Dear editor,

Please find attached all the documents requested for the revisions of the manuscript. This includes a revised version of the manuscript (“egusphere-2024-2074-manuscript-version3.pdf”) and the supplement (“egusphere-2024-2074-supplement-version2.pdf”), a point-by-point reply to the comments (“egusphere-2024-2074-author_response-version1.pdf”), and a marked-up manuscript version showing the changes (“egusphere-2024-2074-ATC1.pdf”).

This file provides a detailed, point-by-point response to the comments from the two referees, as a complement to the previous answers we provided during the open discussion, which can be found here:
Reply on referee 1 (RC1): https://doi.org/10.5194/egusphere-2024-2074-AC1
Reply on referee 2 (RC2): https://doi.org/10.5194/egusphere-2024-2074-AC2

The main revisions in the manuscript are shown here in green, while the explanations are provided in black.
It is accompanied by a marked-up version of the manuscript which highlights the changes. Text highlighted in blue indicates insertions or modifications, while text in green denotes sections that have been moved.

1) Issue in the system of equations 1

RC1: “Specific dynamic action is a respiration term and thus, represents a loss of carbon. However, this is not included in the system despite the fact that it is routed to inorganic nutrients.”

There was a problem in writing the system of equations 1 as we did not include the specific dynamic action in the metabolic products of the consumers (C). We replaced the term *mC* by *Dm* (Eq.6), which includes all the metabolic products.

- Line 109 Eq.1:

$$\frac{\partial C}{\partial t} = -\frac{\partial (wC)}{\partial z} + edG - D_m - \mu C$$

2) Issues in daily evolution of light in equation S1 of the supplement

RC1: “This equation is difficult to read because the exponent n should apply to the sin function and not to wt. Furthermore, this equation implies that light levels are zero at night meaning that visual predators cannot feed at night when they stay close to the surface. The only available temporal window in that case is during dusk and dawn (about 2-3 hours a day). However, during that period, they move either up or down which implies that they are not colocated with their preys. Thus, according to that equation, they should not really be able to feed and they should starve and die. Yet, this is not the case. I was also disturbed by figure 2 which shows the daily evolution of light at the surface. On that figure, the relative light level during the night is not zero as it should be according to the equation displayed in the supplementary materials but somewhere between 0 and 0.6. I inspected the code and saw indeed that the actual coded equation is not exactly that of the supplementary materials but rather equation 1 to which a constant 0.5 is added. This explains why the consumers are able to survive in the model since with this 0.5, they are then able to feed at night. However, this 0.5 implies that light level during the night is about one third of its value during the day, which is obviously not correct! In addition, the Beer-Lambert equation is used with an attenuation coefficient of 0.001 m^(-1), meaning an attenuation depth of 1000 m! In very clear water, the coefficient is rather of the order 0.02-0.03, which is at least one order of magnitude higher ... This is not a typo because this 0.001 is the actual value used in the code. And the option to use a chlorophyll dependant coefficient is not activated and not included in the call to the beer-lambert function. To conclude with my issues on light, once in the manuscript and once in the supplementary materials, the authors say that day length at the winter solstice is 6 hours and is 12 hours at the summer."

RC2: "The equation in the supplementary materials assumes that surface irradiance is zero at night, which is not entirely accurate. Even at night, there is still some ambient light (e.g., from the moon), and predators that rely on visual predation may still be able to feed, albeit less effectively. The current model restricts feeding to dusk and dawn, which is problematic since micronekton are supposed to be migrating between surface and deeper layers during these periods. According to this assumption, predators would be unable to feed and, over time, would likely starve. However, when examining Figure 2 in the manuscript, it appears that surface light never actually reaches zero, contradicting the assumption in the equation. This inconsistency suggests that something might be missing or oversimplified in the supplementary equation. Could it be that the equation does not fully account for low-light conditions at night? is there a missing parameter to this equation? Additionally, have you considered varying light levels to simulate different migration depths?"

We implemented in the section *Vertical distribution modeling* of the *Material and methods* and in the section *Modeling irradiance* of the Supplement, the modifications of the formulation of the daily irradiance (I_0), the swimming speed (w) and the visual capture rate (α_v).

To model daily irradiance, we used a sinusoidal curve. For the gradient of surface irradiance (cf Eq.S1), which allows us to calculate migration speed, we now set a threshold (Δ_{mig}): when micronekton reaches the surface, they begin migrating once the light gradient falls below this threshold. The threshold is set to 0.1 and the sensitivity of this parameter on carbon production is investigated in the sensitivity analysis (Fig.5).

We also added a constant I_{min}, to prevent the light level from reaching zero (Eq.S1).

- Section *Modeling irradiance* of the Supplement:

Surface irradiance (I_0 in Eq.2,4) was modeled as a periodic function of time t, varying over the day as follows,

$$I_0(t) = (I_{min} + I_{max}) - I_{max}\exp(-a\ sin^n(\omega t)) \tag{1}$$

with $I_{min} = 0.01$ and $I_{max} = 1$, the minimum and maximum level of light, $\omega = (2\pi)/2H$ where H=24h, the parameter n=15, defining the timing of twilight hours, and the parameter $a = 4$ defining the degree of flattening of the curve (see an example in Fig.2).

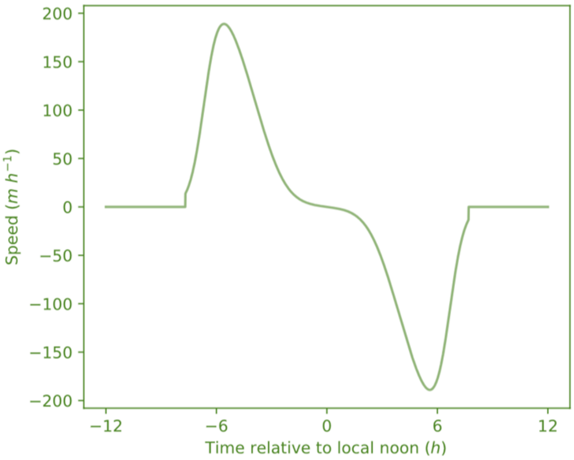
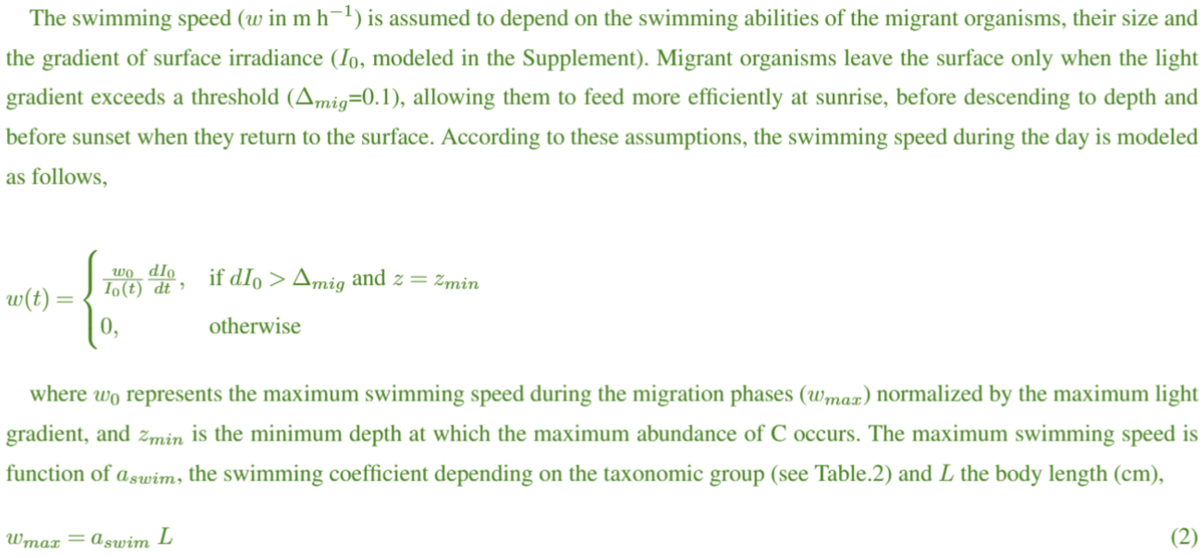


Figure S4: Relative daily migration speed for a fish measuring 35mm. A positive swimming speed causes organisms to go down to the bottom of the water column, and a negative speed causes them to rise to the surface.

- Lines 125-132:



The swimming speed (w in m h^{-1}) is assumed to depend on the swimming abilities of the migrant organisms, their size and the gradient of surface irradiance (I_0, modeled in the Supplement). Migrant organisms leave the surface only when the light gradient exceeds a threshold (Δ_{mig}=0.1), allowing them to feed more efficiently at sunrise, before descending to depth and before sunset when they return to the surface. According to these assumptions, the swimming speed during the day is modeled as follows,

$$w(t) = \begin{cases} \frac{w_0}{I_0(t)} \frac{dI_0}{dt}, & \text{if } dI_0 > \Delta_{mig} \text{ and } z = z_{min} \\ 0, & \text{otherwise} \end{cases}$$

where w_0 represents the maximum swimming speed during the migration phases (w_{max}) normalized by the maximum light gradient, and z_{min} is the minimum depth at which the maximum abundance of C occurs. The maximum swimming speed is function of a_{swim}, the swimming coefficient depending on the taxonomic group (see Table.2) and L the body length (cm),

$$w_{max} = a_{swim}\, L \qquad (2)$$

- Line 137 and Eq.S5: We defined a different coefficient of attenuation based on field data (ψ=0.05). We already implemented in the seasonal scenario in Figure 7 and 8 a coefficient of attenuation that varies according to the concentrations in chlorophyll a (Chl-a) (Eq.S5). According to this equation, the coefficient of attenuation varies between 0.04 and 0.07. We changed the value of 0.001 by a value between this range for the simulations that do not include seasonal variations of the environment.

- **Line 434**: We specified that the variation in migration depth shown in Figure 8 is due to seasonal changes in light levels.

3) Calibration of the coefficient c_α

RC1: "I don't understand the changes they impose on the parameter C_alpha. In scenarios 1 and 2, this parameter is set to 3 but when light is seasonally varying (scenarios 3 and 4), it is set to values that are between 2 and 3 orders of magnitude lower. Yet, the resulting detritus biomass is similar. Furthermore, the chosen values in that second case are not consistent with figure S8.**"**

RC2: "I am also unclear about the changes imposed on the parameter Cα and why even though it varies between the scenarios we still have the same resulting detritus concentration.**"**

The calibration of the coefficient c_α for the different simulations, involving different average community size, taxonomy (fish, crustacean or cephalopod) and environmental conditions, needed clarification as mentioned by both referees.

The calibration of this coefficient is explained **lines 269-275**. As we changed some aspects of the model including the coefficient of attenuation (ψ) affecting the capture rate (α_v), we redefined new values of c_α that are listed in the Supplement in **Table S3** for the seasonal simulations and in **Table S4** for the simulations involving different size and taxonomic group.

The capture rate coefficient (c_α) is calibrated to ensure a consistent transfer efficiency (γ) of 10% between the biomass of consumers and their resource (Table.1). This transfer efficiency is further adjusted using a taxonomic ratio (δ), which allows for the estimation of the relative biomass distribution among fishes, crustaceans, and cephalopods within the micronekton community.

Therefore, the value of c_α is estimated for each simulation, allowing the calibration for P and C concentrations. This calibration varies according to size, taxonomic group, and seasonal simulation. The values used in each simulations are provided in the Supplement (see Table S3,S4).

4) Remineralization term in the fecal pellets equation

RC1: "I don't understand why the authors have added a **remineralization term** in the fecal pellets equation (equations 6). Are the detritus pools prognostic variables or simply diagnostic variables?"

RC2: "In equation 6, it is unclear to me, if remineralization only applies to fecal pellets or if the author considered it also in the dead organisms, considering that both processes would contribute to organic matter degradation, so excluding remineralization for dead bodies seems inconsistent."

Line 145 Eq.5: We corrected the equation of fecal pellets production as followed to not include the remineralization term, as discussed by both referees.

$$\frac{\partial D_g}{\partial t} = (1-e)dG$$

5) Wrong unit of production

RC1: "On the topic of production, I don't understand what is displayed in Figure 7a. If this is the temporal evolution of detritus production, then the units are wrong. If this is the temporal evolution of the detritus pools, this is impossible since the animal dead bodies and the inorganic pool do not have a sink term. This is also the case in Figure S4."

Fig.7a and Fig.S5: As mentioned by RC1, in figure 7a and S5 we show the temporal evolution of the daily detritus production. We corrected the unit in mgC m^{-2} d^{-1}.

6) Definition of the pe-ratio

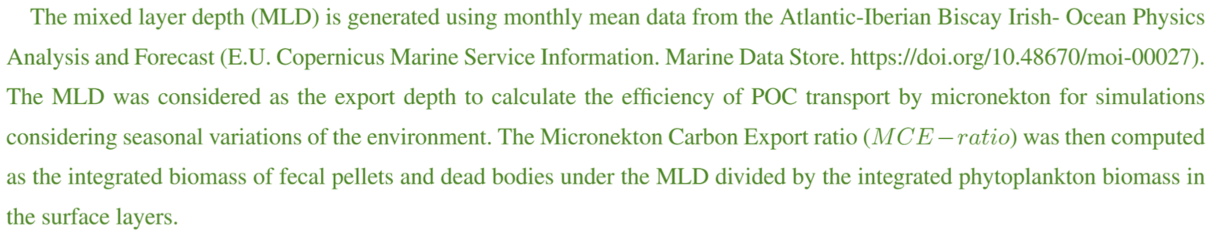
RC1: "I was a little bit disturbed by the definition of the pe-ratio which traditionally is the ratio of the export at some depth over PP whereas here, this a ratio between a flux and biomass."

RC2: "I would also like to have clarifications for the choice of 200 m depth as the euphotic zone for calculating the efficiency of particulate organic carbon (POC) transport. Most studies typically use a depth of 100 m for the euphotic zone, so it's important to explain the reasoning behind your choice of depth. Was this depth based on specific data from the PAP-SO station, or was it taken from existing literature?

The export efficiency is usually calculated using the flux at a specific depth over the net primary production, what does integration phytoplankton concentration in the surface layers represent? is it a biomass?"

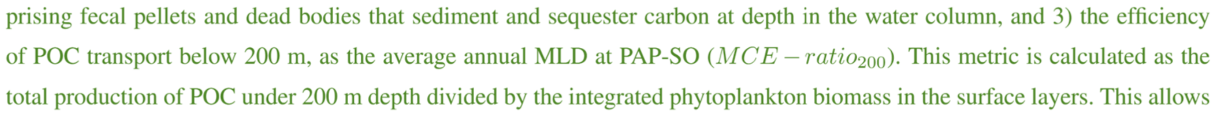
We defined the efficiency of carbon transport as the proportion of carbon biomass exported below a specified depth, referred to as the export depth, situated beneath the mixed layer depth (MLD), relative to the phytoplankton biomass (mgC m^{-3}). Initially termed the pe-ratio, this metric was renamed as it represents a distinct measure. We now refer to it as the Micronekton Carbon Export ratio (MCE-ratio). In **Fig.3 and Fig.5**, the MCE-ratio is calculated below 200 m, using an annual average MLD value. In **Fig.7**, we incorporate the seasonal variation of the MLD at PAP-SO to compute the MCE-ratio.

- **Lines 222-227:**



The mixed layer depth (MLD) is generated using monthly mean data from the Atlantic-Iberian Biscay Irish- Ocean Physics Analysis and Forecast (E.U. Copernicus Marine Service Information. Marine Data Store. https://doi.org/10.48670/moi-00027). The MLD was considered as the export depth to calculate the efficiency of POC transport by micronekton for simulations considering seasonal variations of the environment. The Micronekton Carbon Export ratio ($MCE-ratio$) was then computed as the integrated biomass of fecal pellets and dead bodies under the MLD divided by the integrated phytoplankton biomass in the surface layers.

- **Lines 235-237:**



prising fecal pellets and dead bodies that sediment and sequester carbon at depth in the water column, and 3) the efficiency of POC transport below 200 m, as the average annual MLD at PAP-SO ($MCE-ratio_{200}$). This metric is calculated as the total production of POC under 200 m depth divided by the integrated phytoplankton biomass in the surface layers. This allows

7) Small peaks in the production of dead bodies

RC1: “Regarding the results, one intriguing observation is the occurrence of small, localized peaks in the production of dead bodies between the epipelagic zone and the depth at which organisms reside during the day. What could explain these peaks?”

Line 124 and Fig.3: We used a smaller time step (dt=0.1) than the previous one (dt=0.8), to avoid the intermediate small peaks that were observed in Fig.3, regarding the production of dead bodies.

8) Validation and calibration of the model with trawl and acoustic data

RC2: “ Incorporating net sampling and acoustic data, if available, would be crucial for calibrating and validating the model outputs. The authors mention the presence of trawl and acoustic sampling data from the APERO cruise, conducted in the same region during June and July, but it is unclear whether these data were used for model validation.”

Lines 380-387: We discussed about the validation of the model for the depth ranges showed in Fig.3.

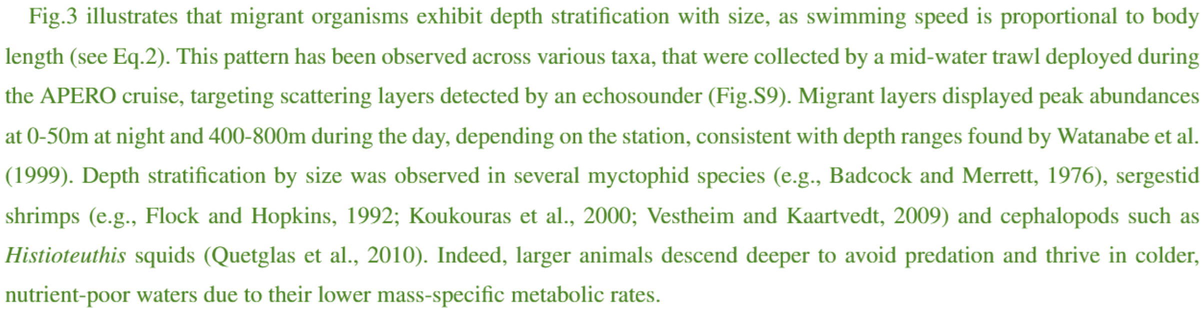


Fig.3 illustrates that migrant organisms exhibit depth stratification with size, as swimming speed is proportional to body length (see Eq.2). This pattern has been observed across various taxa, that were collected by a mid-water trawl deployed during the APERO cruise, targeting scattering layers detected by an echosounder (Fig.S9). Migrant layers displayed peak abundances at 0-50m at night and 400-800m during the day, depending on the station, consistent with depth ranges found by Watanabe et al. (1999). Depth stratification by size was observed in several myctophid species (e.g., Badcock and Merrett, 1976), sergestid shrimps (e.g., Flock and Hopkins, 1992; Koukouras et al., 2000; Vestheim and Kaartvedt, 2009) and cephalopods such as *Histioteuthis* squids (Quetglas et al., 2010). Indeed, larger animals descend deeper to avoid predation and thrive in colder, nutrient-poor waters due to their lower mass-specific metabolic rates.

9) DVM of zooplankton

RC2: “One significant assumption is that mesozooplankton do not migrate and are restricted to the epipelagic layer, which could influence the estimated carbon flux. Numerous studies, including those by Kiko et al. (2017, 2020), and Bianchi et al. (2013), have demonstrated that zooplankton also exhibit DVM and that they are usually present between 300–600 m. Incorporating a portion of zooplankton in the deeper layers of the model would be important, as they could serve as prey for micronekton, potentially contributing to fecal pellet production and, in turn, to carbon transport.”

Lines 475-480: As pointed out by the second referee, we clarified why we did not include the DVM of zooplankton.

Another factor influencing micronekton feeding behavior is the spatial distribution of their prey. Analysis of gut contents from migratory species during the APERO cruise suggested that these organisms primarily feed at the surface (data unshown), leading us to constrain their resources to this layer. While zooplankton is known to exhibit

DVM (e.g., Bianchi et al., 2013; Kiko et al., 2020), they typically migrate to relatively shallow depths. As a result, we did not incorporate zooplankton DVM into the model, as it is unlikely to significantly affect micronekton consumption patterns.

10) Oxygen limitation

RC2: “For instance, oxygen concentration plays a crucial role, especially when micronekton inhabit oxygen minimum zones (OMZs). In such zones, low oxygen availability limits respiration and metabolic rates, impacting vertical migration behavior. However, the model assumes that micronekton feed exclusively at the surface, without considering the potential effects of hypoxic conditions on DVM patterns and metabolic processes, this might be due to the modeling of the PAP-SO station.”

Lines 455-461: We discussed about the importance of considering oxygen limitation when modeling DVM, in order to use the model at a global scale, as pointed out by the second referee.

Light is a key factor in avoiding visual predators, but oxygen gradients may play a stronger role, particularly in regions with oxygen minimum zone (OMZ) (Bianchi et al., 2013). In regions without OMZs, migration depths are primarily controlled by light levels, but to achieve a global perspective, our model should incorporate co-limitation by both oxygen and light. Nevertheless, our method allowed us to reproduce consistent migration speeds and daytime depth residence in a non-hypoxic region, as inferred from sound scattering layers data recorded at sea, with an approximate migration duration of 2 hours (e.g., Bianchi and Mislan, 2016; Cade and Benoit-Bird, 2015).