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Key Points:

- Mesopelagic layers of small particles are detected in 9% of BGC-Argo float profiles globally
- These layers contain approximately 8% of global small-particle mesopelagic carbon stock
- 60% of layers are found in oxygen minimum zones, where they are often associated with denitrification

Supporting Information:

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

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Unexpected Global Prevalence of Mesopelagic Particle Layers Detected by BGC-Argo Floats

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Abstract Particulate organic carbon transported to the deep ocean forms a critical component of the Earth's carbon cycle. The concentration of these particles is generally parameterized in models to decrease continuously with depth, but isolated layers of small particles ($\leq 20 \mu\text{m}$) observed within the mesopelagic challenge this assumption. Since their global distribution and contribution to sub-surface carbon stocks is unknown, we have developed a new algorithm for detecting these layers in backscattering data collected by BGC-Argo floats. Our results show that these layers are present in 9% of 70,668 profiles and are distributed widely across the global ocean. They are most abundant in oxygen minimum zones (OMZs), where they contribute $\sim 16\%$ toward mesopelagic particulate carbon stocks and often coincide with nitrate deficits, suggesting a role of denitrifying bacteria. Outside OMZs, subduction only explains 12.5% of layers, implying the main cause remains unidentified.

Plain Language Summary Carbon transported to the deep sea in the form of microscopic particles plays a key role in how our oceans regulate global climate. As these particles descend, they are degraded by bacteria meaning that their concentration is expected to decrease with depth. Contrary to this assumption however, particles have been observed to accumulate deep in the ocean, forming distinct layers where concentrations were previously expected to be low. Despite previous occasional observations of these layers, their global distribution remains unknown. To address this uncertainty, we used data from autonomous robots spread around the oceans to map the location of these layers in the global ocean for the first time. We find that these layers are widely distributed (from the polar regions to the tropics) and contribute considerably toward the total concentration of small particles in the deep sea. Understanding how these layers form is therefore important because they may be a key part of how organic carbon is stored in the deep ocean.

1. Introduction

The phenomenon of isolated mesopelagic particle layers has been observed several times throughout the global ocean, typically at depths between 100 and 600 m (Chen et al., 2021; Johnson & Omand, 2021; Kiko et al., 2017; Llort et al., 2018; Lovecchio et al., 2025; Naqvi et al., 1993; Omand et al., 2015; Roullier et al., 2014; Whitmire et al., 2009). These features are characterized by subsurface maxima in particulate organic carbon (POC) and can be formed by particles as small as individual phytoplankton and bacterial cells (Naqvi et al., 1993; Omand et al., 2015; Roullier et al., 2014) or by larger detritus up to $\sim 500 \mu\text{m}$ in diameter (Kiko et al., 2017; Lovecchio et al., 2025). Potential causes include the accumulation of denitrifying bacteria (Naqvi et al., 1993; Roullier et al., 2014), eddy-driven subduction (Chen & Schofield, 2024; Llort et al., 2018; Omand et al., 2015), and particle creation by diel migrating zooplankton (Kiko et al., 2017; Lovecchio et al., 2025).

Since small particles can contribute significantly to fluxes of POC in the ocean (Baker et al., 2017; Dall'Olmo & Mork, 2014; Giering et al., 2016; Riley et al., 2012) it is important to understand the potential significance of these layers for global mesopelagic carbon storage. Despite this, observations revealing these features are spatially limited and their global distribution has not yet been established.

These layers are also not reproduced by current biogeochemical models, possibly due to the implicit assumption that particle concentration decreases with depth (Armstrong et al., 2001; Boyd & Stevens, 2002; Gloege et al., 2017; Henson et al., 2015). Alternatively, these models may be missing one or more process with importance for mediating mesopelagic particle concentration. Either way, it remains challenging to simulate these layers in models because of large uncertainties regarding their global spatial and temporal distribution and associated formation mechanisms.

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To address these uncertainties, we developed a new algorithm for detecting sub-surface particle layers from backscatter data collected by Biogeochemical-Argo (BGC-Argo) floats. We thus show the first global scale distribution of these features, allowing inter-regional comparisons in their properties and potential drivers. We further quantify the proportion of layers mediated by two possible formation processes, denitrification and subduction, as identified using other relevant data recorded by BGC-Argo floats.

2. Methods

2.1. Data and Derived Variables

We use BGC-Argo float optical backscattering coefficient (b_{bp}), dissolved oxygen, nitrate, temperature and salinity data from 2015 to 2024 inclusive (Argo (2000), (Claustre et al., 2020; Wong et al., 2020).

In addition to automatic quality control performed by the BGC-Argo data assembly centers (Bittig et al., 2019) we performed extra QC on the b_{bp} data, by first removing spikes following (Briggs et al., 2011) and then applying further QC following (Dall'Olmo et al., 2023). After quality control (see Section S1 in Supporting Information S1), our global data set included 70,668 profiles with data for all required parameters, apart from nitrate which was only available for 56% of profiles.

b_{bp} was used as a proxy for POC concentration (Reynolds et al., 2016). Variability in b_{bp} is mainly driven by changes to particle concentration, particle reflectance, size and shape (Reynolds et al., 2016; Stramski et al., 2004). Once spikes in the backscatter signal are removed, most particles captured by the sensor are expected to be in the size range 0.2–20 μm (Dall'Olmo & Mork, 2014; Stramski et al., 2004).

POC concentration can be estimated from backscatter using empirical relationships (Cetinic et al., 2012; Gardner et al., 2006; Johnson et al., 2017; Koestner et al., 2022; Rasse et al., 2017; Stramski et al., 2008, 2023). Currently there is no consensus regarding which of these relationships is most appropriate for use at the global scale (see Section S2 in Supporting Information S1). We used the slope of the linear relationship from (Johnson et al., 2017) (solid red line in Figure S1 in Supporting Information S1), as it was derived from BGC-Argo float data.

We calculated apparent oxygen utilization (AOU) as the difference between the surface saturation oxygen concentration and depth-dependent dissolved oxygen concentration, following (Llort et al., 2018). Saturation oxygen concentration was approximated from temperature and salinity following (Garcia & Gordon, 1992). We defined profiles within hypoxic and suboxic OMZs as those where the average upper-mesopelagic (150–500 m; (Bianchi et al., 2013)) dissolved oxygen concentration fell below either 120 or 10 $\mu\text{mol O}_2 \text{ Kg}^{-1}$ respectively (Stramma et al., 2008).

Mixed layer depth (MLD) was calculated using the definition from (de Boyer Montegut et al., 2004) which defines the MLD to be the shallowest value of two criteria: (a) The depth where there is an increase in temperature of 0.2°C relative to the value at 10 m, or (b) the depth where the density increases by 0.03 Kg m^{-3} , also relative to the value at 10 m. Water density was calculated from temperature and salinity using the MATLAB function “Seawater density from salinity, temperature and pressure” (Ruiz-Martinez, 2023).

2.2. Particle Layer Detection Algorithm

Our new algorithm for detecting profiles containing mesopelagic particle layers is based on finding maxima and minima of POC concentration within specified depth limits. The minimum depth limit (Z_1) is fixed at either the MLD or 100 m (whichever is deeper) and the maximum depth limit (Z_2) is progressively increased between Z_1 and 500 m with each algorithm iteration. The minimum POC concentration between Z_1 and Z_2 is subtracted from the POC concentration at Z_2 and the depth where this difference is greatest is defined as Z_{Peak} (Figure 1a). The value of this maximum difference is called the particle layer's magnitude, or ΔPOC (Figure 1a). The particle layer's start depth (Z_{Start}) marks the depth of minimum POC concentration between Z_1 and Z_{Peak} (Figure 1a). The particle layer's end depth (Z_{End}) marks the shallowest depth between Z_{Peak} and 1,000 m where POC concentration is less than or equal to the value at Z_{Start} (Figure 1a). Particle layer thickness is then defined as the difference between Z_{End} and Z_{Start} . Particle layer durations are calculated by identifying series of consecutive float profiles, which all contain particle layers, and then determining the time difference (in days) between the first and last profile of those series.

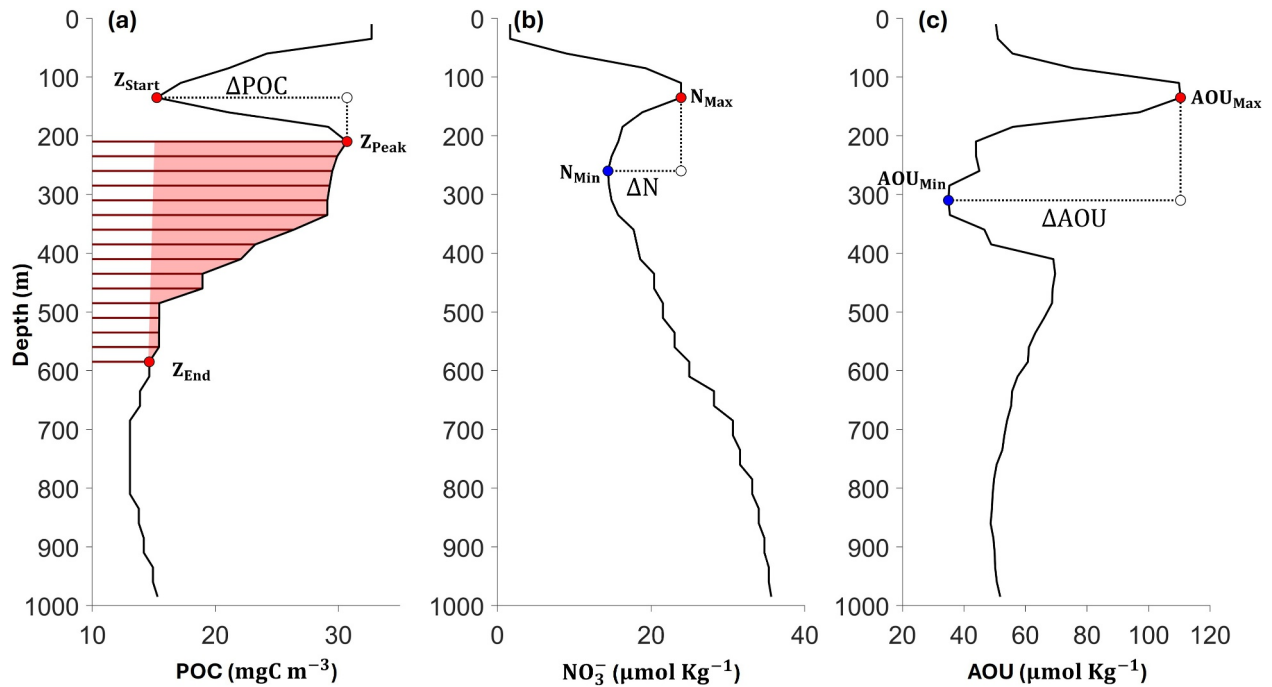


Figure 1. Example profiles of (a) POC, (b) Nitrate, and (c) Apparent Oxygen Utilization (AOU) from float profiles with particle layers from the Arabian Sea (panels a and b) and the North Atlantic (panel c). (a) The start and end depth of the layer are marked by Z_{Start} and Z_{End} respectively and Z_{Peak} shows the depth of maximum POC concentration within the layer. ΔPOC shows the particle layer's magnitude. Red bars show the total mesopelagic POC stock, and the pink shaded area shows the integrated mesopelagic POC concentration missed if POC concentration is assumed to decrease linearly with depth between Z_{Start} or 200 m (whichever is deeper) and Z_{End} . In (b) ΔN indicates the nitrate deficit used to identify profiles associated with denitrification. In (c) ΔAOU shows the AOU deficit used to identify particle layers associated with subduction.

Mesopelagic layers are identified in profiles where Z_{Peak} and ΔPOC exceed 200 m and 3 mgC m^{-3} respectively (see Section S3 in Supporting Information S1 for details on threshold selection). The impact of uncertainty in ΔPOC on the global distribution of particle layers is explored in a sensitivity analysis presented in Section S4 in Supporting Information S1. The 200 m threshold represents the maximum depth of the euphotic zone (Davies & Smyth, 2025) and chlorophyll maxima (Cornec et al., 2021). Implementing this constraint on our algorithm therefore minimizes the likelihood of a particle layer being associated with living phytoplankton cells. The distribution of such events is already carefully examined by (Cornec et al., 2021) so will not be considered here.

The mesopelagic POC stock of small particles (POC_{MESO}) is defined as the total integrated POC concentration between 200 and 1,000 m. The fraction of the total mesopelagic POC stock contained within particle layers (POC_{PL}) is defined as the ratio of the integrated POC concentration between Z_{Start} (or 200 m whichever is deeper) and Z_{End} (red bars in Figure 1a) to POC_{MESO} (Equation 1). We define POC_{Missed} as the total POC excluded when POC concentration is assumed to decrease linearly with depth between Z_{Start} and Z_{End} (pink shaded region in Figure 1a). The fraction of POC_{MESO} missed when assuming linear attenuation between Z_{Start} and Z_{End} is calculated using Equation 2.

$$\text{Fraction of Total Mesopelagic POC in Layers} = \frac{POC_{PL}}{POC_{MESO}} \quad (1)$$

$$\text{Fraction of Total Mesopelagic POC Missed} = \frac{POC_{Missed}}{POC_{MESO}} \quad (2)$$

2.3. Detecting Particle Layers Associated With Denitrification and Subduction

To identify particle layers in oxygen minimum zones (OMZs) associated with denitrification, we developed an algorithm for calculating an apparent mesopelagic nitrate deficit (ΔN , see Figure 1b), which we attributed to denitrification (Naqvi et al., 1993).

In the algorithm, ΔN is calculated as the difference between the maximum nitrate concentration (N_{Max}) between the surface and Z_{Peak} , and the minimum nitrate concentration (N_{Min}) between the depth of N_{Max} and Z_{End} (Figure 1b). Profiles are labeled as denitrification events if they are in suboxic regions and if ΔN exceeds $1 \mu\text{mol NO}_3^- \text{ Kg}^{-1}$ (see Section S3 in Supporting Information S1 for threshold validation).

A method for detecting subduction events in the Southern Ocean with data from BGC-Argo floats is described by (Llort et al., 2018). First, the AOU anomaly (ΔAOU , see Figure 1c) is calculated as the difference between the maximum AOU between the surface and Z_{Peak} (AOU_{Max}) and the minimum AOU between the depth of AOU_{Max} and Z_{End} , AOU_{Min} (Figure 1c). Then, a ΔAOU threshold is applied as a minimum bound, where any profile with a deficit greater than or equal to this value is predicted to be associated with a subduction event. To apply the algorithm from (Llort et al., 2018) globally, we found it necessary to alter their AOU threshold to limit the false identification of subduction events in regions where they are not expected to occur, such as the equatorial Indian Ocean (Omand et al., 2015). Our validation process (see Section S3 in Supporting Information S1) finds the optimum ΔAOU threshold to be $19 \mu\text{mol Kg}^{-1}$.

We also found it necessary to filter the identified subduction events based on their instantaneous surface-to-mesopelagic density gradient ($\Delta\rho$) to further limit the identification of subduction events in regions where they are not expected (Figure S4 in Supporting Information S1), namely the equatorial Indian Ocean and Bay of Bengal (Omand et al., 2015). $\Delta\rho$ is calculated as the difference in median density from the surface (0–25 m) to upper mesopelagic (150–500 m). We set the value of $\Delta\rho$ to 2 Kg m^{-3} . The impact of uncertainty in $\Delta\rho$ on the global distribution of subduction events is evaluated in a sensitivity analysis presented in Section S5 in Supporting Information S1.

3. Results and Discussion

3.1. Spatial Distribution of Particle Layers and Their Significance for Carbon Stocks

In 70,668 backscatter profiles from 2015 to 2024, we detect mesopelagic particle layers in 9% of profiles; that is, 6,577 cases or approximately 1 in 11 profiles. The features are detected in every major basin across all latitudes and oxygen regimes (Figure 2a). This distribution agrees qualitatively with the locations of previous particle layer observations (Chen et al., 2021; Johnson & Omand, 2021; Kiko et al., 2017; Llort et al., 2018; Lovecchio et al., 2025; Naqvi et al., 1993; Omand et al., 2015; Roullier et al., 2014; Whitmire et al., 2009).

Our study is the first to identify where these layers occur globally using consistent methods of detection, enabling inter-regional comparisons for the first time. This advancement reveals that, although widespread, the frequency of particle layers is particularly high in the tropics and hypoxic OMZs (Figure 2a). Specifically, 20% of profiles inside OMZs have particle layers, compared to only 4.3% outside OMZs (Figure 2b). Moreover, layers are present in 75% of profiles from the Arabian Sea implying that these features are a key characteristic of how small-particle concentration varies with depth in this basin. By contrast, particle layers in the Southern Ocean are only present in 2% of profiles, exhibiting a patchier spatial distribution with more isolated cases which may be due to strong advective currents and vertical mixing dispersing the layers relatively quickly from where they are formed (Johnson & Omand, 2021; Llort et al., 2018).

There is no clear spatial variability in Z_{Peak} , either latitudinally or across different basins (Section S6, Figure S7 in Supporting Information S1). The globally averaged values of Z_{Peak} and particle layer thickness are $317 \pm 87 \text{ m}$ and $458 \pm 204 \text{ m}$ respectively. The globally averaged particle layer magnitude is 8.6 mg C m^{-3} , but this differs considerably between cases inside (9.6 mg C m^{-3}) and outside (6.5 mg C m^{-3}) OMZs (Figure 2c). The integrated small-particle POC stock contained within all sub-surface layers accounts for 7.5% of the global mesopelagic total, but again there are clear contrasts between different oxygen regimes (Figure 2d). The POC contained within these layers account for 3% of total mesopelagic POC stock outside of OMZs and 16% inside OMZs (Figure 2d). Globally, 72% of layers lasted less than 10 days and 2.3% exceeded 6 months. The longest lasting layer (689 days) was detected in the Arabian Sea. Generally layers in the Arabian Sea were more persistent than elsewhere (Section S6, Figure S8 in Supporting Information S1), with 15% lasting longer than 6 months and 4% exceeding 1 year.

Particle concentration is generally expected to decrease with depth in the mesopelagic (Gloege et al., 2017; Martin et al., 1987), but the global prevalence of these sub-surface particle layers (Figure 2a) challenges this assumption.

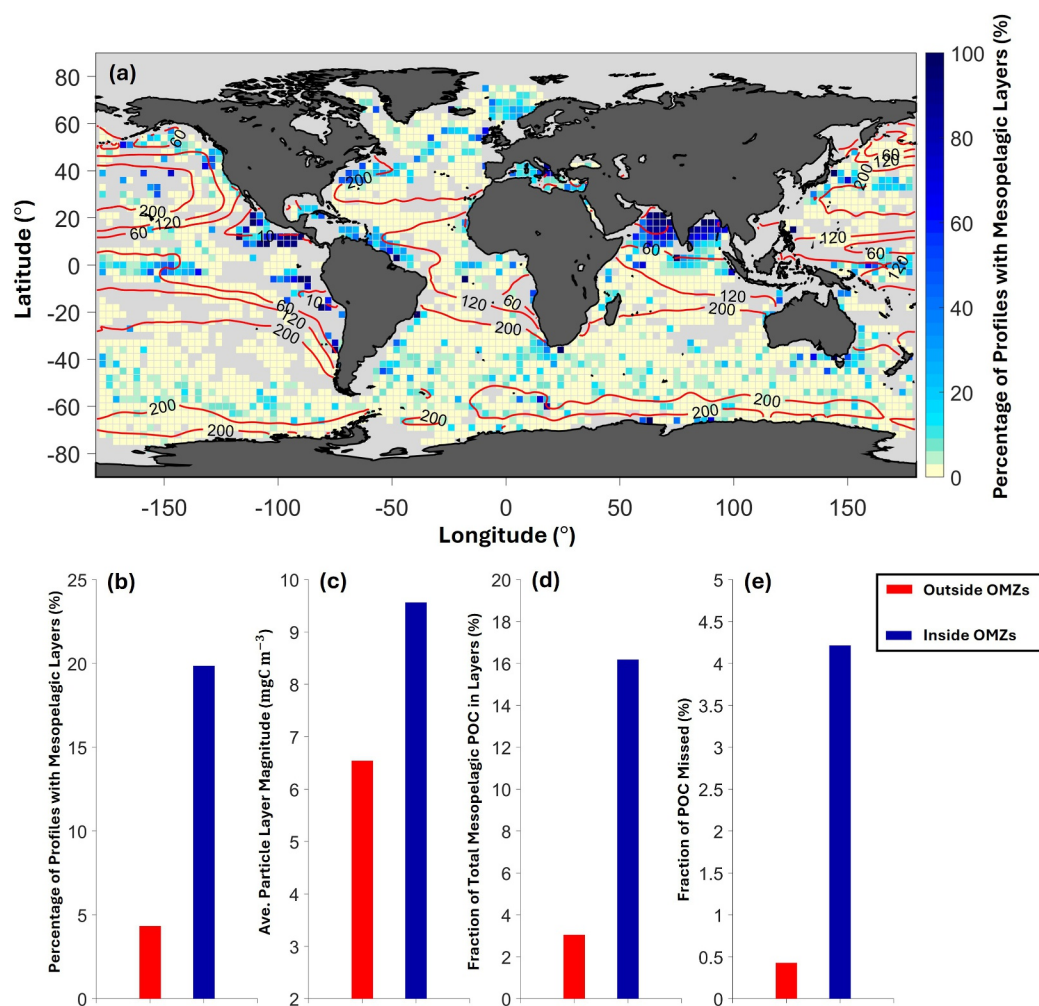


Figure 2. Global distribution of mesopelagic particle layers and their significance for mesopelagic small-particle POC stocks inside and outside of oxygen minimum zones (OMZs). (a) The percentage of profiles containing a particle layer within 3° resolution grid cells. Gray grid cells indicate locations with no profiles. Grid cells with values of 100% do not necessarily imply layers are present there throughout the year. Red lines mark dissolved oxygen contours of 10, 60, 120 and 200 $\mu\text{mol Kg}^{-1}$ at 300 m using data from World Ocean Atlas 2018 (Garcia, Boyer, et al., 2019; Garcia, Weathers, et al., 2019; WOA 2018 Oxygen, 2018). OMZs are defined where dissolved oxygen concentrations fall below 120 $\mu\text{mol Kg}^{-1}$ (Stramma et al., 2008). (b)–(e) Comparisons of particle layer properties inside and outside of OMZs. (b) Differences in the percentage of profiles containing particle layers. (c) Average particle layer magnitude. [d] Contribution of integrated particle layer POC concentration toward total mesopelagic (200–1,000 m) POC stocks (e) Percentage of mesopelagic POC stock missed if POC concentration is assumed to decrease linearly with depth.

To test the potential impact of ignoring these layers, we estimated the fraction of mesopelagic POC stock missed if particle concentration was assumed to decrease linearly between the layer's start and end depth. We estimate that small-particle POC stock is underestimated by 1.7% globally. Again, this varies significantly between cases inside (4.2%) and outside (0.4%) OMZs (Figure 2e), and in the Arabian Sea, the fraction missed is significantly higher (16%). Including the processes responsible for creating these layers is therefore likely to improve modeled representations of mesopelagic particle dynamics, especially in OMZs such as the Arabian Sea. Consequently, it is important to constrain the mechanisms responsible for the formation of particle layers in different regions of the global ocean.

3.2. Causes of Particle Layers

The observed dominance of particles layers in OMZs (Figure 2) may arise from the effect of oxygen on bacterial remineralization rates. In severe OMZs, such as the Arabian Sea and Eastern Tropical North Pacific (ETNP),

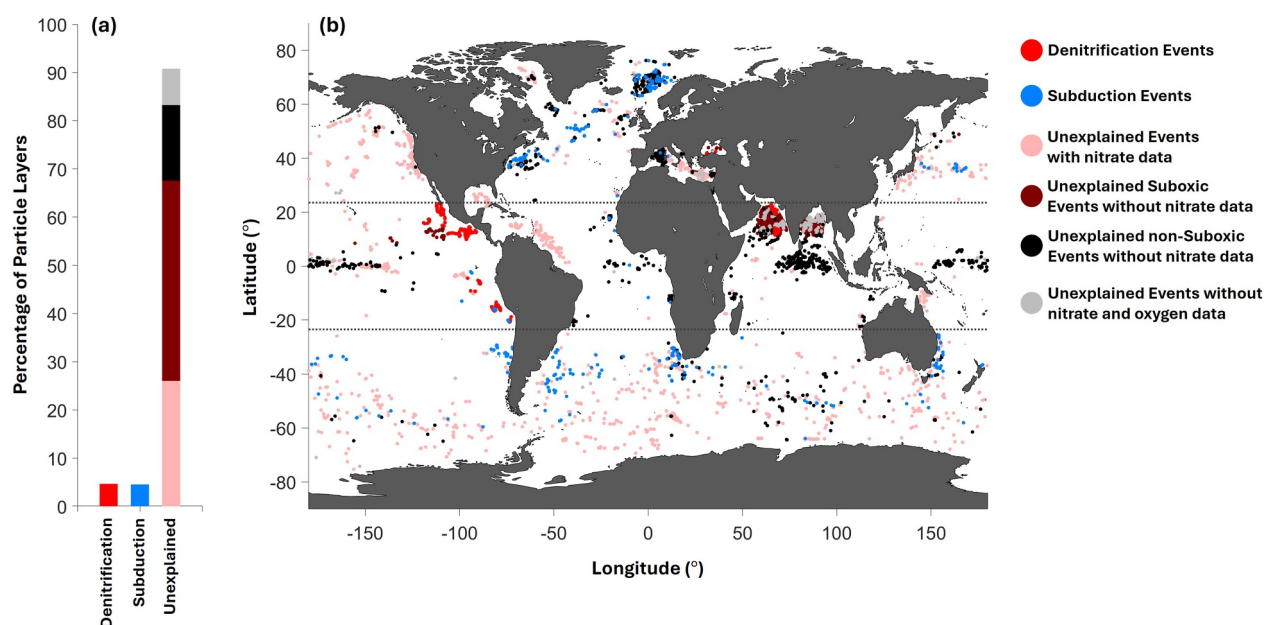


Figure 3. (a) Percentage of profiles with particle layers attributed to subduction (blue), denitrification (red) or unexplained processes (black). (b) Spatial distribution of particle layers associated with subduction (blue points), denitrification (red points) or unidentified causes. Pink points show unexplained events with available nitrate data. Dark red points show events in suboxic zones without nitrate data (meaning they cannot be tested for denitrification). Black points show unexplained events outside suboxic zones without nitrate data. Gray points are unexplained events lacking reliable oxygen data. Black horizontal lines at 23.5°N and 23.5°S define the boundaries of the tropics.

where dissolved oxygen concentration is consistently lower than $10 \mu\text{mol Kg}^{-1}$ (Figure 2a), carbon transfer to the deep mesopelagic (1,000 m) can be elevated due to reduced attenuation rates and reduced aerobic remineralization (Cram et al., 2022; Weber & Bianchi, 2020). If particles are lost more slowly with depth, they will be more likely to accumulate within the OMZ core and lead to the formation of a particle layer.

Oxygen availability only directly affects particle loss rates, however, so cannot fully explain particle layer formation. An increase in particles with depth would require additional processes producing particles, or a reduction in particle sinking speed at the depth of the layer's formation. Reduced oxygen concentrations observed in OMZs therefore likely aid the formation of layers, amplifying their magnitude or associated carbon stock, but cannot be solely responsible for their occurrence. This said, the impacts of oxygen availability on particle attenuation and aerobic remineralization rates may explain why these layers contribute more significantly toward total mesopelagic stocks within OMZs than elsewhere (Figure 2).

Denitrification (involving nitrate reduction to nitrite or ammonium) by bacteria, archaea and fungi, is a key mechanism of particle remineralisation under suboxic and anoxic conditions (Bianchi et al., 2012; Lam & Kuypers, 2011; Ulloa et al., 2012; Zumft, 1997). Apparent denitrification is identified in 13.6% of layers detected by floats with nitrate sensors (which constitute 4.7% of all profiles with particle layers; Figure 3a). These cases are mainly concentrated in tropical OMZs such as the Eastern Tropical South Pacific (ETSP), ETNP and Arabian Sea, but are also found in the Black Sea (Figure 3b). These locations match well with regions where denitrification has been predicted previously (Bianchi et al., 2012). These findings support previous work hypothesising POC-enriched layers in the Arabian Sea to be caused by denitrifying bacteria (Naqvi et al., 1993; Roullier et al., 2014) and also demonstrate that such features are not exclusive to the Arabian Sea but can occur in other severe OMZs too.

Due to the limited availability of nitrate-sensor-equipped floats in severe OMZs such as the Arabian Sea and Bay of Bengal (Figure 3b), we expect that our results underestimate the true scale of denitrification-driven particle layers in these regions. We anticipate most unexplained suboxic layers (which represent 46.3% of all unexplained layers; Figure 3a) to be associated with denitrifying bacteria since these bacteria dominate the microbial community within the core of OMZs (Stewart et al., 2012). Supporting this, 88.2% of suboxic particle layers detected by floats with nitrate sensors passed our denitrification testing algorithm.

Eddy-driven subduction is important for transferring particles to mesopelagic depths and contributes up to 5% toward annual flux at basin scales (Boyd et al., 2019; Resplandy et al., 2019). Our subduction detection algorithm identifies 12.5% of particle layers outside OMZs to be associated with these events, or 4.5% of all particle layers globally (Figure 3a). This global percentage (4.5% value) ranges from 1.6% to 7.4% depending on the value of $\Delta\rho$ (which was varied from 0.5 to 4 Kg m^{-3} ; Figure S6 in Supporting Information S1). With $\Delta\rho$ set to 2 Kg m^{-3} , subduction events are detected in regions where they have been observed or predicted to occur previously (Chen et al., 2021; Chen & Schofield, 2024; Johnson & Omand, 2021; Llorc et al., 2018; Omand et al., 2015); namely the North Atlantic, Greenland Sea, Norwegian Sea, Southern Ocean and along the Kuroshio extension (Figure 3b).

Particle layers currently unexplained by either denitrification or subduction (90.8% of all events) are not confined to any particular basin or latitudinal zone and there remain large regions (e.g., Bay of Bengal) where none of the detected layers are attributed to either process (Figure 3). We observe modest seasonal variability in unexplained particle layers outside the tropics (Figure S9a in Supporting Information S1), with 15% of these layers occurring in winter compared to 35% in summer. There is no clear seasonality in the tropics (Figure S9b in Supporting Information S1) except for the Arabian Sea (Figure S9c in Supporting Information S1) with seasonality reflecting regional monsoon cycles (Luis & Kawamura, 2004).

The lack of nitrate-sensor-equipped floats in suboxic regions (e.g., Arabian Sea) limits our ability to identify all denitrification-associated events. However, 50.1% of unexplained layers with reliable oxygen data either occur outside of suboxic conditions, or cannot be explained by denitrification even with the availability of nitrate data. Therefore, resolving this limitation of the data set would still leave most layers unexplained by either denitrification or subduction.

As for alternative explanations, there are many processes known to transport small particles below the mixed layer, with the contribution from each varying seasonally (Boyd et al., 2019).

The mixed layer pump (MLP), for example, operates during early spring when the water column re-stratifies after winter, and is limited to regions with large seasonal variability in MLD such as the Southern Ocean, North Atlantic and north-west Pacific (Boyd et al., 2019; Dall'Olmo et al., 2016). Further, as the layers we detect occur between depths of 200 and 500 m, we would only expect the MLP to cause these features in regions where the MLD exceeds 200 m, which is mainly limited to the North Atlantic and Southern Ocean (Dall'Olmo et al., 2016).

Another possible mechanism is the mesopelagic-migrant pump (Boyd et al., 2019). Migrating and resident zooplankton can remineralise, repackage (into faecal pellets) or fragment particles within the mesopelagic (Steinberg et al., 2017), with the latter two of these providing plausible mechanisms of layer formation. As these processes occur globally (Steinberg et al., 2017), including severe OMZs (Luo et al., 2000), and since they have already been suggested to cause deep particle layers (Kiko et al., 2017; Lovecchio et al., 2025), they have strong potential for explaining the layers not attributed to either subduction or denitrification (Figure 3b).

Previous studies suggest that, among other environmental factors such as light intensity, oxygen concentrations can have an important influence on the depth of migrating organisms, which is generally shallower in OMZs than elsewhere (Bianchi et al., 2013; Bianchi & Mislán, 2016). Consequently, if the particle layers we detect were signatures of diel vertical migration, we might expect these features to be shallower in hypoxic regions. Supporting this, particle layers occur marginally deeper outside OMZs (354 m) than within them (296 m). As further evidence, the average depth of our unexplained layers is 325 m, which falls within the globally predicted zooplankton and micronekton migration depth range of 200–650 m (Bianchi et al., 2013). Unfortunately, it is not possible to conclusively test the role of zooplankton in forming these layers with the data available to us due to the absence of acoustic data or zooplankton abundance information. Nevertheless, the actions of migrating and resident zooplankton within the mesopelagic and their associated production of small particles through fragmentation remains our main hypothesis for producing the particle layers we cannot currently explain.

4. Summary

We developed a new algorithm for detecting mesopelagic layers of small particles from BGC-Argo float backscatter profiles. When applying this to 10 years of float data we found that such layers are widespread in the global ocean and present in approximately 9% of all profiles analyzed. When not accounted for, global small-particle mesopelagic carbon stocks may be underestimated by ~2%. These layers are most abundant in OMZs

however, where their presence could cause mesopelagic carbon stocks to be underestimated by ~4%. Within OMZs these layers frequently coincide with a decrease in nitrate concentration, which suggests a role of denitrifying bacteria. Subduction only explains 12.5% of layers outside OMZs implying the main cause in these regions remains unknown. It is important to better understand the mechanistic causes and potential impact of these layers on carbon sequestration, particularly given their dominance within OMZs that are expected to expand with future climate change (Cabr   et al., 2015; Stramma et al., 2008; Zhou et al., 2022).

Critically, the global prevalence of these layers makes predicting mesopelagic POC flux significantly more challenging because these features cannot be described by traditionally used exponential or power-law functions (Armstrong et al., 2001; Martin et al., 1987). Our results suggest that models using these approaches are likely underestimating mesopelagic carbon stocks. Additionally, given the significance of small particles to POC flux (Alonso-Gonzalez et al., 2010; Baker et al., 2017; Durkin et al., 2015; Gali et al., 2022), it would be valuable to further investigate the fate of these layers and to quantify their contribution to global carbon fluxes. Addressing this will remain challenging, however, until existing uncertainties regarding particle sinking speeds are resolved, so addressing this problem should be a priority of future work in this field. Finally, until the processes responsible for forming these layers are constrained, it will remain difficult to parameterize these features in global biogeochemical models. Future work should therefore be targeted at addressing this problem to reduce uncertainties regarding mesopelagic organic carbon storage.

Conflict of Interest

The authors declare no conflicts of interest relevant to this study.

Availability Statement

Publicly available data used in this work are referenced in our Bibliography as “Argo (2000)” and “WOA 2018 Oxygen (2018).” Instructions on how to access BGC-Argo float data are available via the following website: <https://biogeochemical-argo.org>. All figures were produced using MATLAB (version R2022b). The code and underlying data to produce these figures are archived on Zenodo and openly available at <https://zenodo.org/records/21822943> (Williams et al., 2026).

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