels (Kwon et al., 2009; Lauderdale & Cael, 2021), this knowledge gap has significant implication for climate modeling. It affects the representation of the BCP in the Earth System Models used to predict how the ocean's capacity to sequester  $\text{CO}_2$  via the BCP will respond to ongoing ocean warming brought about by climate change (Liu et al., 2023; Sanders et al., 2016; Siegel et al., 2016).

One reason for the diametrically opposed geographic latitudinal patterns in  $T_{\text{eff}}$ , even in data-based studies, is the reliance on one-off measurements, which risk capturing episodic events that are not representative of seasonal variation (de Melo Virissimo et al., 2024) or the long-term average (Bisson et al., 2018). However, time-series measurements, which provide long records of data through repeated visits to ocean sites, enable the identification and exclusion of anomalous data points by comparison with the long-term average conditions, thus yielding more robust data. Although about 30 ocean time-series sites have been providing measurements of POC flux using sediment traps (Figure 1), many ocean basins, including the South Pacific, South Atlantic and Indian Ocean, lack such data due to their remote locations, rendering routine monitoring impractical. This much reduced spatial coverage is a downside of time-series measurements. A second reason for the differing patterns in  $T_{\text{eff}}$  arises from the choices related to the timing (pre-bloom, bloom, post-bloom) and depth (surface, mesopelagic, near seafloor) of data sampling, as well as the choice of technology used for data collection and methods for data processing. For instance, the dataset of Henson et al. (2012) spans all ocean basins and uses a radiometric technique ( $^{234}\text{Th}/^{238}\text{U}$  radionuclide disequilibrium) to measure surface ocean POC flux, while using sediment traps for the deep ocean (1.5–3.5 km) that record a full annual cycle. In contrast, Marsay et al. (2015) compiled sediment trap data for the upper 500 m of the North Atlantic and North Pacific oceans, focusing on the summer months with a sampling period of 2–4 days.

Here, we seek to understand the consequences of the uncertainties in oceanographic POC flux measurements for robustly detecting geographic latitudinal trends by analyzing a variety of POC flux measurements and BCP metrics in a self consistent manner. Specifically, we test the null hypothesis that  $T_{\text{eff}}$  does not present coherent geographical variability and that the suggested geographical patterns could instead be methodological artifacts resulting from the choices made to collect and process POC flux measurements. We focus on six extensively sampled ocean locations spanning distinct open-ocean biomes: equatorial, subtropical, subpolar and polar oceans.

We analyze data from a variety of sources, including time-series and one-off measurements using diverse data collection methods, from traditional techniques to imaging sensors. We derive average values and uncertainties for three metrics characterizing mesopelagic POC flux transfer efficiency: Martin's  $b$  coefficient, the remineralization length scale coefficient and  $T_{\text{eff}}$ . Our analysis reveals large uncertainties in these metrics which obscure geographical differences. These results suggest that limitations of currently available data may pose a major challenge to ongoing efforts to understand the geographical variations of  $T_{\text{eff}}$ , which is crucial for identifying the factors that control  $T_{\text{eff}}$  and predicting how it might change in response to climate change.

## 2. Data and Methods

### 2.1. Data Sources

We compiled a dataset of oceanic POC flux measurements from two traditional collection methods—sediment traps and radionuclides—at six extensively sampled open-ocean time-series study sites (Figure 1, sites in bold). Spanning 1978–2022, the dataset includes time-series, one-off measurements and cross-project data from international programs such as JGOFS (Joint Global Ocean Flux Study), GEOTRACES and EXPORTS (EXport Processes in the Ocean from RemoTe Sensing), along with pivotal local programs like HOT and BATS. The selected six sites—EqPac (central equatorial Pacific upwelling system), HOT/ALOHA (subtropical NE Pacific), BATS/OFP (subtropical NW Atlantic), PAP-SO (subpolar NE Atlantic), OSP (subpolar NE Pacific) and HAUSGARTEN (polar Atlantic-Arctic boundary)—cover a range of biomes, from cold equatorial and high-latitude regions to the warmer subtropical areas, a geographical gradient where other studies have shown variations (e.g., Marsay et al. (2015) and Henson et al. (2012)). Our site selection criteria, which excluded some locations shown in Figure 1, were as follows: (a) open-ocean biomes to ensure that particle fluxes primarily reflect local ocean biogeochemical factors rather than terrestrial inputs from continents; (b) visits by multiple research teams, providing data using diverse collection methods; and (c) extensive coverage across multiple depths to capture mesopelagic attenuation processes. Tables S1–S6 in Supporting Information S1 summarize the references used, including data acquisition and quality control details, and Text S2 in Supporting Information S1 outlines the data processing methods.

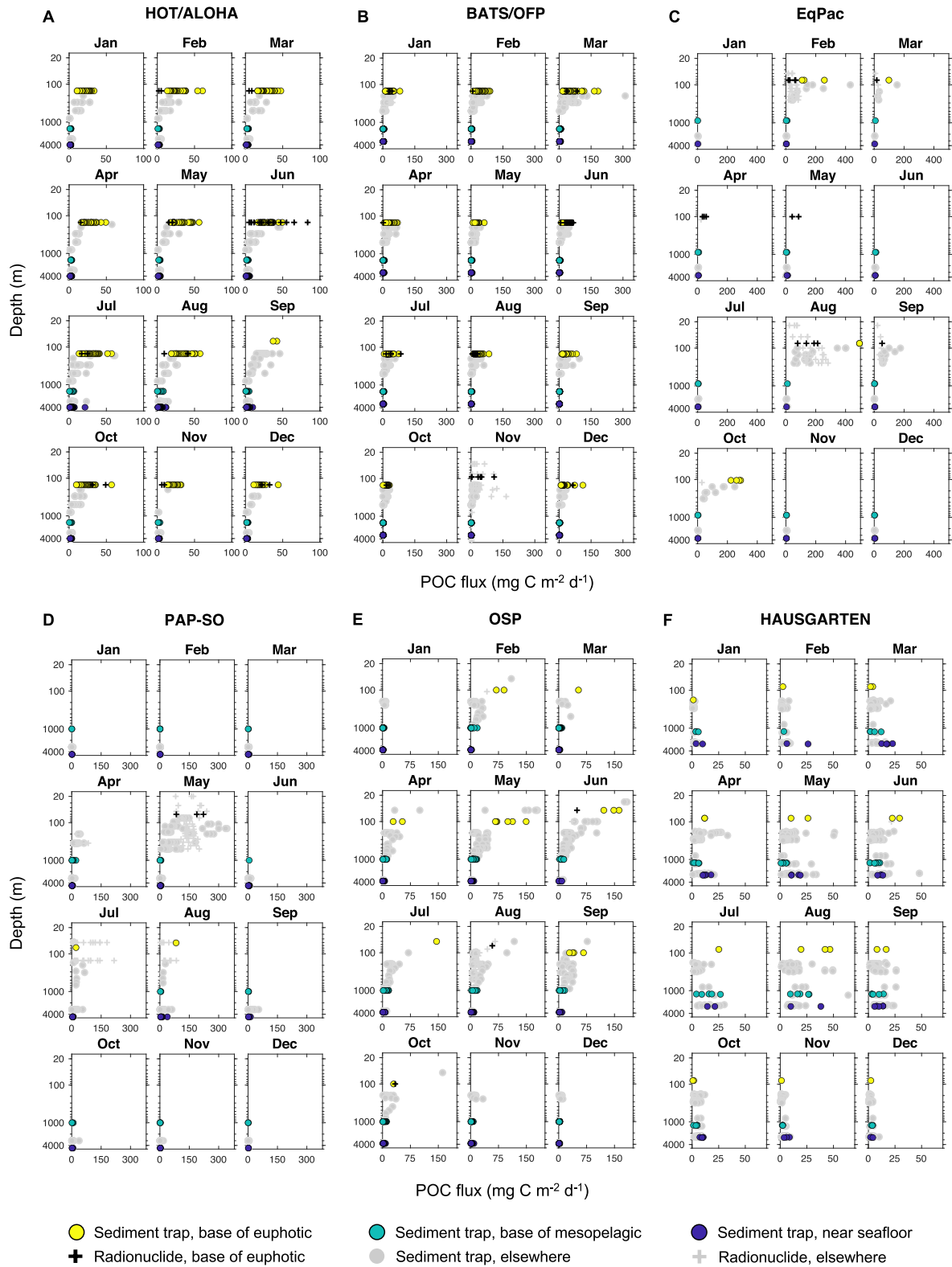
The primary data collection method featured in our compilation is long-term time-series sediment traps on bottom-tethered moorings (i.e., near-seafloor measurements). To enhance data representation in the upper water column, we supplemented time-series measurements with data from shorter-term studies conducted in these locations using surface-tethered sediment traps, neutrally buoyant sediment traps and radionuclides. Despite the different integration times of sediment traps and radionuclides (Th-based estimates typically integrate over 3 weeks whereas trap measurements can span from days to months, Buesseler et al. (2007)), individual data points show good overlap (Figure 2).

In addition to POC flux measurements from sediment traps and radionuclides, we explored an alternate collection method: marine particle imaging using the Underwater Vision Profiler 5 (UVP5). Particle data from the UVP5, sourced from the compilation by Kiko et al. (2022), was converted into POC flux using the approach outlined by Bisson et al. (2022) (Text S3 in Supporting Information S1). The use of an underwater camera like the UVP5 offers significantly higher depth and temporal resolution than traditional POC flux sampling methods and has gained popularity over the past decade as a valuable proxy for POC flux (Chai et al., 2020; Claustre et al., 2021; Giering et al., 2020; Siegel et al., 2023).

### 2.2. Calculation of Metrics

Our study evaluates three BCP mesopelagic transfer efficiency metrics: Martin's  $b$  coefficient, which assumes a power-law decay of POC flux with depth (Martin et al., 1987); the remineralization length scale coefficient ( $\tau^*$ ), which assumes an exponential decay (Armstrong et al., 2002); and the fraction of POC flux exported from the euphotic zone ( $\sim 50$ – $200$  m) that reaches the base of the mesopelagic ocean ( $\sim 1,000$  m) ( $T_{\text{eff}}$  between  $z_{\text{eu}}$ – $z_{\text{meso}}$ ), which makes no assumption on manner of decay (Buesseler & Boyd, 2009). These three metrics are interrelated (can be derived from one another) and the equations for each are provided in Text S1 in Supporting Information S1.

Metrics were derived from five distinct data groups: (a) POC flux measurements from sediment traps and radionuclides (compiled specifically for this study), (b) POC flux estimates from the UVP5 (sourced from Kiko



**Figure 2.** Compilation of particulate organic carbon (POC) flux measurements from sediment traps and radionuclides at the six ocean time-series sites used in this study, showcasing data distribution by month and depth ( $N = 7162$ ). Colored data points represent different collection methods and depth zones (see Table S7 in Supporting Information S1) and are used for data summaries in Figures S1–S2 in Supporting Information S1. Note the y-axis in  $\log_{10}$  scale, and the x-axis typically limited to the maximum POC flux value at each site.

et al. (2022)), (c) published BCP metrics calculated from canonical fits to POC flux data from sediment traps, radionuclides, UVP5 and in situ filtration systems (Buesseler & Boyd, 2009; Francois et al., 2002; Guidi et al., 2015; Lam et al., 2011; Mouw, Ciochetto, et al., 2016), (d) published BCP metrics calculated from statistical fits to physical and biogeochemical data (Henson et al., 2012; Marsay et al., 2015), and (e) published BCP metrics estimated using a diagnostic model constrained by biogeochemical data (Weber et al., 2016). This approach allowed us to incorporate metrics from a range of collection methods (e.g., collection technology, timing of the sampling, depth resolution) and processing methods (e.g., data aggregation, error propagation and metric calculation) across local and international programs. Table S8 in Supporting Information S1 lists the contributing studies with local scope, while details of data processing for each data group are documented in Texts S2–S6 in Supporting Information S1.

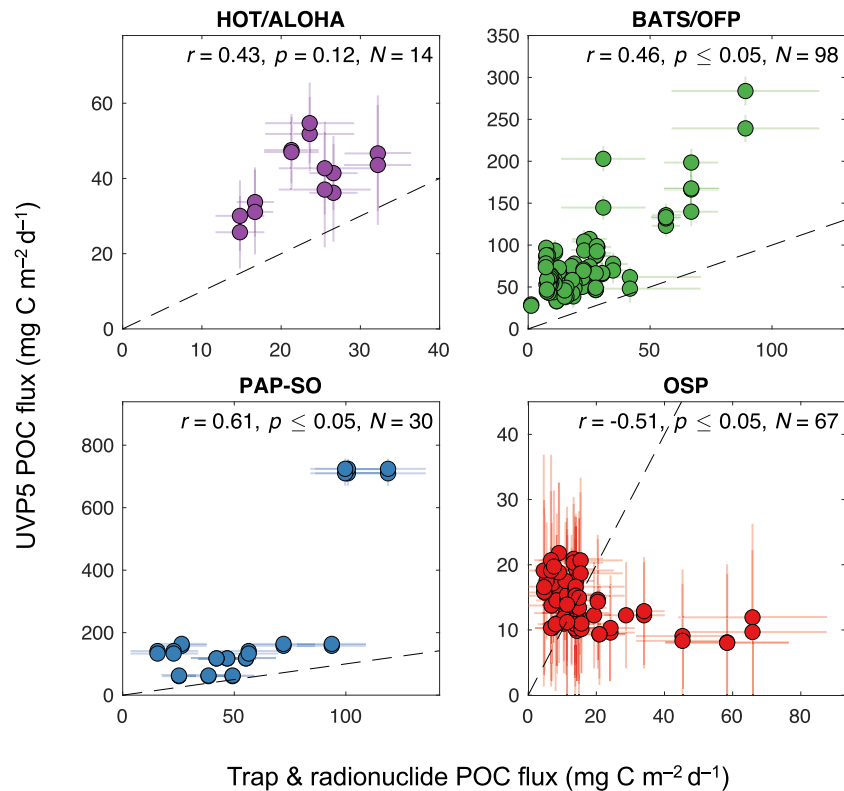
Error quantification for POC flux data from sediment traps and radionuclides (group i) distinguishes between random and systematic errors (Text S2 in Supporting Information S1), following the ISO Guide to the Expression of Uncertainty in Measurement (GUM, 2020). For UVP5 data (group ii), uncertainties were derived from particle sampling volumes, as described by Bisson et al. (2022) (Text S3 in Supporting Information S1). Error propagation to monthly POC flux averages in both groups was performed using MATLAB's Worst-Case Propagation of Uncertainty algorithm (Ridder, 2023). For all data groups (i to v), error propagation from monthly POC flux estimates to BCP metrics, or between metrics, was performed using a Monte Carlo-based approach implemented in MATLAB by Robens (2023) (described in Text S7 in Supporting Information S1). This approach simulates the probability distribution of the metrics, from which we can directly derive their confidence intervals, offering a simpler alternative to more complex calculations typically required for error propagation when multiple sources of uncertainty are involved.

### 3. Results

POC flux measurements from sediment traps and radionuclides (Figure 2) show good agreement in their ranges, supporting their combined use for calculating monthly averaged POC fluxes (Figure S2 in Supporting Information S1). While overlap is not always expected (e.g., Buesseler et al., 2006), here the two methods align well. Both reveal substantial depth heterogeneity, with better coverage of the mesopelagic and bathypelagic zones compared to the surface, and enhanced sampling of the surface ocean during warmer months (e.g., OSP and PAP-SO). Most monthly POC flux profiles show a typical depth decay (except HAUSGARTEN), indicative of subsurface attenuation processes. Notably, surface ocean POC fluxes vary up to 10-fold (e.g., HOT/ALOHA in June; BATS/OFP in March; EqPac in August; PAP-SO in July; OSP in May).

Compared to UVP5-derived POC flux (Figure S5 in Supporting Information S1), sediment trap and radionuclide measurements show less overlap, with UVP5 estimates generally being higher, a trend confirmed by the BCP metrics derived from POC fluxes (Figure S6 in Supporting Information S1 and Tukey-Kramer post-hoc test,  $p \leq 0.05$ ). A matchup analysis of UVP5 and combined sediment trap and radionuclide POC flux data (Figure 3) reveals a low (HOT/ALOHA and BATS/OFP) to moderate (OSP and PAP-SO) correlation between these collection methods (Spearman's rank, all statistically significant with  $p \leq 0.05$ , except HOT/ALOHA). This substantial mismatch was also noted by Fender et al. (2019, see their Figure 3).

Figure 4 compares three metrics of BCP mesopelagic transfer efficiency (Martin's  $b$ ,  $z^*$ ,  $T_{\text{eff}}$ ) across various studies at our six study locations. Visibly, there is considerable variability within each location, making it difficult to identify differences between biomes. In fact, statistical analysis reveals no significant differences between locations for any of the metrics (Kruskal–Wallis ANOVA,  $p > 0.05$ ), implying that distinct ocean biomes, as represented by our locations, do not display significantly different BCP mesopelagic transfer efficiencies, thus accepting the null hypothesis of this study. Our results contrast with previous studies suggesting geographic latitudinal differences in these metrics and, in an effort to explain them, arguing that temperature may control their large-scale geographical variability. In Figure 4, such a temperature-based control of  $T_{\text{eff}}$  would imply a left-to-right transition from warm (subtropical) to cold (upwelling equatorial, polar and subpolar) biomes. While this pattern is evident in individual studies (e.g., Marsay et al. (2015), Weber et al. (2016), and Mouw, Ciochetto, et al. (2016) show an increase of  $T_{\text{eff}}$  left-to-right, while Henson et al. (2012) and Guidi et al. (2015) show a decrease), such patterns do not hold when considering all studies collectively. Moreover, the sediment trap/radionuclide and UVP5 datasets processed in this study—for which we did not have prior expectations of a specific pattern—do not appear to follow a consistent trend.



**Figure 3.** Comparison of particulate organic carbon (POC) flux matchups between Underwater Vision Profiler 5 (UVP5) estimates and sediment trap/radionuclide combined measurements at the four ocean study sites used in this study with spatio-temporal matchups. Matchups were identified using a depth tolerance of 5 m, time tolerance of 2 days and a latitude/longitude tolerance based on geographic search coordinates (see Tables S1–S6 in Supporting Information S1 for sediment trap/radionuclide data and Figure S4 in Supporting Information S1 for UVP5 data). UVP5 error bars reflect uncertainty propagated from water sampling volumes imaged during casts conducted on the same day, while sediment trap/radionuclide error bars reflect the combined random and systematic measurement uncertainties in the collection of POC flux. Spearman's rank correlation coefficient ( $r$ ),  $p$ -value and number of local matchups ( $N$ ) are provided. A total of  $N = 209$  matchups were identified from 7,162 sediment trap/radionuclide measurements of POC flux and 43,703 UVP5-derived estimates.

#### 4. Discussion and Conclusions

In this study, we tested the null hypothesis that the BCP's mesopelagic transfer efficiency does not present coherent geographic latitudinal variability by analyzing, in a self consistent manner, an extensive compilation of open-ocean data covering distinct ocean biomes. Previous studies have suggested that  $T_{\text{eff}}$  is strongly controlled by temperature (although the sign of the relationship is disputed), which should be reflected in geographic latitudinal variations (Buesseler & Boyd, 2009; Cram et al., 2018; DeVries & Weber, 2017; Guidi et al., 2015; Henson et al., 2012; Lam et al., 2011; Marsay et al., 2015; Weber et al., 2016). However, our analysis reveals no such statistically significant geographical variations in  $T_{\text{eff}}$ , accepting the null hypothesis. If such geographical trends do exist, they are obscured by natural variability (associated with location, depth and season; Figure 2) as well as differences in working protocols (associated with data collection and processing methods; Text S2–S6 in Supporting Information S1).

Latitudinal gradients reflect the uneven distribution of sunlight and heat across the Earth's surface, closely linking them to temperature. Many marine ecosystem variables, such as phytoplankton growth, heterotrophic respiration and phytoplankton cell size, are temperature-dependent. However, the invoked mechanisms through which temperature affects  $T_{\text{eff}}$  differ among authors. For instance, Henson et al. (2012) suggested that in warm, low-latitude systems, the tighter coupling between phytoplankton growth and zooplankton grazing—resulting in the increased production of fecal pellets, which are fast-sinking particles that are transferred more efficiently—along with the smaller size of phytoplankton cells—producing particles that are less palatable and harder to digest, resulting in slower decomposition of POC—leads to higher  $T_{\text{eff}}$ . In cold, upwelling systems, the reverse

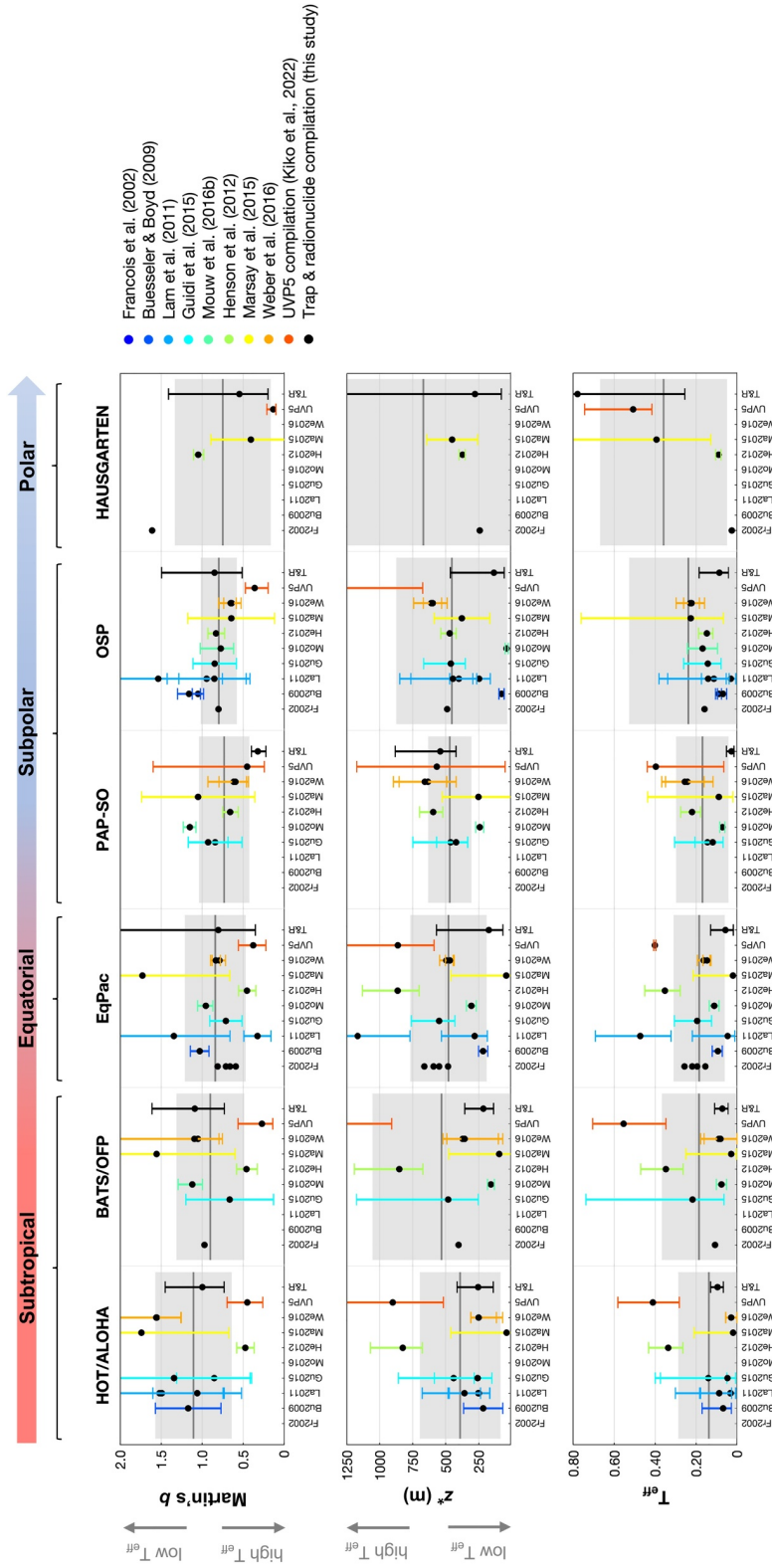


Figure 4.

pattern is observed. In contrast, Marsay et al. (2015) attributed lower  $T_{\text{eff}}$  in warmer systems to slower heterotrophic metabolism, leading to slower degradation of POC, with the smaller size of phytoplankton cells contributing to slow-sinking particles.

The absence of a clear latitudinal gradient in BCP transfer efficiency metrics across studies (Figure 4)—despite distinct latitudinal patterns observed in individual studies—can be attributed to six factors we identified. First, differences in protocols for error quantification and error propagation may limit comparability between studies (Text S2 in Supporting Information S1). Second, mathematical artifacts can affect metric calculation; for instance, the coefficients  $b$  and  $z^*$  are sensitive to the curve fitting method applied and reference depths (Text S2 in Supporting Information S1; Figure S3 in Supporting Information S1; Olli (2015)), while UVP5-based BCP metrics are sensitive to range of particle size classes and assumptions made in the calibration of the power-law coefficients linking particle size to POC flux (Bisson et al., 2022; Iversen et al., 2010; McDonnell & Buesseler, 2012). Third, the collection method to acquire POC flux data introduces variability (Figure 3; Cael et al. (2018); Fender et al. (2019); Bisson et al. (2022)), as methods differ in integration times (e.g., up to a year for a sediment trap and instantaneous for UVP5), POC flux facets detected (e.g., UVP5 detect passively sinking particles, like marine snow, and actively sinking particles, like zooplankton, whereas radionuclides measure only passively sinking), or detection sensitivities (e.g., UVP5 is insensitive to very small and very large particles while radionuclides are highly sensitive to physical processes in the water column). Fourth, the temporal sampling window varies, with studies often focusing on different seasonal periods (pre-bloom, bloom or post-bloom period), which may be more or less representative of the annual average (Bisson et al., 2018), and data gaps exist, particularly during winter months at higher latitudes (e.g., OSP and PAP-SO, Figure 2). Fifth, the depth resolution of sampling varies across projects, affecting the choice of reference depths to obtain POC flux profiles (Figure S3 in Supporting Information S1 and Buesseler, Boyd, et al. (2020)). Lastly, the dynamic nature of POC flux requires large sample sizes for accurate long-term estimates, rendering one-off (episodic) measurements potentially biasing and undersampling at different depths and times a concern (Cael et al., 2018, 2021). Indeed, the diametrically opposed temperature-driven geographical patterns in Henson et al. (2012) and Marsay et al. (2015) likely stems from differences in the POC flux datasets they used, which amalgamate various collection technologies, depth ranges covered, timings and sample sizes. Thus, researchers must carefully consider these factors before attributing spatial or long-term representativeness to their estimated metrics, as dataset limitations can significantly impact results.

One implication of a lack of identifiable geographic latitudinal variability in  $T_{\text{eff}}$  is that temperature may not be its dominant control. Indeed, other factors controlling  $T_{\text{eff}}$  have been proposed, such as net primary production and phytoplankton community composition (Cram et al., 2018; Francois et al., 2002; Guidi et al., 2009; Lam et al., 2011). Furthermore, a recent study by de Melo Virrissimo et al. (2024) examined the seasonal variability in  $T_{\text{eff}}$  and concluded that the high seasonality in POC flux attenuation patterns could preclude attributing a single annual average mode of geographical behavior to  $T_{\text{eff}}$ . Accounting for these additional factors could reveal geographical patterns that temperature alone has not identified in our study.

Determining the fractional contribution of the six factors outlined above to measurement uncertainty would be a valuable exercise but was beyond the scope of our null hypothesis testing exercise. While sustained observations from time-series sites could help sectioning uncertainty into its various contributors, future efforts should also focus on reconciling methods and uncertainty quantification in raw POC flux data, alongside collecting equivalent data from a broader range of contrasting sites. Our approach provides a first-hand exploration of uncertainty in POC flux measurements across a diverse array of methods, reflecting the real-world, multiple-choice challenges researchers face when selecting data to validate their studies. Given the variety of data collection and processing methods, we opted to incorporate data from all available methods, addressing the researcher's practical dilemma of dataset selection while recognizing the limits of detailed uncertainty quantification.

**Figure 4.** Comparison of published BCP mesopelagic transfer efficiency metrics (Martin's  $b$  coefficient,  $z^*$  coefficient and  $T_{\text{eff}}$  between  $z_{\text{eu}}-z_{\text{meso}}$ ) across six sites associated with time-series programs (HOT/ALOHA, BATS/OFP, EqPac, PAP-SO, OSP and HAUSGARTEN) arranged by ocean biome (from warm subtropical, to cold equatorial, subpolar and polar). The individual values shown are the median and 68% confidence intervals (equivalent to one standard deviation). The dark gray horizontal line represents the group simple mean of study references, with overlaid gray bounds indicating standard deviation. For publications that employed different methods to collect/process raw POC flux data, or sampled at different seasons of the year, their average values are reported separately and represented as distinct scatter points (see Text S8 in Supporting Information S1 for further explanation). The y-axis of  $b$  and  $z^*$  is limited to a range of reasonable values (assessed after Henson et al. (2012) and Marsay et al. (2015)); note that some values confidence intervals extend beyond this range and are truncated. All plotted values are provided in Dataset S2.

Traditionally, assessing the BCP's mesopelagic transfer efficiency relied on sediment traps and  $^{234}\text{Th}$  measurements. The advent of new technologies, like low-powered optical scattering and chlorophyll fluorescence sensors mounted on autonomous platforms such as gliders and floats (Briggs et al., 2011, 2020), and the UVP6 (Picheral et al., 2022), brings a transformative change in the way oceanographers observe POC fluxes. These technologies offer unprecedented spatio-temporal resolutions, especially crucial in the undersampled mesopelagic zone (100–1,000 m). However, as new technologies proliferate, there is a parallel need to work toward studies that intercompare them. Our analysis in Figure 3 highlights the importance of exercising caution when inferring large-scale patterns in POC fluxes from a single collection method or when combining datasets from different technologies, as each captures different facets of POC flux at varying spatio-temporal resolutions. Such comparative studies are crucial for end-users of the data, enabling them to make informed decisions about the most suitable data to use for their specific research purposes. Importantly, uncertainties in oceanographic observations propagate into climate models which, depending on their parametrization, variably project either enhanced or decreased mesopelagic transfer efficiency under future climate change scenarios. This discrepancy in even the directionality—the enhancement or reduction of POC flux processes—has obvious ramifications for our ability to predict the long-run effects of global warming in the ocean.

### Data Availability Statement

The raw POC flux data compiled for this study and plotted in Figure 2 are available from the references cited in Tables S1–S6 in Supporting Information S1. The data plotted in Figure 4 are available in Dataset S2. All analyses were done using MATLAB (R2021a, MathWorks Inc) and the code and processed data are available in the GitHub repository [https://github.com/annarufas/Rufas\\_et\\_al\\_2024\\_GRL](https://github.com/annarufas/Rufas_et_al_2024_GRL) and is archived at Rufas (2024). MATLAB's Worst-Case Propagation of Uncertainty algorithm (Ridder, 2023) and MATLAB's Monte Carlo Error Propagation algorithm (Robens, 2023) were used to perform error propagation, and MATLAB's Shapiro-Wilk and Shapiro-Francia normality tests (BenSaïda, 2024) were used for our ANOVA analysis. Required MATLAB's toolboxes include “Curve Fitting”, “Optimization”, and “Statistics and Machine Learning.”

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