>>>We are grateful for the comments on our manuscript from the reviewer. We feel that this new version of the paper is much stronger as the result of the comments we received on the original manuscript. We have addressed all of the comments and have detailed our response to specific comments below. Our response to each comment is bulleted and in italics below the relevant comment behind>>>

Anonymous Referee #2
Received and published: 6 September 2020

The manuscript titled "Diapycnal mixing across the photic zone of the NE-Atlantic" by Haren et al. quantified the upper ocean nutrient flux using a custom modified CTD and nutrient measurements at discrete depths from a latitudinal transect along 17_5_W between 30 and 62_N in summer. The authors observed no increase in vertical mixing or diapycnal nutrient flux from south to north, where the temperature increased. Further, they opined that nutrient supply by diapycnal flux to the euphotic zone might not be affected by the physical process of global warming. It is a well-written manuscript and presents an interesting take on the ocean biophysical coupling in the global warming scenario. However, I feel that the authors jumped into a conclusion without providing enough evidence to support their say. Hence I recommend major revision.
>>>Thank you for the appreciation. To be noted, temperature decreased, not increased, from south to north and we like to add that stratification, the medium to support internal gravity waves, also decreased.

Major Comments

L63-96 The introduction needs a more general introduction to the oceanography of the region. Especially knowledge of bathymetry, background internal wave field, eddy kinetic energy, and wind conditions during summer.
>>>We have no objection to add information on the North-Atlantic Ocean in general. However, the observations were made in the upper 500 m, and water at all stations were >1000 m deep with only 3 <2000 m. Local bottom topography did not influence the internal wave field directly. We added this consideration now in the revised manuscript. We also added that the survey was done in summer time,with in general moderate to good weather conditions, no big storms. We have no information on the eddy kinetic energy at the time, other than the generally excepted view from literature, which we also added to the revised manuscript.

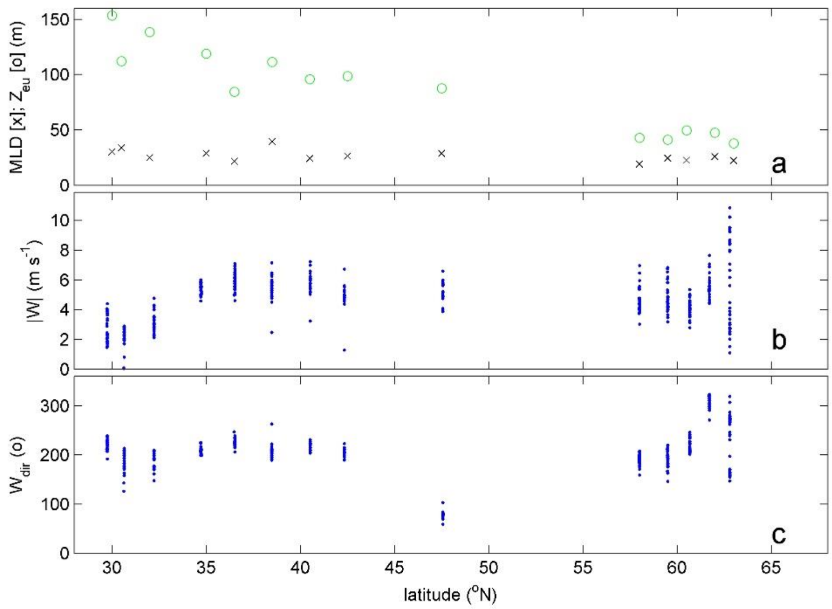
L123 In the Thorpe length calculation section, please mention the lowering speed of the CTD. A slow lowering can resolve overturns efficiently. In the mixed layer, the Thorpe method will consider it as a large overturn. How you will justify the validity of diffusivity within the mixed layer, where N2 is weak. A brief discussion on lowering speed of CTD and justification for the diffusivity within the mixed layer will give clarity to the reader.
>>> We agree with the reviewer that we should have added the lowering speed, it was 1 m^{-1}s. Yes, slow lowering resolves overturns better, but in doing so it is lowered obliquely through the overturns in case of non-zero background flow, which is nearly always present. A completely and thoroughly mixed layer hardly ever exists, but the stratification is often weak in the upper 20-30 m while is varies in height and time. For the validity of choice of parameters we refer to the extensive work by Oakey (1982) who demonstrated upper ocean parametrization to vary over at least one order of magnitude but, given enough data points, with a particular average value as used here. This is confirmed in more recent works (Gregg et al 2018) for ocean observations and Portwood et al (PRL2019) for modelling work. We added this information to the manuscript at P14: 'Although the general understanding, mainly amongst modellers, is that the Thorpe length method overestimates diffusivity (e.g., Scotti, 2015; Mater and Venayagamoorthy, 2015), this view is not shared amongst ocean observers (e.g., Gregg et al., 2018). In the large parameter space of the high Reynolds number environment of the ocean, turbulence properties vary constantly, with an interminglement of convection and shear-induced turbulence at various levels. Given sufficient

averaging, and adequate mean value parametrization, the Thorpe length method is not observed to overestimate diffusivity. This property of adequate and sufficient averaging yields similar mean parameter values in recent modelling results estimating a mixing coefficient near the classical bound of 0.2 in stationary flows for a wide range of conditions (Portwood et al., 2019). It is noted that diffusivity always requires knowledge of stratification to obtain a turbulent flux, and it is better to consider turbulence dissipation rate for intercomparison purposes. Nevertheless, future research may perform a more extensive comparison between Thorpe scale analysis data and deeper microstructure profiler data.'

L256-258 Substantiate the surface cooling and internal wave breaking using data.
>>>This was indeed not clear. We meant that the main process in the upper layer is convective surface cooling, and internal wave breaking in the more stratified layers below. We changed the text l.289-291: The trends suggest only marginally larger turbulence going poleward, which is possibly due to larger cooling from above and larger internal wave breaking deeper down.

L264-265 I could not understand this sentence.
>>>Perhaps 'confirm' was misused here; we meant to say that the deeper layers show the same latitudinal trend in turbulence and stratification values as the upper layer. We rephrased the sentence to' The data from well-stratified waters deeper down thus show the same latitudinal trend as the observations from the near-surface layers.' (line 298-300).

L284-286 The nutrient flux depends on the eddy diffusivity and the nutrient concentration gradient, which changes dramatically with depth. The nutrient fluxes thus may vary with two-or-three orders difference. In the manuscript, nutrient flux is calculated using a low-resolution profile of nutrients. Does this discrete measurement introduce bias to the flux calculation? What is the typical depth of the euphotic zone in the study region?
>>>We would have liked a denser sampling of nutrients, but that was impossible in the cruise plan. On the other hand, the large gradients in nutrients are indeed in the vertical, and variations in the horizontal plane are less strong. We note that, due to overturn sizes over which we must average, turbulence is gridded in equally large vertical distances. The typical depth of the 0.1% irradiance penetration is about 50 to 100 m, see the figure panel 'a' below in which we compare this depth with the 'mixed layer depth', defined as the depth at which the temperature difference with respect to the surface was 0.5℃ (as in Jurado et al 2012). We have added this information on p.12: 'The mixed layer depth, defined as the depth at which the temperature difference with respect to the surface was 0.5□C (Jurado et al., 2012), varies between about 20 and 30 m on the southern end of the transect and weakly becomes shallower with latitude (Fig. 7a). This weak trend may be expected from the summertime wind conditions that also barely vary with latitude (Fig. 7b,c). In contrast, the euphotic zone, defined as the depth of the 0.1% irradiance penetration level (Mojica et al., 2015), demonstrates a clear latitudinal trend decreasing from about 150 to 50 m (Fig. 7a).'



(New) Figure 7. Latitudinal transect of near-surface layers and wind conditions measured at stations during the observational survey. (a) Mixed layer depth (x) and euphotic zone (o). (b) Wind speed. (c) Wind direction.

L318-320 General understanding is that the Thorpe length method overestimates the diffusivity (Mater and Venayagamoorthy 2015; Alberto Scotti 2015).

>>>That is indeed a general understanding amongst modellers, but not amongst ocean observers (e.g. Gregg et al 2018). In the high Reynolds number environment of the ocean turbulence properties vary constantly, an interminglement of convection and shear-induced turbulence at various levels. Given sufficient averaging, and adequate mean value parametrization, the Thorpe length method does not overestimate diffusivity, see also recent modelling results by Portwood et al (PRL2019). It is noted that diffusivity always requires knowledge of stratification to obtain a turbulent flux, and it is better to consider turbulence dissipation rate for intercomparison. We clarified this in the revised manuscript (lines 364-377): 'Although the general understanding, mainly amongst modellers, is that the Thorpe length method overestimates diffusivity (e.g., Scotti, 2015; Mater and Venayagamoorthy, 2015), this view is not shared amongst ocean observers (e.g., Gregg et al., 2018). In the large parameter space of the high Reynolds number environment of the ocean, turbulence properties vary constantly, with an interminglement of convection and shear-induced turbulence at various levels. Given sufficient averaging, and adequate mean value parametrization, the Thorpe length method is not observed to overestimate diffusivity. This property of adequate and sufficient averaging yields similar mean parameter values in recent modelling results estimating a mixing coefficient near the classical bound of 0.2 in stationary flows for a wide range of conditions (Portwood et al., 2019). It is noted that diffusivity always requires knowledge of stratification to obtain a turbulent flux, and it is better to consider turbulence dissipation rate for intercomparison purposes. Nevertheless, future research may perform a more extensive comparison between Thorpe scale analysis data and deeper microstructure profiler data'.

L328-329 Here you can add a detailed discussion on how internal waves can be a feedback mechanism to counteract the suppression of mixing by increased stratification.

>>> Although originally it was merely meant as an introductory sentence to the paragraphs below, we see reviewer's point and we added it in the revised manuscript. (line 384-386 and pages that follow): 'We hypothesize that internal waves may drive the feed-back mechanism, participating in the subtle balance between destabilizing shear and stable (re)stratification as outlined below.'.

L344-364 Authors need to provide data evidence to prove that Internal wave energy/eddy kinetic energy is more in Northern stations, and thus, the relatively increased stratification (compared to south) could not suppress the diapycnal flux of nutrients to the euphotic zone from deeper depths. This will give the readers a better understanding of the lack of correspondence between temperature /stratification and diapycnal flux with latitude.
>>>There seems to be a misunderstanding here: Stratification is less in the north, compared to the south. We have emphasized this in the text. We would have loved to include direct observational information on internal wave and eddy kinetic energy but we do not have such data available in the present study. Instead, we refer to previous work in which we had such data. Using that information, we now better tried to explain as the reviewer suggests. In the discussion we support our suggested hypothesis with the (previous) observation that the state of ocean is one of marginal stability, in which stratification is a subtle balance between internal wave shear and -breaking.

One could employ the GM spectrum calculated using gridded Historical data sets (ARGO) to give an idea on the background Internal wave energy. However, I won't insist on doing this analysis.
>>>We think it is better that modelers take up this task, they will perform much better than we can on this.

A discussion on the meteorological conditions during the observation period is also warranted. What if the southern stations were characterized with anomalously calm weather that mixing was inactive and became comparable to the northern stations.
>>>This is a good idea, we added this information. For the information of the reviewer: meteorological conditions were moderate to good throughout the cruise, see for Wind Speed the panel b (and c for Wind direction) in the figure given above. This is the new Fig. 7 now.

References

Scotti, A. (2015). Biases in Thorpe-scale estimates of turbulence dissipation. Part II: energetics arguments and turbulence simulations. Journal of Physical Oceanography, 45(10), 2522-2543.

Mater, B. D., Venayagamoorthy, S. K., St. Laurent, L., & Moum, J. N. (2015). Biases in Thorpe-scale estimates of turbulence dissipation. Part I: Assessments from largescale overturns in oceanographic data. Journal of Physical Oceanography, 45(10), 2497-2521.